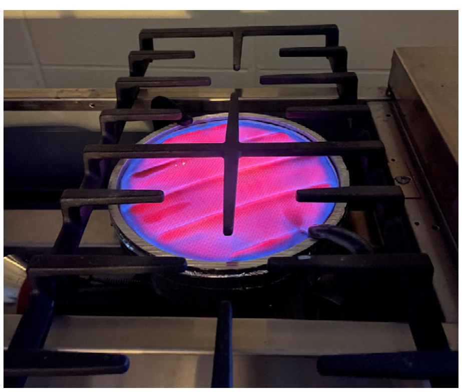
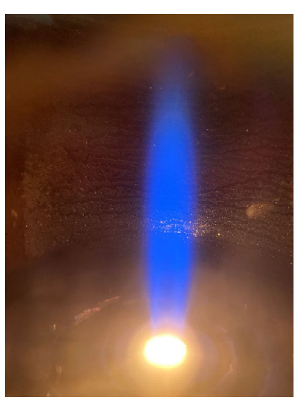
UTD

Utilization Technology Development

RESEARCH PROJECT SUMMARIES

2023 - 2024





Utilization Technology Development, NFP
RESEARCH PROJECT SUMMARIES
2023 - 2024

Legal Notice

This report was prepared by Utilization Technology Development, NFP (UTD). Neither UTD, the members of UTD, nor any person acting on behalf of any of them:

- Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately-owned rights. Inasmuch as many projects are experimental in nature, the technical information, results, or conclusions cannot be predicted. Conclusions and analysis of results by UTD represent UTD's opinion based on inferences from measurements and empirical relationships, which inferences and assumptions are not infallible, and with respect to which competent specialists may differ.
- Assumes any liability with respect to the use of, or for any and all damages resulting from the use of, any information, apparatus, method, or process disclosed in this report; any other use of, or reliance on, this report by any third party is at the third party's sole risk.

UTD RESEARCH PROJECT SUMMARIES
2023 - 2024
Table of Contents

Letter to Our Stakeholders

UTD Impact

Example Technical Publications and Presentations

PROJECT SUMMARIES

Project		Page
	RESIDENTIAL AND LIGHT COMMERCIAL, INCLUDING mCHP	
1.11.H	Next-Generation Residential Gas Heat Pump Water Heater	**3**
1.15.C	Next-Generation Advanced Residential Gas Clothes Dryer	**5**
1.15.E	Gas-Fired High-Efficiency Liquid Desiccant Air Conditioning and Humidity Control	**7**
1.16.H	EnergyPlus™ Models for Advanced Gas Space-Heating Systems and Combination Systems	**9**
1.17.B	Thermoelectric Generator for Self-Powered Water Heater	**11**
1.17.F	Combination Heating/Cooling Vuilleumier-Cycle Heat Pump	**13**
1.18.C	Advanced Nozzle Burner for Commercial Water Heaters	**15**
1.18.F	Mitigating Methane Emissions from Residential and Light Commercial End-Use Equipment	**17**
1.18.H	Economical High-Efficiency Residential Gas Absorption Heat Pump with Integrated Cooling	**19**
1.18.I	Gas Heat Pump RTU Cold-Climate Performance Assessment	**21**
1.19.C	Integrated, Self-Powered, High-Efficiency Burner System	**23**
1.19.E	Sequestering Non-Condensable Gases for Enhanced Gas Absorption Heat Pump Reliability	**25**
1.20.E	Gas-Fired Binary-Fluid Ejector Heat Pump Water Heater	**27**
1.20.G	High-Efficiency Combination System Integrating PV and Self-Power	**29**
1.20.H	Hydrogen-Blended Gas in Residential/Commercial Combustion Equipment	**31**
1.20.J	Integrated mCHP System for Multi-Family Buildings	**33**

Project **Page**

RESIDENTIAL AND LIGHT COMMERCIAL, INCLUDING mCHP *(cont.)*

1.21.A	HeatAmp Adsorption Thermal Heat Pump	**35**
1.21.B	Technical Support for Residential & Light Commercial Gas Equipment Testing, Performance and Safety	**37**
1.21.C	Clean O2 CarbonX™ Carbon Capture	**39**
1.21.E	Gas Engine Heat Pump Modeling, Testing, and Implementation	**41**
1.21.F	Commercial Heat Pump Water Heater Field Performance Comparison	**43**
1.21.I	Ionic Liquid Absorption Heat Pump for Commercial Water Heating	**45**
1.22.A	Hydrogen Blending End-Use Performance and Safety Field Demonstration	**47**
1.22.C	Fuel-flexible Ultra-Low NOx Catalytic Burners for Residential/Commercial Appliances	**49**
1.22.E	Deep Energy Customized Affordable Retrofits of Building Envelopes and Mechanicals	**51**
1.22.G	Safe Use of Hydrogen in Buildings	**53**
1.22.H	Hybrid Fuel-fired and Electric-driven Residential/Commercial HVAC Systems	**55**
1.22.P	Emerging Distributed Methane Pyrolysis Technologies	**57**
1.22.B	Blue Frontier RTU AC System with Integrated mCHP - Laboratory Evaluation	**59**
1.23.E	Combustion Technology for Emerging Low Carbon Manufactured Gases	**61**
1.22.G	Accelerated Life Testing of ResCom Equipment Components with Hydrogen-Blended Gases	**63**
1.22.H	Impacts of Hydrogen-Blended Gas on Venting, Condensation, and Weatherized Equipment	**65**
1.22.I	Inherently Safe ResCom Combustion Systems for Hydrogen-Blended Gases	**67**
1.22.J	Hydrogen Flame Visibility and Colorants	**69**

LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

2.14.O	Field Validation of Gas-Quality Sensor	**71**
2.16.A	Next-Generation Infrared Burner	**73**
2.20.A	Low-Emission Efficient Burner for Ovens and Dryers – Field Evaluation	**75**
2.20.C	High-Efficiency, Low-Emission Commercial Baking Oven Field Demonstration	**77**
2.20.E	Energy Source Options for Industrial and Large Commercial Gas Users	**79**
2.21.A	High-Hydrogen Burner for Commercial and Industrial Applications	**81**
2.21.B	Field Demonstration of Energy Recovery from Brewing/Distilling Operation	**83**
2.21.C	Zero-Emission Processes with Carbon Recovery	**85**
2.22.B	Ribbon Burner Performance with Hydrogen-Blended Gases	**87**
2.22.D	High Performance Adjustable-Port Burner	**89**
2.22.F	Tecogen Hybrid Gas/Electric Chiller Laboratory Evaluation	**91**
2.23.A	Decarbonizing Large Commercial and Industrial Equipment with Hydrogen	**93**
2.23.B	Mobile Modular Resilient Gas-fired Power Generation	**95**
2.23.C	Controlled Mixing Burner for Process Heating	**97**
2.23.D	Flex Fuel Gas Nozzle and Burner for Boilers	**99**

Project **Page**

FOOD PREPARATION AND SERVICE

1.14.B Commercial Foodservice Equipment Demonstrations **101**
1.14.C Demonstration of High-Production Fryers **103**
1.17.H Residential Cooking Pollutants and Indoor Air Quality **105**
1.19.A High-Efficiency Smart Convection Oven **107**
1.19.B Gas-Fired Warewasher **109**
1.20.K Field Evaluation of Indoor Air Quality in Residential Kitchens **111**
1.21.G Technical Support to Address Gas Foodservice Technologies **113**
1.21.H CFS Burner Technology Carbon Gas Reduction Including Hydrogen Blending .. **115**
1.23.K CFS Decarbonization Tool Development and Demonstration **117**
1.23.L Technical Assistance to Advance Gas Foodservice Equipment **119**
1.23.M Advanced Controls for Residential Kitchen Ventilation Systems **121**
1.23.N Next Generation Commercial and Residential Range Top Burner **123**

CLEAN TRANSPORTATION

2.18.I Cost-Effective CNG/GH2 Pre-Cooling Technologies **125**
2.19.G CNG Dispenser – Tank Communication **127**
2.20.F Next-Generation NGV Driver Information System **129**
2.20.G Smart CNG Station Field Demonstration **131**
2.21.F CNG/RNG Locomotive Field Demonstration **133**
2.21.G Distributed RNG or Biogas Production and Cleanup **135**
2.21.H Improved Hydrogen Fueling for Heavy-Duty Vehicles **137**
2.21.I Technical Support for Clean Transportation Testing, Performance, and Safety .. **139**
2.22.G Cost-Effective Pre-Cooling for High-Flow Hydrogen Vehicle Fueling **141**
2.22.H Heavy-duty Hydrogen Vehicle Development and Deployment **143**
2.23.E Adsorbed Natural Gas Vehicle Field Demonstration **145**
2.23.G Small-Scale Natural Gas SMR Technology Optimization with Carbon Capture .. **147**

Letter to Our Stakeholders

We're pleased to provide this summary of the technical progress and market impacts made by Utilization Technology Development, NFP (UTD), a not-for-profit applied research organization directed by 20 leading North American utilities that supply gaseous fuel. These efforts advance innovations across residential, commercial, industrial, and transportation markets for the 35+ million customers served by these utilities.

Although high inflation rates receded during the past year, energy insecurity remains a persistent challenge for many households. Low-income households are especially impacted, as highlighted in the latest U.S. Energy Information Administration *Residential Energy Consumption Survey*. Natural gas continues to provide highly affordable, reliable, resilient energy for all of society and remains especially important for under-resourced individuals and enterprises - - even as critical energy use goals, needs, and opportunities are addressed through technical innovation and other market transformation. These technologies have never been more important as energy costs may increase given the anticipated energy demand to serve data centers and other markets.

The 70+ active research projects summarized in this report demonstrate focused action to accelerate the availability and use of innovative, economical gas-fired technologies and products to reduce energy use and costs, integrate more renewable energy (e.g. via renewable natural gas, low-carbon hydrogen, or hybrid gas/electric technologies that leverage PV), and enhance the safety, reliability and resiliency of end-user operations. These innovations also help gas utilities strengthen their energy efficiency, emerging technology, and market transformation programs. For example, in 2024 large-scale production began of ANESI gas-fired heat pumps which provide 140% AFUE-rated efficiency, after UTD's long-time technical development support for this product.

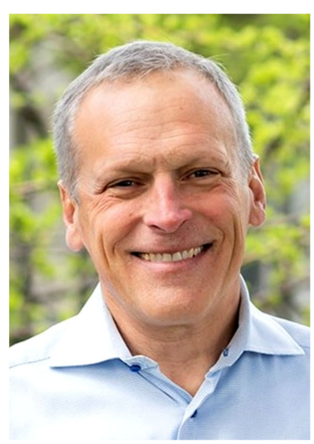
Collaboration remains a cornerstone of UTD's efforts to address GHG reduction and other environmental goals, while meeting ratepayer needs for affordable, resilient, reliable energy. We thank the researchers, innovators, governmental funding agencies, and partners from academia, industry and elsewhere who work with us to create, develop and demonstrate new products and technologies, such as the U.S. Department of Energy (DOE) and Department of Defense (DoD), California Energy Commission (CEC), Propane Education & Research Council (PERC), Natural Gas Innovation Fund (NGIF), Northwest Energy Efficiency Alliance (NEEA), national laboratories, university researchers, entrepreneurs, leading manufacturers, and utility customers.

Utilities participating in UTD

> APGA Research Foundation members
> Atmos Energy Corporation
> DTE Energy
> Enbridge Gas (US & Canada)
> Intermountain Gas Company
> Louisiana R&D Committee
  - Atmos Energy Corporation
  - CenterPoint Energy, Inc.
  - Entergy Corporation
> National Fuel Gas Distribution Corporation
> National Grid
> New Jersey Natural Gas
> New York State Electric & Gas Corporation
> NW Natural
> Nicor Gas
> Oklahoma Natural Gas Company
> Pacific Gas and Electric Company
> Peoples Gas, a WEC Energy Group Co.
> SEMCO Energy Gas Company
> Southwest Gas Corporation
> Spire Energy
> TECO Peoples Gas

Lori Blattner
Chair

Ron Snedic
President



UTD IMPACT

Utilization Technology Development

January 2025

Leading researchers, entrepreneurs, universities, governmental agencies, governmental laboratories, customers, manufacturers, and others partner with UTD as a 501(c)(6) not-for-profit organization of utilities to develop and demonstrate affordable new gas solutions for end users, and accelerate the transition to a lower-carbon future.

Development and demonstration of economical new products, systems, and technologies helps customers save money, save energy, reduce GHG emissions, integrate renewable energy (including renewable natural gas and RE-derived hydrogen), and maintain safe, reliable, resilient operation of their homes and facilities with superior environmental performance.

Please contact us if you have any questions about UTD.

Ron Snedic (1.847.768.0572)   **Rich Kooy** (1.847.768.0512)

UTD helps utilities provide exciting new technologies to benefit their customers and society, while enhancing the impacts of utility energy-efficiency programs.

Utilities participating in UTD serve more than 35 million gas customers in North America.

Together we're shaping the energy future with clean, efficient end-use technologies.

Visit www.utd-co.org for more information.

COMMERCIALIZED PRODUCTS

SMTI ANESI Gas-fired Absorption Heat Pump for Space Heating and/or Water Heating

Provides AFUE-rated efficiency of 140% (~45% gas savings) with ultra-low NOx emissions of ≤14 ng/J while using zero GWP fluids, and performs reliably in extreme cold weather. Commercially introduced in 2023 after long-term technology RD&D support from UTD, including laboratory work and prototype field applications in CA, WI, IL, TN and Canada, with support also from U.S. DOE, CEC, NGIF and others.

SMTI ANESI

Scott Reed

818-421-4229

sreed@stonemtntechnologies.com

www.AnesiComfort.com

EC Power XRGI® MicroCHP

EC Power's XRGI efficiently produces heat and 24kW of power from the same fuel source. UTD collaborated with the CEC, SoCalGas and others to advance this engine-based micro-CHP system towards compliance with California Air Resource Board requirements. UTD also prototyped its use for multi-unit buildings applications and reported energy savings in technical publications.

EC POWER Inc.

Anders Thorsen

585-205-5127

ath@ecpower.com

www.ecpower.com

COMMERCIALIZED PRODUCTS (continued)

CleanO2 CarbinX™ Carbon Capture

CleanO2's revolutionary CarbinX unit captures CO2 from the flue gas of boilers and furnaces to reduce GHG emissions, and turns it into a beneficial consumer product. UTD's members provided technology development expertise and support to CleanO2 since 2018 to refine early prototypes and partner with CleanO2 to identify and make product improvements.

CleanO2, Inc.

Jaeson Cardiff

carbinX@cleano2.ca

www.carbinx.com

Yanmar 3-Pipe Engine-driven Gas Pump

Yanmar's 3-pipe, 14-ton Gas Heat Pump (GHP) with variable refrigerant flow (VRF) offers an important energy-efficiency option for the North American market by combining heat recovery with simultaneous heating and cooling. In a 2018-24 field tests, UTD validated equipment performance and published technical summaries of the results.

YANMAR America Corp.

Eddie Caton

770-877-7733

eddie_caton@yanmar-es.com

www.yanmar-es.com

GRIDIRON PowerPlant™ H24 and HA65

The PowerPlant HA65 from GRIDIRON (formerly M-Trigen) provides high-efficiency microCHP with integrated cooling to homeowners, small businesses, and other users. UTD provided technical support for a notable demonstration by partnering with NYSERDA, National Grid, NJNG, and PERC to independently validate performance. UTD also supported GRIDIRON in its optimization of PowerPlant HA65 to minimize emissions, and its development of PowerPlant H24.

GRIDIRON

713-574-4506

info@gridironenergy.com

www.gridironenergy.com

Tecogen Hybrid-Drive Air-Cooled Chiller

Through laboratory validation and other efforts, UTD is supporting Tecogen's commercial introduction of a Hybrid-Drive 100-ton chiller that seamlessly operates on natural gas or electric grid power in order to integrate more renewable energy, reduce operating costs up to 50% compared to all-electric chillers, provide dual-power-source resiliency, and provide efficient hot water as well as chilled water.

Tecogen

Steve Lafaille

617-678-2429

stephen.lafaille@tecogen.com
www.tecogen.com

TMCAqua Energy and Water Recovery

TMCAqua's unique porous membrane technology developed with UTD's support simultaneously recovers both heat and water from boilers, ovens, dryers and similar equipment. It can increase boiler efficiency from 80% to 93% - typically saving customers 15% in energy while also reducing water demand.

TMC Aqua

TMCAqua@green-swans.com

www.green-swans.com/tmcaqua-technology/

U.S. Boiler K2 High Efficiency Gas Boiler

The K2 high efficiency condensing gas boiler offers 95% AFUE with 10:1 turndown, and uses a novel sheet metal burner from Europe. UTD validated its performance via laboratory tests to support potential gas utility MT incentives, and identified pathways to achieve <5 ppm NOx emissions.

U.S. Boiler Inc.

Craig Eshenaur

717-239-4490

ceshenaur@usboiler.net

www.usboiler.net

COMMERCIALIZED PRODUCTS (continued)

Condensing Dedicated Outside Air System/Rooftop Unit

Condensing heating versions of Munters Dedicated Outside Air System (DOAS) and other rooftop unit (RTU) products increase heating efficiency from 80%-81% to 90%-93%. Multiple RTU manufacturers are now offering DOAS with 90+% efficiencies, facilitated by the availability of condensing duct furnace modules first developed with UTD support.

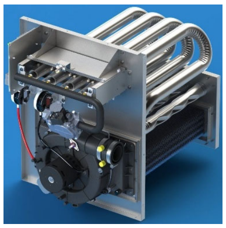
Munters Corporation

Larry Klekar

210-249-3883

larry.klekar@munters.com

www.munters.com



Condensing Duct Furnace Modules

High-efficiency condensing heating modules developed with UTD support are now available from Beckett Gas and other OEMs, including Heatco, and are being applied to DOAS and other products including Make-Up Air Units available from multiple manufacturers including Aaon, Daikin, and RuppAir.

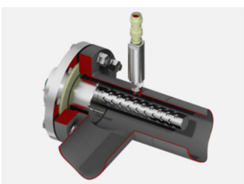
Beckett Gas, Inc.

Joel Mohar

440-783-7610

jmohar@beckettcorp.com

www.beckettgas.com



Gas Quality Sensor

The Gas Quality Sensor (GQS) uses solid-state infrared light absorption spectroscopy to measure Btu content and composition of natural gas and bio-methane fuels. It provides very fast response (3 seconds) at much lower cost than a gas chromatograph. It was developed with UTD's support and was commercially introduced by CMR Group in 2019.

CMR Group

Julien Moynet

+33 (0) 4 91 11 37 00

julien.moynet@cmr-group.com

www.cmr-group.com

Dettson Chinook Low-Capacity Furnace

This novel low-capacity furnace permits right-sizing for low-load buildings and aids integration with renewable energy and improved building envelopes. UTD researchers identified best application practices and provided supporting technical info.

Dettson

Philippe Verhas

1-800-567-2733

pverhas@dettson.ca

www.dettson.com

iFLOW and Advanced Combination Systems

UTD researchers demonstrated how a forced-air condensing tankless water heater combi system using the iFLOW can achieve 30-50% energy savings relative to best-in-class condensing furnaces and water heaters, and used a rigorous Virtual Test Home analysis to assess annualized performance.

iFLOW

Steve Bagshaw

1-800-985-9227 ext 102

steve.bagshaw@iflowhvac.com

www.iflowhvac.com

S.U.N. Equinox Solar-Assisted Heating System

The Equinox system is a combination solar/natural gas water heating system that uses an efficient evacuated tube design. It can be used in residential, commercial, or industrial locations and can meet 100% of domestic hot-water and space heating needs. UTD validated its energy performance in a field demonstration.

Solar Usage Now, LLC

Thom Blake

260-657-5605

tblake@solarusagenow.com

www.solarusagenow.com

iGEN Self-Powered Furnace

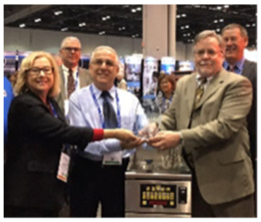
The innovative iGEN furnace generates its own electric power and contains an integrated battery, providing homeowners with continuous heating even during electricity outages. UTD supported the technical refinement of this product with laboratory testing, validation, and recommendations.

iGen Technologies

letstalk@igentechnologies.ca

www.igentechnologies.ca

COMMERCIALIZED PRODUCTS (continued)



ENERGY STAR® Fryers

Royal Range introduced the high-efficiency RHEF-75 fryer in 2019 - building on the success of the smaller-capacity, high-efficiency RHEF -45 fryer that received the National Restaurant Association's Kitchen Innovation Award and GFEN's Blue Flame Product of the Year Award. Independ-ent testing showed 63% heavy-load cooking energy efficiency.

Royal Range of California

Robert Lutz

951-360-1600

robert@royalranges.com

www.royalranges.com

Low-Oil-Volume Fryers

Marketed by Frymaster as Protector® fryers, this equipment increases energy efficiency while also extending cooking-oil quality and life to provide significant customer savings. Field demonstrations completed by UTD have shown an average savings of $4,800 per year per fryer.

Frymaster

800-221-4583

www.frymaster.com

ENERGY STAR Conveyor Oven

ENERGY STAR rated conveyor ovens from Lincoln include an ad-vanced energy-management system to reduce energy consumption up to 38%.

Lincoln, a division of Manitowoc Foodservice

260-459-8200

www.lincolnfp.com

ENERGY STAR Convection Oven

This unit showed improved efficiency and 40% energy savings com-pared to a standard oven during field testing and achieved an ENER-GY STAR rating.

Garland

905-624-0260

www.garland-group.com

High-Efficiency Broiler

This broiler features infrared burners and an energy-saving hood that showed an average of 23% energy savings during field testing. It of-fers more efficient cooking as well as reducing heat gain to the kitch-en.

Royal Range of California

800-769-2414

www.royalranges.com

ENERGY STAR Countertop Steamer

A compact, gas-fired countertop steamer for commercial foodservice offers enhanced cooking rates while providing energy savings and reduced water consumption. It was the first gas-fired boilerless steamer on the market and received an ENERGY STAR rating.

Market Forge Industries Inc.

617-387-4100

866-698-3188

custserv@mfii.com

www.mfii.com

High-Efficiency Broiler

The Montague Company commercialized a version of the advanced broiler technology using thermostatic broiler-temperature control and an energy-saving hood. It was recognized with a Kitchen Innovations Award in 2013.

Montague

800-345-1830

www.montaguecompany.com

L9N

Cummins Westport 8.9L Near-Zero Emission NGV Engine

This 8.9L 320-HP NGV engine is widely used, with 50,000+ engines sold for transit, refuse-collection, and regional hauling applications since 2007. In 2016, it was advanced to become the first engine certified in North America to meet the 0.02 g/bhp-hr optional Near Zero (NZ) NO_x emissions standard (i.e. 90% lower than the current EPA NO_x limit of 0.2 g/bhp-hr).

Cummins Westport Inc.

Yemane Gessesse

812-377-5000

yemane.gessesse@cummins.com

www.cumminswestport.com

B6.7N

Cummins Westport 6.7L Medium-Duty NGV Engine

This 6.7L 240-HP natural gas vehicle (NGV) engine is used in school buses, shuttle buses, medium-duty trucks, and other vocational uses. It went into full commercially production in December 2016. It meets U.S. 2017 EPA GHG requirements as well as NZ NO_x emissions standard of 0.02 g/bhp-hr.

Cummins Westport Inc.

Yemane Gessesse

812-377-5000

yemane.gessesse@cummins.com

www.cumminswestport.com

ISX12N

Cummins Westport 11.9L Near-Zero Emission NGV Engine

This 11.9L 400-HP NGV engine is used in large trucks, buses, and refuse vehicles. Engine sales since 2013 are approaching 10,000 units and 25,000+ engines will likely be sold in N.A. by 2020, yielding emissions reductions and $600+ million in annual fuel sales. In Model Year 18, it became CWI's second engine certified to meet NZ NO_x emissions standard of 0.02 g/bhp-hr.

Cummins Westport Inc.

Yemane Gessesse

812-377-5000

yemane.gessesse@cummins.com

www.cumminswestport.com

U.S. Hybrid Near Zero Emission Plug-in Hybrid Powertrain

This hybrid powertrain uses a CNG/RNG-powered engine and electric motor in parallel to provide 640 HP and 1770 lb-ft of maximum torque, to increase the use of electricity produced from RE, use less fuel, increase operating range and resiliency, and provide superior operating performance. It was developed with support from DOE, CEC, SCAQMD, SoCalGas, UTD, and others.

U.S. Hybrid

310-212-1200

sales@ushybrid.com

www.ushybrid.com

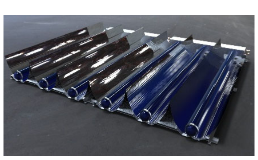
Heat Sponge Economizer for Industrial/ Commercial Boilers

In either condensing or non-condensing configurations, this heat recovery system for commercial and industrial boilers (over 140,000-unit market in U.S.) increases boiler efficiency from 80% to a range of 85%-93% (validated by UTD lab testing). It also saves customers 5%-15% in annual energy costs. UTD completed a field test in Utah to validate energy savings.

Boilerroom Equipment, Inc.

866-666-8977

www.heatsponge.com



External Concentration Parabolic Collector

This patented, non-tracking, extremely-low-profile concentrator can achieve 200°C (392°F) solar thermal energy to economically serve commercial and industrial facilities and reduce GHG emissions. It can also be integrated with natural gas as a supplemental energy source. UTD provided technical and product development support and experimental validations over a seven-year period.

Artic Solar Inc.

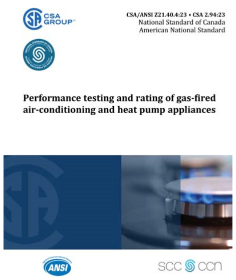
Bill Guiney

904-513-4638

bill@articsolar.com

www.articsolar.com

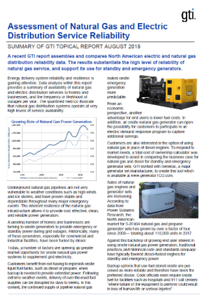
KEY INFORMATION & ANALYTICAL TOOLS



CSA/ANSI Z21.40.4-23/CSA 2.94-2023 Performance Testing and Rating of Gas-Fired Air Conditioning and Heat Pump Appliances Technical Committee Support

ANSI/CSA Z21.40.4 issued in 2023 and was a major upgrade and update to the 1996 edition of this Method of Test for GHPs. Updates included: increasing what can be rated with residential seasonal efficiency metrics; enhanced calculations and test conditions to better reflect systems designed for heating operation; more optional operating points; and expanded scope to include VRF-type engine-driven systems. UTD supported participation on the Technical Task Force that updated the Standard.

Available at https://webstore.ansi.org



Reliability, Cost and Environmental Impacts of Standby Generation Systems

Generac's website provides technical information related to emissions, reliability and costs of natural gas generators that was developed with UTD's support. For example, UTD researchers published a white paper that provided new data on the reliability of natural gas service and assisted in the development of a Total Cost of Ownership calculator that compares emissions and costs of natural gas vs. diesel-fueled standby generators.

Available at https://www.gti.energy/wp-content/uploads/2019/02/Assessment-of-Natural-Gas-Electric-Distribution-Service-Reliability-SummaryReport-Jul2018.pdf and https://www.generac.com/Industrial/all-about/natural-gas-fuel

U.S. DOE Building America

Under five separate UTD projects from 2011 to 2021, UTD has developed key information and tools to support the U.S. DOE's Building America research, development, and demonstration program, which helps accelerate use of best practices by residential builders, remodelers, installers, code officials, designers, raters, teachers, and others.

Available at https://www.gti.energy/BuildingAmerica and https://basc.pnnl.gov/library

Commercial Foodservice (CFS) Equipment Calculator

This website provides the restaurant industry and others with information and tools to determine the economic and environmental benefits of using new, more advanced and efficient CFS equipment. The website was developed with UTD support and has been showcased at several restaurant trade shows. Further enhancements were made in 2024.

Available at http://cfscalc.gastechnology.org. For more info, contact Frank Johnson; fjohnson@gti.energy

Commercial Foodservice Energy Monitoring Systems (FEMS)

A real-time energy monitoring system for use in cooking demonstrations, trade shows, test kitchens, and similar venues was developed to help CFS customers better understand the GHG reduction and economic benefits of using higher-efficiency equipment.

For more info, contact Shawn Scott; sscott@gti.energy

Virtual Test Home

A Virtual Test Home (VTH) in a laboratory was developed with UTD's support. The VTH holistically analyzes equipment and system performance by assessing part-load, annualized performance for various locations. The VTH helps accelerate the adoption of advanced gas technologies (such as GHPs, combis and modulating furnaces) in the marketplace and in performance assessment tools such as U.S. DOE's *EnergyPlus*™ or other energy software.

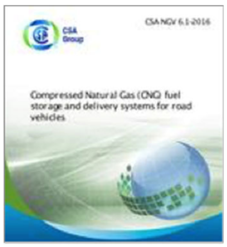
For more info, contact Tim Kingston; tkingston@gti.energy An overview is also available at https://neea.org/product-council-documents/virtual-test-home

KEY INFORMATION & ANALYTICAL TOOLS

CSA NGV4.3 NGV Storage and Delivery Standard Technical Committee Support

CSA NGV4.3 was updated in 2022 and specifies requirements for temperature compensation control used to prevent compressed natural gas (CNG) dispensing systems from exceeding a safe fill level of vehicle fuel storage container(s). It contains safety performance guidelines and field evaluation methods for existing dispensing systems. UTD supported participation to lead the Technical Task Force that created the Standard in 2018 and updated it in 2022.

Available at www.csagroup.org



CSA NGV6.1 NGV Storage and Delivery Standard Technical Committee Support

CSA NGV6.1 was introduced in 2016 and defines the requirements for the balance of systems and equipment onboard a NGV, which is not otherwise defined by NGV1 for the receptacle or NGV2 for the storage containers. UTD supported participation on the Technical Committee.

Available at www.csagroup.org

CSA NGV5.1 and NGV5.2 Fueling Appliance Standard Technical Committees Support

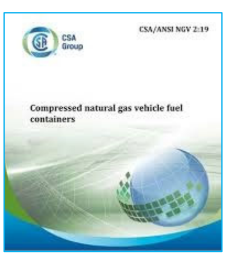
CSA NGV5.1 was introduced in 2015 and updated in 2016, and provides mechanical, physical, and electrical requirements for residential fueling appliances (RFAs) that dispense natural gas for NGVs, including indoor and outdoor fueling appliances that connect to residential gas piping. A complimentary standard, NGV5.2 for vehicle fueling appliances (VFAs) in non-residential locations, has been developed and was published in late 2017. UTD supported participation on both of the Technical Committees.

Available at www.csagroup.org

CSA SPE-2.21.1:20 Best Practices for CNG Vehicle System Leak Inspection Standard Technical Committee Support

In 2020, the first edition of CSA SPE-2.21.1 was published. It provided additional specific guidance and best practices to enhance user safety and mitigate potential leaks. Recommendations regarding in-service leak detection, inspection and repair are provided, including leak detection methods. UTD supported participation on the Technical Committee.

Available at www.csagroup.org



CSA NGV2 CNG Vehicle Fuel Containers Standard Technical Committee Support

The sixth edition of CSA NGV2 issued in 2019 and contains updated information and requirements for the material, design, manufacture and testing of serially-produced, refillable Type NGV 2 containers intended only for the storage of CNG for vehicle operation. The 2019 revision includes localized fire tests and conformable storage topics. UTD supported participation to lead the Technical Task Force that created the Standard.

Available at www.csagroup.org

EnergyPlus™ Technical Support/Input

UTD-funded research and publications have provided detailed performance data of high-efficiency fuel-fired heat pumps, innovative combination and hybrid systems, tankless water heaters, and other advanced fuel-fired equipment in order to support continuous improvement to DOE's flagship EnergyPlus whole-building energy simulation program, which engineers, architects, and researchers use to model energy consumption in buildings.

Available at https://energyplus.net

TECHNOLOGY ADVANCEMENTS

Hydrogen-Blended Gas in Residential, Commercial and Industrial Applications

UTD is performing substantial research on the blending of hydrogen into natural gas and the performance of blended fuels in many types of equipment commonly used in residential, commercial and industrial applications, such as to assess impacts on emissions, leakage, venting and safety. UTD is also developing new burner technologies that can operate on up to 100% hydrogen fuel, and identifying potential colorants to enhance flame visibility.

Project Managers: Multiple

Robur K18 Gas Heat Pump for Residential Space Heating and/or Water Heating

UTD is supporting the potential introduction into the North American market of Robur's K18 Gas Absorption Heat Pump. This 60,000 Btu/hr thermally-driven air-source heat pump will offer very high efficiency operation, with support from a long-established manufacturer. UTD performed laboratory testing to establish detailed performance curves, which can be incorporated into energy modeling tools in order to accelerate product adoption in North America.

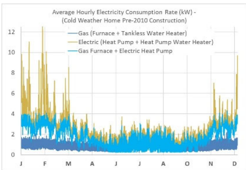
Project Manager: Alejandro Baez Guada

Ultra-Low NO_x Burner

This innovative firetube boiler technology has multiple years of proven successful operation at a Mission Linen Supply facility in California. It improves efficiency and achieves NO_x emissions below 9 vppm, while avoiding the significant efficiency, capital cost, and/or operating cost penalties if conventional Selective Catalytic Reduction or burner enhancements such as external Flue Gas Recirculation and/or High Excess Air firing were used.

Project Manager: David Cygan

Hybrid Fuel-fired and Electric-driven ResCom HVAC Systems



Researchers are evaluating emerging or commercially-available hybrid gas furnace/electric heat pump products in the North American market, in order to identify the more promising hybrid systems and develop installation and operation guides that can help end users accelerate their integration of electricity derived from renewable energy with fuel-fired equipment.

Project Manager: Alejandro Baez Guada

FlexCHP High-Efficiency Ultra-Clean Power and Steam Package

This innovative CHP package allows flexible steam production while meeting stringent California emission levels without a SCR system and across the full range of firing rates — achieving NO_X levels 50% below CARB limits. An installation in California operates with 84+% system efficiency and system emissions well below 9 ppm NO_X. UTD has provided long-term support, including efforts to apply the technology to broader application sizes (e.g. to 400 kW / 400 BHP).

Project Manager: David Cygan

Blue Frontier Rooftop AC Unit with Integrated Energy Production and Storage

UTD researchers are collaborating with Blue Frontier to help accelerate commercialization of its novel desiccant-based cooling technology that provides very high efficiency cooling with a Dedicated Outdoor Air System, in part by assessing in a laboratory prototype the feasibility of integrating on-site energy production in order to further enhance system efficiency, operational resiliency, and the benefit of this unique technology's integral energy storage.

Project Manager: Lee Van Dixhorn

TECHNOLOGY ADVANCEMENTS (continued)

Gas-Fired Warewasher

A gas-fired warewasher is being advanced in conjunction with a leading OEM. The estimated annual savings for restaurant, cafeteria, and other commercial food service operators is $1,100-$9,000 per warewasher (depending on size and type) while also saving energy and chemicals, when compared to electrically-heated warewashers that operate at lower temperature and thus require one-time use and environmental impact of chemicals.

Project Manager: Shawn Scott

Cost-Effective Compressor/Expander for Natural Gas and Hydrogen-fueled Vehicles

With UTD cost share and U.S. DOE funding, GTI Energy and the University of Texas, Austin developed a novel approach using a linear motor compressor with only one moving piston. The technology was recently scaled up to 50 SCFM capacity with UTD funding, and gas expansion applications are also being developed. The technology has the potential to significantly enhance CNG and H2 vehicle fueling operations, and a 2024 award selection from U.S. DOE will also advance its potential application as a refrigerant compressor.

Project Manager: Jason Stair

On-Demand Heat and Power System

This unique new technology has received a remarkable three rounds of funding from U.S. DOE ARPA-E, along with UTD and other co-funding support. This technology captures and stores renewable energy (or other resources, including waste heat), augments it with natural gas as needed, and delivers heat and power on-demand to commercial, industrial, and other users. The technology has been demonstrated at a pilot field installation in California.

Project Manager: David Cygan

SMTI ANESI Gas-fired Absorption Heat Pump Residential Water Heater

A field test of five prototype units of this efficient residential Gas-Fired Heat Pump Water Heater was successfully completed in Southern California during 2020, with support from CEC, UTD, SoCalGas and a prospective manufacturing partner. The unit has a projected Uniform Energy Factor (UEF) of 1.20-1.30 and ultra-low NOx emissions of ≤10 ng/J. Potential commercial production is being evaluated.

Project Manager: Paul Glanville

Energy Recovery Heat Exchanger

UTD researchers collaborated with CEC to demonstrate in California an advanced recuperator to increase energy efficiency at an aluminum die casting operation. Test results demonstrated 6-16% energy reduction. A 2024 award selection from U.S. DOE will further advance its technical development in 2025-27, in partnership with UTD and many others.

Project Manager: David Rue

Customized Affordable Retrofits of Building Envelopes and Mechanicals

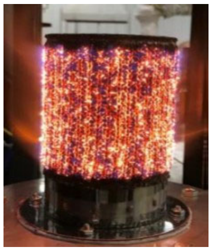
UTD researchers are partnering with Hydronic Shell Technologies LLC (HST) to advance a new technology that can rapidly integrate highly innovative building envelope improvements with next-generation HVAC equipment retrofits to reduce GHG emissions by >50%, while providing significant operating cost savings for and minimal disruption to homeowners, residents in income-eligible housing or multi-family buildings, and others.

Project Manager: Jason LaFleur

HeatAmp Adsorption Thermal Heat Pump

The product development effort couples a proprietary triple-state sorption technology with a novel product design integration that is expected to yield a family of cost-effective, high-efficiency, robust appliances with few moving parts. Example applications are water heating or combination water/space heating. UTD is helping HeatAmp develop its new product with laboratory testing, validation, design recommendations, and a review of applicable N.A. engineering standards.

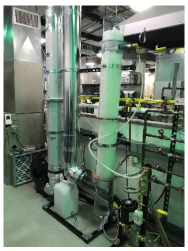
Project Manager: Paul Glanville



ThermoLift Ultra-High-Efficiency, Heating/Cooling Vuilleumier Cycle Heat Pump

Vuilleumier cycle-based heat pumps could provide a step-change efficiency improvement over vapor absorption- or compression-based cycles, achieving cooling COP > 1 and heating COP > 2. UTD is working with a leading developer to advance key system components using both computational and experimental analysis, to help achieve performance goals in alpha prototype testing funded by DOE, UTD and others.

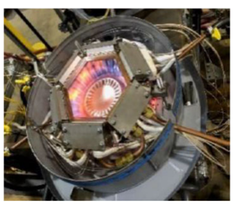
Project Manager: Alex Fridlyand



Next Generation Liquid Desiccant-based, Heat-Driven HVAC System

Liquid desiccant-based systems can efficiently remove moisture from air and reduce the amount of mechanical energy and water required by conventional HVAC technologies that de-humidify, condition, and re-humidify space air. In cooperation with NYSERDA and others, UTD is testing a novel new non-corrosive, non-toxic desiccant in a gas-driven system that offers a potential 30% increase in COP on a seasonal basis over conventional HVAC technologies.

Project Manager: Rich Swierczyna



Self-Powered Water Heaters

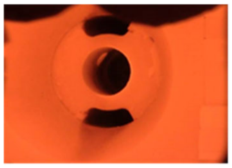
Higher-efficiency water heaters typically require the added expense of an electrical connection and are susceptible to power outages unless a separate battery back-up system is installed. UTD researchers have assessed leading thermoelectric generator (TEG) technologies, and in 2024 further analyzed opportunities in coordination with a major OEM to economically integrate TEGs and other technologies into a prototype water heater design.

Project Manager: Sandeep Alavandi

Emerging Fuel Cells

UTD researchers experimentally tested and evaluated several fuel cells that are entering (or exploring entry into) the North American market in order to serve residential and light commercial end users. UTD research also identified and optimized the applications that can maximize the benefit of the high efficiency and reliability of these units.

Project Manager: Tim Kingston



FlexGen-H™ High Efficiency, Fuel-Flexible, Ultra-Low NOx Regenerative Burner

UTD is partnering with the U.S. DOE, an industry-leading OEM, SoCalGas and others to develop and test in a laboratory a next-generation 1.5–2.0 MMBtu/hr regenerative high-efficiency burner system that incorporates novel inserts and integrated cooling to: decarbonize process heating and related industrial use sectors such as iron, steel and aluminum by allowing flexible use of up to 100% H_2; and expand potential applications of high-efficiency regenerative operation to more industries when operating solely on renewable or fossil natural gas.

Project Manager: Sandeep Alavandi

TECHNOLOGY ADVANCEMENTS (continued)

CNG/RNG Locomotive

With prime funding from U.S. DOE, UTD and other entities are funding the development of a prototype locomotive that can run on fossil or renewable natural gas to serve Class I, II or III railroads in multi-engine, line-haul service, but achieve Near Zero Emissions and target 20% less fuel consumption than a diesel locomotive.

Project Manager: Bart Sowa

Distributed RNG/Biogas Production

UTD is partnering with leading technology developers such as Chomp Energy to increase renewable natural gas (RNG) or biogas production at end-use customer sites in order to reduce landfill requirements, reduce the transport of food waste, and meet de-carbonization goals. UTD is supporting technical advancements such as improved instrumentation, controls and designs.

Project Manager: Travis Pyrzynski

High Efficiency Convection Oven

UTD researchers tested design changes and innovations to achieve a 10% efficiency improvement vs. best-in-class Energy Star convection ovens. By their inherent design, these ovens constantly flow hot air out of the oven. There are an estimated 650,000-700,000 convection ovens in the US, according at a 2015 DOE study. Discussions with leading OEMs are in progress in order to commercialize this technical advancement.

Project Manager: Shawn Scott

Thermal Ejector Technology to Recover Energy and Water from Hot Flue Gases

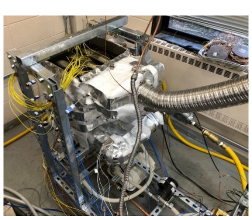
In a field demonstration at a large industrial plant in California, UTD researchers partnered with CEC and a major manufacturer to apply a novel new thermal ejector technology which recovers useful process water from the plant's humid exhaust gas, which in turn increases energy efficiency. Opportunities to install the technology at larger scale at other facilities are being sought.

Project Manager: Lee Van Dixhorn

Energy Recovery System for Brewing and Distilling Operations

UTD researchers are testing a novel heat exchange system to recover previously-wasted energy at two micro-breweries in California, with funding from UTD and prime funding from CEC. Project goals include to recover 15-25% of heat from brew kettles, and reduce CO_2 emissions by up to 25%, while maintaining superior process operations.

Project Manager: David Rue



Ionic Liquid Technology for Residential and Commercial Gas Heat Pumps

Researchers at the University of Florida and Micro Nano Technologies are partnering with UTD to design and demonstrate an early prototype of a low-cost, ultra-high-efficiency thermally-driven heat pump for residential and commercial water heating or combination water heating/space heating which employs the unique thermal properties of ionic liquids. A 2024 award selection from U.S. DOE will further advance its technical development in 2025-27, in partnership with UTD and many others.

Project Manager: Paul Glanville

TECHNOLOGY ADVANCEMENTS (continued)

High Efficiency and Low Emission Charbroiler

An advanced charbroiler is being created and demonstrated at laboratory scale that has the potential to improve efficiency by 20-30%, reduce particulate emissions by 20-50%, and reduce NOx emissions by 20-30%.

Project Manager: Shawn Scott

Next Generation Infrared Burner

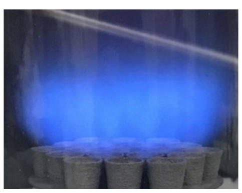
In partnership with a leading OEM, UTD-funded researchers are testing a variety of unique metal foam materials in a laboratory to evaluate their potential performance as next-generation, high-efficiency, rapid-response, low-emission infrared burners that are directly fired with fossil or renewable natural gas. Field tests are in development.

Project Manager: Sandeep Alavandi

Furnace Retrofit for High-Efficiency Heating and Humidification

Tests of a patented Transport Membrane Humidifier (TMH) technology in four homes in Minnesota demonstrated a 14% increase in furnace efficiency while providing humidification without water supply. Interested licensees should contact Rich Kooy at rkooy@utd-co.org.

Project Manager: Dexin Wang



Low NO_x Energy-Efficient Advanced 3D-Printed Nozzle Burner

A novel design for next-generation retention nozzles leverages new additive manufacturing capabilities and equipment. In 2023, UTD is evaluating applications for boilers, water heating and air heating. Laboratory tests have demonstrated a robust, high-efficiency (3-6% increase), ultra-low emissions burner, with >10:1 turndown. It achieved 50%-75% reduction in NO_X emissions compared to current burners, with the potential to reach <5 ppm NO_X.

Project Manager: Sandeep Alavandi

WORKING WITH PARTNERS TO CO-FUND UTD INITIATIVES

In 2024, each $1.00 in new UTD funding was leveraged by $7.80 of funding from government and industry partners for related end-use R&D. GTI Energy secured $37.6 million from federal and state government partners and $6.5 million from manufacturing partners and other gas industry resources (outside of UTD) for related end-use R&D. Manufacturing partners also provided significant additional in-kind co-funding.

Examples include:

- U.S. Department of Defense (DOD) funding of $20.9 million for four awards to apply advanced energy efficiency and heat pump technologies, and to develop and demonstrate novel distributed energy resources, in order to reduce GHG emissions and energy use while increasing resiliency.
- U.S. Department of Energy (DOE) funding of $6.0 million to develop and test an advanced mobile hydrogen refueling system, with pilot deployments at various field sites to demonstrate capability.
- U.S. Department of Energy (DOE) funding of $5.9 million for two awards to develop innovative fuel-flexible burners and combustion systems to expand use of low-carbon fuels such as hydrogen.
- California Energy Commission (CEC) funding of $2.9 million to design, build, install and measure performance of two prototype energy-efficient manufactured homes with innovative insulation panels.

Example Technical Publications/Presentations 2023-24
developed in part with UTD's Support

Ahsan, A., "Laboratory Evaluation of Thermally Driven Adsorption Heat Pump for Domestic Hot Water", ACEEE Hot Air and Hot Water Forum, Atlanta, GA, March 13, 2024, https://drive.google.com/file/d/15J5EUtN8LRi9Ww2wSi5EB6aD3CiAEGRU/view (results in part from UTD project 1.21.A).

Alavandi, S., Abbasi, H., Cygan, D., Wagner, J., "Advanced Hydrogen Burner for Commercial and Industrial Applications", AFRC Industrial Combustion Symposium, Calgary, AB, Canada, September 30-October 3, 2024 (results in part from UTD project 2.21.A).

Alavandi, S., Abbasi, H., Cygan, D., Wagner, J., Pondo, J., Gnatenko, V, Laclair, T., Gluesenkamp, K., Ghoshal, U., and Noska, B., "Grid Resilient Self Powered Heating System", International Refrigeration and Air Conditioning Conference, West Lafayette, IN, July 15-18, 2024 https://docs.lib.purdue.edu/iracc/2559/ (results in part from UTD project 1.19.C).

Chudnovsky, Y., Buyadie, D., Buyadie, O., Drakhnia, O., "Method and System of Thermo-Vacuum Drying and Processing", U.S. Patent No. 11,885,563 B2, Jan. 30, 2024 (results in part from UTD projects 2.14.A and 2.17.C).

Dharmarajan, R., Rowley, P., Stein, J., Ravi, A., and Scott, S., "Performance Validation and Curve Fit Generation of Natural Gas and Electric Heat Pump VRF Systems", ASHRAE 2024 Winter Conference paper #CH-24-C056, Chicago, IL, January 2024 (results in part from UTD projects 1.21.E, 1.19.F and 1.17.G).

Glanville, P., Fridlyand, A., PhD, Zhao, Y., PhD, Kar, T., PhD, Asher, W., PhD, Jogineedi, R., PhD, "Is the Heating Industry Hydrogen-Ready?; A Meta-Analysis of Hydrogen Impact Assessments on Combustion Equipment in Buildings", ASHRAE 2024 Winter Conference paper #CH-24-C035, Chicago, IL, January 2024 (results in part from UTD projects 1.20.H and 2.23.A).

Glanville, P., Guada, A.B., Kumar, N., LaFleur, J., and Shah, H., "The Heat Pumps Are Coming! How Thermally-Driven, Hybrid, and Latent Cooling Solutions Can Drive Building Decarbonization", *Proceedings of the 2024 International Gas Research Conference*, Banff, AB, Canada, May 13-16, 2024 (results in part from UTD projects 1.21.A, 1.21.I, and 1.22.H).

Glanville, P., Alavandi, S., Fridlyand, A., Kar, T., Zhao, Y., and Kozlov, A., "Decarbonizing Heating Equipment by Adopting Hydrogen-based Fuels: Review of Recent Progress in North America", *Proceedings of the 2024 International Gas Research Conference*, Banff, AB, Canada, May 13-16, 2024 (results in part from UTD projects 1.20.H, 2.22.B, and 2.23.A).

Guada, A.B., Kingston, T., Armatis, P., LeFleur, J. "Benefits of Integrated Energy Systems for Multi-Family End-Use Load Including EV Charging", ASHRAE 2024 Winter Conference paper #CH-24-C033, Chicago, IL, January 2024 (results in part from UTD project 1.20.J).

Johnson, F., PhD, Swierczyna, R., Sutherland, B., Pixler, J., "Cooking Emissions from Food for Natural Gas, Propane, and Electric Range Tops", ASHRAE 2024 Winter Conference paper #CH-24-C020, Chicago, IL, January 2024 (results in part from UTD project 1.17.H).

Halliday, D., "Free-Piston Expander for Hydrogen Cooling", U.S. Department of Energy Merit Review, Washington, DC, May 7, 2024 https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review24/in016_halliday_2024_o.pdf?sfvrsn=d9e63023_3 (results in part from UTD project 2.18.I).

Halliday, D., “Cost-Effective Pre-Cooling for High-Flow Hydrogen Fueling”, U.S. Department of Energy Merit Review, Washington, DC, May 7, 2024 https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/review24/in036_halliday_2024_o.pdf?sfvrsn=6b5d4094_3 (results in part from UTD project 2.22.G).

Kingston, T., Guada, A.B., and Sishtla, C., “Emerging Residential/Commercial Solid Oxide Fuel Cells Laboratory Evaluations”, *Proceedings of the 2024 International Gas Research Conference*, Banff, AB, Canada, May 13-16, 2024 (results in part from UTD project 1.20.F)

Kumar, N., PhD, “Hybrid (Dual-Fuel) Systems Control Optimization for Annual Operating Cost and Emission”, 2024 ACEEE Hot Air and Hot Water Forum, Atlanta, GA, March 13, 2024 https://drive.google.com/file/d/1CKpXqUiiNkYdj3yfuuRTxtpY4a-8CMc8/view (results in part from UTD project 1.22.H).

Kumar, N., PhD, Armatis, P., Guada, A.B., Kingston, T., “Hybrid Heat Pump System's Control Optimization for Annual Heating Operating Cost and Emission Minimization”, ASHRAE 2024 Winter Conference paper #CH-24-C024, Chicago, IL, January 2024 (results in part from UTD project 1.22.H).

LaFleur, J., Biswas, K., PhD., Briggs, J., PhD, Dwiggins, D., Ortiz, C., Scherrer, E., “Prefabricated R30 Retrofit Panel Development and Verification”, ASHRAE 2024 Winter Conference paper #CH-24-C039, Chicago, IL, January 2024 (results in part from UTD project 1.22.E).

Pixler, J., Komar, J., Bushell, M., Ambroz, S., Zhao, Y., Johnson, F., “Cooking with Hydrogen”, presentation at American Society of Gas Engineers 2024 Technical Conference, Las Vegas, NV, June 4, 2024 (results in part from UTD project 1.21.H).

Sowa, B., “Field Demonstration of a Near-Zero, Tier 5 Compliant, Natural Gas Hybrid Line-Haul Locomotive”, U.S. Department of Energy Merit Review, Washington, DC, June 4, 2024, Presentation #TI163 in “Technology Integration” available at https://www.energy.gov/eere/vehicles/2024-vehicle-technologies-office-amr-presentations-program (results in part from UTD project 2.21.F).

Stair, J., “Advances in CNG Fuel Gauge and Dispenser Performance”, presentation at the Illinois Alliance for Clean Transportation 2024 Green Drives Conference, Alsip, IL, May 9, 2024 (results in part from UTD project 2.20.E).

Swierczyna, R., Pixler, J., Sutherland, B., and Johnson, F., “Field Evaluation of Indoor Air Quality in Residential Kitchens”, presentation at Indoor Air 2024 Conference, Honolulu, Hawaii, July 7-11, 2024 (results in part from UTD project 1.20.K).

Van Dixhorn, L., Alavandi, S., Abbasi, H., Cygan, D., Wagner, J., and Pondo, J., “Mitigating Methane Emissions from Industrial and Large Commercial End Use Equipment”, *Proceedings of the 2024 International Gas Research Conference*, Banff, AB, Canada, May 13-16, 2024 (results from UTD 2.22.E).

Zhao, Y., “United States Hydrogen Hubs and Required NOx Emission Regulations”, Association of Energy Engineers AEE West 2024 Conference, Bellevue, WA, May 1-2, 2024 (results in part from UTD project 1.22.C).

Zhao, Y., Glanville, P., Fridlyand, A., and Sutherland, B., “Hydrogen Blending into Residential Water Heaters with Hydrogen Content Monitored in the Pipeline”, *Proceedings of the 2024 International Gas Research Conference*, Banff, AB, Canada, May 13-16, 2024 (results in part from UTD 1.20.H).

Other final research reports are publicly available from the U.S. Department of Energy, California Energy Commission, Minnesota Conservation Applied Research and Development, and other governmental agencies which provided prime research funding and for which UTD provided cost share co-funding. Examples include:

Cygan, D., and Hamid A., *High Efficiency Process Heating*, March 2024. California Energy Commission. Publication Number: CEC-500-2024-004 https://www.energy.ca.gov/sites/default/files/2024-03/CEC-500-2024-004.pdf (results in part from UTD projects 2.16.B).

Rue, D., Alavandi, S., Wagner, J., October 2024, *Demonstration of Water Recovery from Hot, Humid Exhaust Gases*, California Energy Commission. Publication Number: CEC-500-2024-099 https://www.energy.ca.gov/sites/default/files/2024-10/CEC-500-2024-099.pdf (results in part from UTD projects 2.17.A).

Sweeney, M., Glanville, P., Mort, D., Slater, M., Livchak, D., June 2024, *Demonstrating Natural Gas Heat Pumps for Integrated Water Heating and Air-Conditioning in Restaurants*, California Energy Commission. CEC-500-2024-058 https://www.energy.ca.gov/sites/default/files/2024-06/CEC-500-2024-058.pdf (results in part from UTD project 1.16.I).

RESIDENTIAL AND LIGHT COMMERCIAL, INCLUDING mCHP

UTD Utilization Technology Development

Next-Generation Residential Gas Heat-Pump Water Heater

A research team designed and demonstrated the first residential gas-fired heat-pump storage water heater. This project advanced this technology from laboratory prototype through multiple field demonstrations, including in California through 2020. It provides a uniform efficiency factor of ≥1.2, to offer homeowners ≥50% energy savings.

Project Description

The industry's first residential gas heat-pump water heater (GHPWH) is near commercialization, with multiple OEM partners and a series of successful field trials advancing the design of each generation of prototypes.

In partnership with other research funding agencies, UTD co-funded a team of researchers to develop the residential/small-commercial GHPWH, reduce its costs, and improve reliability by refining a number of system components.

The initial GHPWH development initiative was funded by the U.S. Department of Energy (DOE). This UTD project effort has been a steady development led by Stone Mountain Technologies, Inc. (SMTI) along with commercial OEM partners and GTI Energy.

The first-generation GHPWH units were designed and demonstrated through laboratory testing from 2011 to 2013. Subsequently, six GHPWH units were installed and monitored in the field. Through these initial field tests, critical information was used to improve the GHPWH control strategies and future design improvements (including system sizing).

The most recent phases of this UTD project focused on supporting an additional five field demonstrations in a program sponsored by the California Energy Commission (CEC) with financial support from Southern California Gas Company (SoCalGas) in addition to UTD, and also investigating enhanced options for system diagnostics and grid interactivity.

In phase 5, the teams goal will be to reduce installation cost/barrier of condensate drain, by developing a proprietary method of neutralizing, collecting, and disposing of combustion condensate, and improving Onboard Diagnostics through Enhanced Solution Level Control (ESLC) to improve system reliability and long-term performance.

In phase 6, the team will be developing strategies to deploy the residential GHPWH as distributed energy resource (DER) for residential grid-level shed and shift events and developing methods to improve DHW capacity with supplemental gas/electric "boost" capabilities.

Benefits / Market Implications

The motivation for developing a GHPWH is efficiency driven. When delivered to the market, the GHPWH will be the only technology and product of its kind with a primary energy efficiency of greater than 100%. These efficiency gains are significant, with project uniform efficiency factors (UEFs) of 1.20 or greater, and consistent field results of 50% or greater energy savings over conventional water heaters, respectively.

Results from this project have the potential to reduce the cost, increase the reliability, and more than double the efficiency of the next generation of gas heat-pump water heaters for homeowners and light commercial end users.

Technical Concept & Approach

The GHPWH units are driven by an air-source single-effect absorption heat pump, itself driven by a gas burner, capable

GHPWH Prototype Unit Installed in Laboratory

"SoCalGas RD&D continues to be impressed with the capabilities of the UTD team. They helped identify test sites, coordinate with installation partners, and share the results with the public through a webinar. This type of partnership and research project is just one way SoCalGas is working to be the cleanest, safest, and most innovative energy company in America."

- Neil Navin
Vice President, Clean Energy Innovations
SoCalGas

of Coefficients of Performance (COP) of 1.4-1.9. This can yield a UEF of 1.20, more than twice the efficiency of standard gas storage water heaters, which are in, for example, 74% of California homes.

Based upon a recent certification, the units are ultra-low-NO_x compliant. The packaged GHPWH heats the 60 to 80 gallons of stored water with a nominal 10,000 Btu/hr output ammonia-water absorption heat pump, driven by a small 6,300 Btu/hr low-NO_x gas burner. With such a small combustion system, the GHPWH offers retrofit installation advantages over other high-efficiency gas products.

Through the broader project funded by the CEC and cofunded by UTD and SoCalGas, the project team focused on the testing of GHPWH units and the development, use, and refinement of advanced fault detection and diagnosis. The goal was to demonstrate that the projected delivered efficiencies of 130% or greater are valid, robust, and are not achieved through a loss of user comfort. Researchers estimated the annual energy, operating cost, and emissions savings and solicited feedback from host end users and installation contractors through pre- and post-installation surveys.

Results

Following a laboratory development program, the first prototype gas heat-pump water heater was installed in a Tennessee residence and investigated over a 10-month period. The laboratory-validated performance and preliminary field test data suggested that the 1.20 UEF target was feasible and the technology could be competitive with other available high-efficiency gas water-heating options.

In 2015, project efforts focused on transitioning the purpose-built prototype from field testing to reliability testing. Reliability testing was completed in 2016.

A report on the initial phases of the project was issued in 2017. In these phases, six GHPWH prototypes were subjected to extended reliability testing. Researchers also performed an analysis of how the GHPWH is impacted by relevant codes and standards in the U.S., Canada, Mexico, and Europe.

In 2017, seven new GHPWH units were built during Phase 4: five units for residential field demonstration; one for evaluation at SoCalGas' *Engineering Analysis Center;* and one for proprietary testing by a manufacturing partner.

In 2018, the project team monitored the performance of the five gas GHPWHs installed at the test sites, which continued through June 2019. Data continued to confirm that ~50% energy savings was achieved on a site-by-site basis and improved as the ambient temperatures rise. Data was collected, aggregated, and analyzed.

Also in Phase 4, two fourth-generation GHPWH units were received from California, with one partially installed in a laboratory. Additional preparations were made to initiate standardized and non-standardized efficiency testing.

In 2020, Phase 5 involved additional laboratory testing of the GHPWH to improve onboard diagnostics and to explore innovations to ease how condensate is handled.

Phase 6 is now expanding grid-interactive capabilities and variable performance to further enhance customer's comfort and operating flexibilities. Efforts are under way to develop and demonstrate strategies to deploy the residential GHPWH as a distributed energy resource for residential grid-level shed and shift events, and develop and explore methods to improve domestic hot water capacity with supplemental gas/electric boost capabilities.

In 2021, the project team expanded its laboratory space to accommodate appliance/water-heating tests and to prepare for the installation and operation of GHPWH hardware. The infrastructure and instrumentation/emissions measurement capacity were completed and commissioned, with hot/chilled water circulation loops functional for water-heater testing.

For Phase 6, an agreement with SMTI to produce a next generation alpha prototype GHPWH was completed, and expectations were identified when SMTI would deliver the updated unit. Researchers completed the Phase 6 test plans and fabricated prototypes of the additional features being developed in Phase 6.

In 2023 the team performed additional preparations and facility improvements for laboratory testing, which included creating water heating test cells ready for future GHPWH testing under this effort.

Status

The team is completing Phase 5 testing, data analysis, and reporting to close out this phase. The team is expecting SMTI to make progress in fabricating the new GHPWH unit and providing it soon to the project team in order to perform UEF and hydrogen-ready testing in Phase 6.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD
Utilization Technology Development

Next-Generation Advanced Residential Gas Clothes Dryer

Researchers are investigating next-generation technologies so that a residential gas clothes dryer can economically provide gas consumers with faster drying times, while achieving 5%-15% higher efficiency than standard-efficiency gas dryers.

Project Description

In this project, researchers are investigating next-generation technologies – including heat recovery, indirect firing, direct venting, and advanced burners – to determine potential efficiency boosts for residential dryers. All of these techniques and technologies were shown to increase efficiencies in other areas, but scaling them to a residential dryer size, determining the additional cost to the dryer, and quantifying the efficiency increases will help dryer manufacturers determine the best path to further advance gas-fired dryers while minimizing cost increases.

UTD's guiding Technical Project Committee indicated that there is also an interest in reducing drying times if possible. This is a benefit of gas dryers for end users – the potential to increase firing rates to reduce drying times. Modulation may allow a high firing rate in the early stages and a low firing rate later to both reduce drying time and save energy.

The goal is to find a technology to achieve a 5%-15% boost over standard-efficiency gas dryers. Project deliverables include an early-stage prototype incorporating the most promising technologies, optimizing their operation in a prototype dryer, and preparing reports detailing the performance improvement provided by all of the technology options investigated.

Benefits / Market Implications

Gas-fired dryers have not had many technological advances in recent years; however, there is potential to enhance the technology. Since about 81% of U.S. households have a clothes dryer, potential efficiency improvements in the design of gas dryers represent sizable savings to residential ratepayers.

Although electric clothes dryers represent the majority of U.S. residential dryers, a 2011 study by others indicates that it is not consumer preference for electricity that is the driving force. Although 60% of survey respondents were currently using electricity for clothes drying, only 34% stated that they actually preferred electricity. In contrast, 40% of respondents stated they currently used gas for clothes drying and 53% said they would prefer to use gas. These results indicate that the cause for gas dryer's minority market share is not due to the inherent characteristics of gas as a fuel, but is driven by other factors such as cost, availability, and other regional factors.

Technical Concept & Approach

The project team will investigate high-efficiency dryer technology options, such as heat recovery, modulating burners, indirect firing, direct venting, and advanced burners. Researchers are also investigating the potential for technologies to reduce drying times.

The effect of each technology modification is being tested using standard methods to determine the performance improvement (efficiency, drying time, etc.) in comparison to the baseline unmodified model. The most promising technologies will be incorporated into an early prototype for demonstration.

Researchers will take the best performing technologies from Phase 2 and combine them into a prototype dryer in Phase 3. The prototype will be modified and optimized to get the best performance of the technologies working together. The prototype will be tested to determine the performance improvement of the technologies (efficiency, drying time, cloth temperature, etc.).

New Environmental Test Chamber during Construction

Results

Phase 1 of this project focused in part on assembling a test station in an environmental chamber to maintain temperature and humidity to ensure accurate testing. It had become apparent during previous UTD dryer research that room temperature and humidity have a very large effect on the dryer efficiency rating. Although the test standard allows for 40%-60% relative humidity (RH) during the test, a dryer will be much more efficient at 40% RH than at 60% RH. With that in mind, researchers decided that it was necessary to arrange the test in an environmental chamber.

Technicians completed the first modifications to the dryer. The unit was fully instrumented to allow for testing different design changes, including changes to primary aeration and air-to-fuel ratio, followed by potential heat-recovery options. Designs to recover heat from the flue were implemented and show promise for improved efficiency in testing. Overall, the heat recovery appears promising while providing a small cost added to the dryer.

Researchers attempted many different configurations for sealing the dryer to maintain stable combustion, and investigated simple heat-recovery options with many different alterations. In the end, it was determined that a novel heat-recovery setup, along with a newly configured and sealed dryer combustion chamber, showed the most promise, with a 4% boost to the dryer efficiency while adding very little cost to the dryer.

For the study, a total of 42 temperature sensors, five gas sample points, a gas meter, and electric power meter were fitted to the dryer.

In Phase 2, researchers investigated additional heat-recovery options, modulation techniques, indirect-fired methods, direct venting, and alternate burners.

Researchers set up a new dryer in the test stand in the environmental test chamber. The project team also set up a new washer test stand to provide clothes with the needed temperature and remaining moisture content for dryer testing.

The research team developed a slightly modified test procedure to provide repeatable results that will allow comparison to technology improvements on a common basis. After this modified procedure was adapted, baseline testing was completed. Researchers also investigated the effect of firing rate on the dry time and efficiency.

It was noticed from previous dryer research that results of dryer efficiency testing according to the U.S. Department of Energy test procedure can vary based on a few factors. The current standard requires allowing the automatic moisture sensor to automatically stop the load. An issue is that the moisture sensor can create significant variability in the test results based on when it determines the load is dry. In many instances, the load is fully dry, but the dryer keeps running before the moisture sensor eventually shuts it off. Researchers need good repeatability to compare the baseline testing of a standard dryer to each technology that is being tested to improve efficiency.

The project team was able to achieve good repeatability by creating a slightly modified test procedure that measured flue RH and determined when the clothes were dry based on the flue RH.

During Phase 2 the project team also developed a slightly modified test procedure to reduce variability of the results and provide repeatable results that will allows researchers to compare technology improvements on even ground. After this modified procedure was adapted, baseline testing was completed of the DOE test clothes as well as a real-world towel load baseline test. Researchers completed single-stage modulating testing at four firing rates, with results showing around a 2% boost consistently with lower firing rates. Technicians then insulated and sealed the dryer to test potential boost from better sealing and allow for implementing heat recovery. After several variations, the team was able to achieve a 5%-6% increase in efficiency with insulation and sealing as well as a 6% reduction in drying time.

The insulation and sealing also allowed for the implementation of a new heat-recovery design. An external air-to-air heat exchanger was purchased and installed on the dryers to determine the potential boost from heat recovery. Testing of the dryer demonstrated a 10%-14% boost to the efficiency of the dryer and a 14%-15% reduction in dry time.

Status

Phase 3 efforts are underway. A new environmental chamber is being used to provide more accurate and consistent test results. Baseline efficiency tests of a dryer were completed within the new environmental chamber. The team began to incorporate a new heat recovery system that could be incorporated into the dryer, rather than an external heat exchanger configuration that was tested in Phase 2. The team has begun testing the new heat exchanger and worked through some issues with the test setup and the new heat exchanger. Work is ongoing to incorporate combined technologies to maximize the efficiency of the final design.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Gas-Fired High-Efficiency Liquid Desiccant Air Conditioning and Humidity Control

A research team is partnering with a chemical manufacturer, two HVAC manufacturers, and others to develop and demonstrate a very-high-efficiency gas-fired liquid-desiccant-based air-conditioning and humidity-control system that uses a novel, non-corrosive, non-toxic desiccant.

Project Description

The goal of this project is to develop a gas-fired liquid-desiccant dedicated outdoor air system (LDDOAS) that addresses many of the critical issues now facing owners and operators of commercial HVAC systems.

The LDDOAS is designed to significantly reduce primary energy consumption, on-peak electrical demand, and water use for air conditioning in commercial buildings. The system can deeply dry a building's ventilation air without inefficient overcooling or reheating, which will enable advanced HVAC solutions (e.g., chilled beams, displacement ventilation, and other approaches) to essentially eliminate fan power for recirculating air within buildings.

In this project, a research team is partnering with a manufacturer to compare the current state-of-the-art LDDOAS technology to other advanced systems, including a concept involving a sub-atmospherically-regenerated LDDOAS system with internal water recovery and reuse capabilities.

The current Phase 2 involves demonstrating this novel technology in a laboratory to determine its potential value to end users. In Phase 2, the project team will design and experimentally evaluate a breadboard LDDOAS test rig rated at approximately 100 CFM capacity using a novel non-corrosive, non-toxic desiccant.

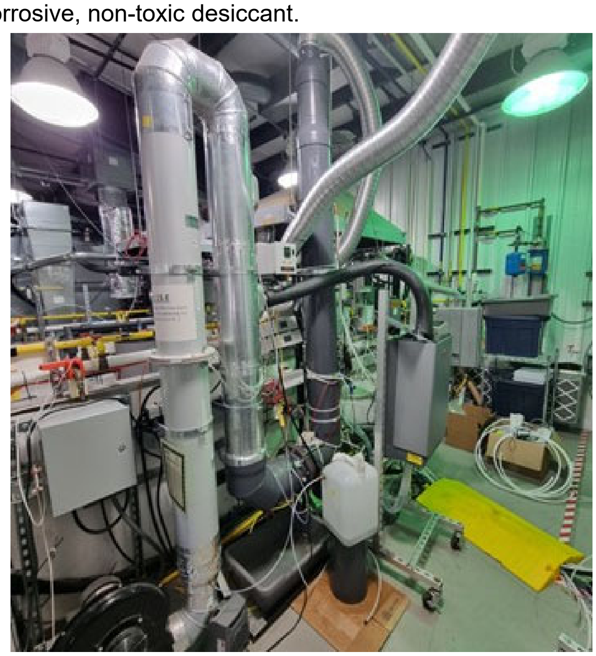
Researchers are partnering with the New York State Energy Research and Development Authority (NYSERDA), a chemical manufacturer, and two HVAC industry partners in Phase 2.

Benefits / Market Implications

New cooling designs that integrate desiccant drying and indirect evaporative cooling in compact cost-effective configurations have the potential to provide residential and commercial market end users with new high-efficiency product choices.

For a summer design day, the LDDOAS' primary energy Coefficient of Performance (COP) is 18% higher than the conventional alternative. This advantage is projected to increase to 30% when averaged over a cooling season. The effective COP for the LDDOAS is estimated to be 2.77 (where the LDDOAS is credited with energy savings for the advanced HVAC systems that it enables). The LDDOAS can also eliminate water use for air conditioning in the more humid eastern U.S.

The burden that air conditioning now imposes on electric grids can be eased as peak loads drop by approximately 75%, from about 1.01 kW/ton-hour to 0.26 kW/ton-hour of cooling.



The regenerator tower

The conditioner tower

Technical Concept & Approach

Desiccant-based dehumidification and air-conditioning systems can employ an open drying cycle wherein a humid gas (generally, air) comes into contact with a desiccant and is dried. The dried air continues to subsequent processes (e.g., sensible cooling), and the desiccant is regenerated by a thermal input. The desiccant loading and regenerating is performed in a cycle, allowing for continuous dehumidification.

The two major system types are liquid and solid desiccants. While solid desiccants have a larger established market presence, the liquid-based systems have gained interest in applications for active dehumidification, enhanced evaporative cooling, and indoor air quality. These liquid desiccant systems, also known as open absorption systems, have had limited market presence due primarily to the inefficiency of current regenerating components and difficulties in handling the caustic strong salt desiccant solutions.

The specific objective of Phase 2 is to prove the LDDOAS' system operation in the laboratory and determine its value to potential end users. In Phase 2, the project team will design and experimentally evaluate a breadboard LDDOAS test rig rated at approximately 100 CFM capacity (approximately 1/10th scale for small RTUs) using the novel non-corrosive, non-toxic desiccant initially evaluated and characterized in Phase 1.

Results

In Phase 1 of this project an experimental gas-fired liquid-desiccant air-conditioning (LDAC) system was constructed. A fluid was demonstrated to operate as a desiccant over a range of process air dew points (for space conditioning) and could be regenerated at low temperatures (<200°F). The absorption/regeneration tower operated as designed (~0.5-2 lb/hr moisture movement at 50 cfm).

During regeneration, with heated liquid and cool regeneration air, 50% of the enthalpy rise in the air was latent. This result was within the expected order of magnitude.

In Phase 2, the project team initiated upgrades to a one-tower test rig. The single-tower apparatus was fully instrumented to measure temperatures, pressures, and flow across the tower to allow completion of the initial test plan. Single-tower experiments were initiated. The preconditioning system for simulating outdoor air temperature and humidity levels was completed and tested.

Liquid desiccant distribution tests in the single tower were completed. Researchers characterized the desiccant distribution in the tower by varying nozzle configurations for distributing the liquid at the top of the tower to identify the optimal nozzle to use and determine whether tower-wall effects were present.

In 2021, rigorous testing of dew-point sensors concluded that the energy imbalance was not due to instrument accuracy. Further testing determined that insufficient mixing was causing the energy imbalance. To ensure proper mixing of the air as it exits the tower, a reducer was constructed for the top of the tower to increase velocity and turbulence of the flow.

In 2022, data analysis was completed for regeneration and batch-conditioning tests. A new digital refractometer was purchased for measuring the refractive index of the desiccant solution. The refractometer was used in conjunction with a Karl Fischer titration, and a new correlation was generated that more accurately characterized the strength of the raw desiccant and diluted solution. Various metrics were calculated and plotted to characterize the performance of the liquid desiccant during simulated regeneration and batch-condition tests. These metrics include effectiveness, water uptake, and the difference in vapor pressure between the liquid desiccant and duct air.

The simulated regeneration tests were performed at two different desiccant dilution rates, which was controlled by setting the peristaltic pump at 30% or 50% of operating speed when injecting water into the desiccant. At greater pump-operating speeds, more water would be injected into the liquid desiccant stream before it entered the tower, making for a weaker desiccant solution. This was done to study the change in regeneration performance by the liquid desiccant at varying solution concentrations. The experimental setup was also upgraded to use gear pumps rather than diaphragm pumps to circulate the liquid desiccant, which provided better control of the flow rate.

Construction of a second packed-bed column tower allowed for simultaneous regeneration and conditioning. All major instrumentation was installed for conditioning and characterizing the air stream, including a resistance heater temperature controller, a steam humidifier, a pitot traverse array, pressure transducers, thermocouples, and humidity sensors.

The lab data analyses are complete and are integrated into the inputs for the simulations. The simulations have been run for the following cities and climate zones: NYC - Manhattan/Climate Zone 4, Long Island - New Hyde Park/Climate Zone 4, Upper Hudson Valley - Albany/Climate Zone 5, Western New York - Buffalo/ Climate Zone 5, Upstate New York - Utica/ Climate Zone 6, Tampa/Climate Zone 2A, Atlanta/ Climate Zone 3A, El Paso/Climate Zone 3B, Albuquerque/ Climate Zone 4B, Seattle/ Climate Zone 4C, Denver/Climate Zone 5B, Great Falls/ Climate Zone 6B.

Status

The team is working to complete the final reports to NYSERDA and to the utilities that participate in UTD.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

EnergyPlus™ Models for Advanced Gas Space-Heating Systems and Combination Systems

In this project, researchers developed models of advanced gas space-heating and water-heating combination systems in the EnergyPlus building energy simulation engine, with an overarching objective to inform and expand energy-efficient choices for building operators, designers, and other stakeholders.

Project Description

EnergyPlus™ is a whole-building energy-simulation program developed with support from the U.S. Department of Energy (DOE) that engineers, facility managers, researchers, and others use to model energy consumption for heating, cooling, ventilation, lighting, and plug-and-process loads as well as water use in buildings. However, the limited capability of EnergyPlus to simulate advanced gas-heating systems makes it difficult to accurately compare these options with other HVAC alternatives.

Data indicate that current models in EnergyPlus are inadequate for estimating the dynamic efficiency of condensing furnaces, gas absorption heat pumps (GAHP), and combination systems using tankless water heaters. Having no module in EnergyPlus to estimate the performance (or, even worse, to do it incorrectly) significantly limits choices for users to consider advanced, energy efficient systems during initial screenings of HVAC options. This project helps to address these limitations in EnergyPlus and helps to provide decision makers with accurate and reliable simulation tools for advanced residential heating systems, to enable equitable comparison with competing technologies and to advance the integration of gas and renewable energy.

In Phase 1 of this project, researchers leveraged technology-performance data for furnaces and gas absorption heat pumps collected as part of other projects to develop custom modules in EnergyPlus, and then used them to estimate energy savings potentials in several climates and use cases.

In Phase 2, the project team focused on GAHP model refinement, a more expansive market analysis and further functional refinements for combined space- and water-heating systems based on tankless water heaters.

Daikin VRV System (L) and EC Power 25 kW mCHP (R)

Phase 3 built on the successes of Phases 1 and 2 by making those results publicly available through updates to EnergyPlus that are supported by peer-reviewed publications. Phase 3 has also analyzed best practices for controlling gas dedicated outdoor air systems when combined with electric variable refrigerant flow (VRF) systems.

Phase 4 focused on including additional next-generation gas equipment models of emerging gas heat pumps (beyond initial absorption-type, and hybrid gas-electric and integrated systems into EnergyPlus that are designed for colder climates. It also focused on deploying the results from modeling advanced equipment in Phases 2 and 3 into the capabilities of the residential building rating software used to determine HERS rating index.

Phase 5 was recently launched and it will focus on: developing models and case studies for Thermal Energy Storage (TES) coupled with mCHP for multi-family and commercial buildings in heating dominated climates; and advancing Gas-fired Dedicated Outdoor Air System (DOAS) and an electric Variable Refrigerant Volume (VRF) hybrid heating system sizing, controls, and case studies.

UTD is partnering in this effort with the Propane Education and Research Council (PERC), which is providing co-funding to this UTD project.

Benefits / Market Implications

Through this project, researchers developed EnergyPlus performance data and/or built-in models for advanced furnaces, gas heat pumps, and tankless water-heater combination systems to allow general users to adjust the parameters (e.g., system size, performance curves, or design features). The outcomes of these efforts were published in peer-reviewed publications, public technical reports, and presented at several industry conferences hosted by Purdue University and ASHRAE, with additional dissemination still pending.

The tools developed as part of this project will enable decision makers to objectively evaluate the technical and economic potential of novel gas heating systems across North America.

Technical Concept & Approach

Specific tasks for Phase 5 include developing and/or refining TES models in EnergyPlus to better represent integration with HVAC and mCHP, and evaluating the use of a gas VAV DOAS with high efficiency ERV as a supplemental/backup heat for an electric VRF system.

"Many states require energy modeling before allowing new equipment into energy codes or for incentive programs. But most engineers won't touch a new technology without knowing energy performance.

With existing software, gas heat pumps aren't a built-in option. That makes this project critical for market acceptance and transformation."

- Kevin Duell
Lead Engineering Consultant
NW Natural

Results

To achieve the project objectives, current limitations of the furnace, tankless water heater, and heat pump models were reviewed and new approaches for modeling were developed, taking advantage of part-load performance data collected on five condensing furnaces from a single manufacturer and prototype GAHP units.

In Phase 1, researchers leveraged extensive data collected in a Virtual Test Home to validate the EnergyPlus models. Using simulations of modern homes in mild and cold climates, the approach helped demonstrate how a modulating furnace could consistently save 10% on the natural gas consumption annually compared to single- and multi-stage furnaces, and an additional 2% if it is right-sized for the home.

Also, as part of Phase 1, GAHP combination system was modeled using a custom EnergyPlus script and available performance data. An analysis was then performed to compare a GAHP combination system to an electric heat pump with three different water-heater alternatives (gas, electric, and electric heat-pump water heater) with a condensing furnace and a premium water heater as the baseline. It was demonstrated that the GAHP combination systems were competitive with electric heat pump and heat-pump water-heater alternatives in mild marine climates, with respect to source energy savings and operating cost savings ($100-$200 per year). The GAHP combination system was the only option offering energy and operating cost savings in the colder climates.

Major accomplishments of Phase 2 included: 1) development of a whole new mathematical framework for simulating tankless-based combination units; 2) refinement of the GAHP combination model; and 3) public dissemination of the results through conference presentations and journal articles presented in 2020-2021. The major conclusion was that the GAHP is the best and most cost-effective option right now (and for the foreseeable future) for reducing CO_2-equivalent emissions in the majority of most cool- and cold-climate locations around North America.

In Phase 3, the project team developed reduced order models that can be readily integrated with simple energy-savings calculators; used models developed in Phase 2 to improve testing protocols for gas heat pumps; calibrated models for all-electric and mixed-fuel ZNE Home; and partnered with an approved EnergyPlus developer to deploy a built-in model for GAHPs and other air-to-water fuel-fired heat pumps. The generalized gas heat pump model is now deployed and publicly available .

During Phase 4, EnergyPlus 23.1 was released and now includes the Gas Absorption Heat Pump model as part of the software. The team completed a preliminary review of all power-generation sub-models in EnergyPlus. The team validated models for cold climates heat pumps, PV generators, and battery electric storage systems and completed the case studies using the validated power gen and HVAC models. A bug was discovered in the battery model of the EnergyPlus, which was validated through troubleshooting with the development team. Phase 4 simulations will be simplified by excluding the battery simulations and this may be picked up in a future phase.

In Phase 5, the team will help address the need to develop new EnergyPlus models to replicate new Thermal Energy Storage (TES) modules. The team reviewed the scripting methodologies and is currently developing a new TES module for potential inclusion in EnergyPlus. The team also built a model for VRF and DOAS systems in EnergyPlus and calibrated that model with existing field data. The team is currently working on performing case studies to evaluate the cost and energy savings of using the eVRF and DOAS systems against hybrid heating systems.

Status

The Final Report for Phase 4 was provided in April 2024. A summary of key findings from Phase 4 is expected to publicly presented at the 2025 ASHRAE Winter Conference.

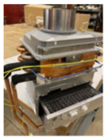
The team is working on Phase 5 and is building and validating a new TES model in EnergyPlus. They also plan to run parametric studies to evaluate the DOAS and eVRF variations across other climate zones.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Thermoelectric Generator for Self-Powered Water Heater



Researchers are developing a prototype self-powered, gas-fired tankless water heater to save ratepayers money and energy while enhancing resiliency. Hardware testing is being performed to develop the critical components and integrate the design to power a condensing tankless water heater.

Project Description

Many consumers are embracing tankless gas-fired water heaters for their high efficiency, compact size and limitless hot water supply with sales growing for these units. Tankless water heaters typically have firing rates in the 120-200 MBH range and in many applications will be the largest single gas appliance in a residence. According to the Residential Building Stock Assessment report by NEEA (2022), the tankless water heater market grew from 3% in 2011 to 9% in 2022. Currently, all gas tankless water heaters require a connection to an electrical supply to maintain operation. Unlike gas storage water heaters, tankless heaters do not hold reserve hot water that can be used during a power outage. However, advances in thermoelectric generators (TEG), low-power components, energy harvesting, and energy storage may make it possible to develop an self-powered gas-fired tankless water heater for the residential market.

In previous efforts, researchers evaluated the potential for thermoelectric concepts for water-heater integration. All of the concepts used a water-cooled TEG device for gas-to-liquid thermoelectric power generation. While difficult to implement in a gas storage water-heater design, the water-cooled TEG concept may be ideal to implement in a tankless water heater where electronics, heat exchangers, and water flow are in close proximity to each other. Components such as the spark ignitor, a gas valve, a flue damper, and energy harvest and storage circuitry may have additional application in the development of a self-powered tankless water heater.

The initial objective for this project was to validate that a Thermoelectric Generator Heat Exchanger (TEG-HX) device can generate enough electric energy to power a tankless natural gas water heater.

In Phase 3, hardware testing was conducted to optimize the TEG-HX design to prove the concept of a self-powered natural-gas-driven tankless water heater with ultra-low emissions (<5 ppm NO_x) and with excess power capability. Three gas-to-water TEG-HX designs were analyzed and tested.

Phase 4 builds upon the hardware testing performed in prior phases to develop the critical components and integrate the design to create a complete alpha working prototype of a self-powered condensing tankless water heater.

Benefits / Market Implications

A self-powered tankless water heater would preserve a key benefit that traditional gas storage water heaters offer – hot water availability during a power outage.

A TEG-HX-based condensing system would provide an enabling platform for higher efficiency self-powered gas appliances and serve end users with greenhouse-gas emissions reductions while still delivering hot water needed in disasters.

A TEG-HX system can also improve the efficiency of traditional storage water heaters by eliminating the energy consumed by the standing pilot light. At 400 Btu/hr, the water heater pilot light in a non-powered gas storage water heater consumes about 35 therms per year, or 16% of the total energy consumption of a typical gas water heater.

This design offers an identified energy savings potential of

LG 25MBH heat pump with evaporator outside (left), tankless water heater with condenser heat exchanger (middle), condenser plate heat exchanger (right)

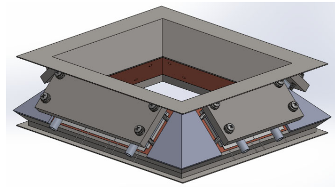
"Our organization supports the development of self-powered natural gas appliances. The technology is something needed in the market today."

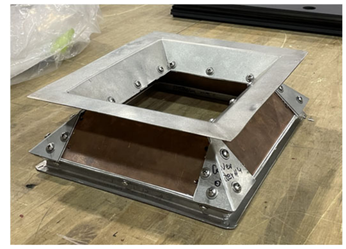
- Chris Latch
Gas & Water Manager
City of Corinth Gas & Water Department

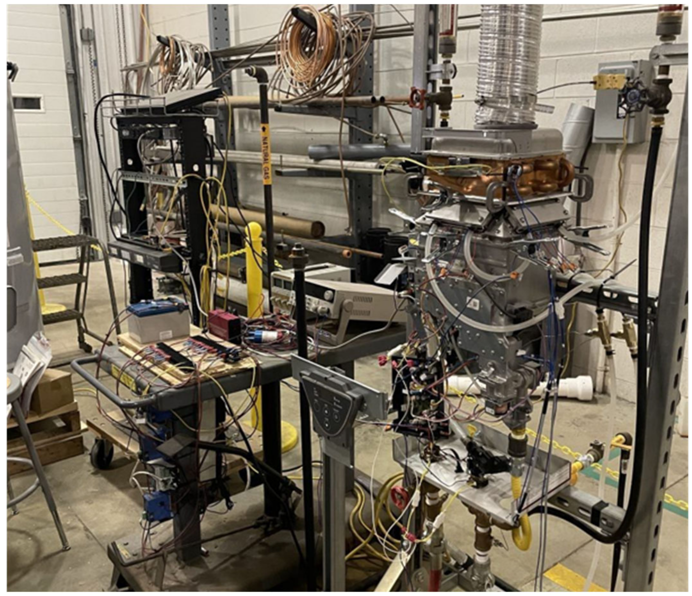
20.9% over typical new natural-gas-driven water heaters and 73.2% over typical new electric water heaters when compared on a source-energy basis – which translates into a total of 0.4 quads savings in primary energy and a reduction of 20 Mt of CO_2 emissions per year in 2030.

Technical Concept & Approach

The project began with a Phase 1 effort that characterized through technical evaluation both the power requirements and operational constraints of a tankless water heater. Capabilities were demonstrated through numerical and analytical models. Phase 2 validated this capability through technical analysis and benchtop testing. Phases 3 and 4 built upon the knowledge and technology developed in prior phases to develop the critical components and prove the concept that a TEG-HX could power a condensing tankless water heater.







TEG integration and testing with the tankless water heater

Results

The project team analyzed and tested various TEG heat-exchanger designs and selected the most promising and most efficient design. Researchers were able to achieve more than 25 watts from a single TEG using the new radiant burner. This showed that more than 10 TEGs can be easily installed in the water heater and provide an excess power of 200 watts – more than is needed to power the water heater.

Researchers designed and tested a TEG-HX with a new radiant burner. Based on the results of experiments and analytical predictions, it was proven that it is possible to achieve an ultra-high efficiency of the tankless water heater.

In 2020, the TEG-HX was optimized to improve performance and reduce the cost to harvest power for self-powered tankless water heater operation and produce excess power. A techno-economic analysis was completed.

In 2021, an advanced radiant burner and primary heat exchanger combination was selected for testing. Researchers modified a heat pump to support laboratory testing of the prototype tankless water heater, and initiated laboratory testing.

In 2022, the tankless water-heater unit with the combustion chamber was disassembled and different sections were reviewed to better understand integration approaches. The section around the combustion zone has space, and additional physical space was identified for integrating the TEGs. A solid model was generated for the integration of the TEG assembly. Three different schemes were developed for optimized integration of the TEG and one was chosen based on the feasibility of the approach.

In 2023, a tankless water heater unit with the combustion chamber was disassembled. Different sections of the water heater were reviewed to better understand integration approaches. A design assembly and a solid model of the TEG with the water heater was developed.

Manufacturing costs were estimated for the new water heater components including the TEG-HX, advanced burner, electric heat pump, primary and secondary heat exchangers, and energy storage. The total added value of the novel tankless water heater compared to an existing tankless water heater is estimated at $320-$680.

Status

Final testing is underway, and then the Final Report will be prepared. The total added value of the novel tankless water heater compared to an existing tankless water heater is estimated at $320-$680. Discussions with potential commercialization partners are in progress.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Combination Heating/ Cooling Vuilleumier-Cycle Heat Pump

This project supports the development of an innovative gas-fired Vuilleumier-type heat pump to substantially increase efficiency over current gas heat pumps that operate using vapor-absorption and vapor-compression (engine-driven) cycles.

Project Description

This project supports the development of a gas-fired heat pump based on the Vuilleumier cycle – a closed-loop system similar in nature to the Stirling cycle – that uses a working fluid (helium) driven across several heat exchangers that interact with the environment.

The working fluid flow is driven through two linked displacers located in opposing cylindrical ends known as the “hot end” (where heat input to the cycle occurs) and the “cold end” (where heat removal from the environment occurs). Competitive with an absorption-cycle heat pump, the gas-fired Vuilleumier-cycle heat pump (GVHP) shows potential for a greater coefficient of performance (COP).

When commercialized, the GVHP would represent a step-change in efficiency over the current gas heat pumps that operate with vapor-absorption and vapor-compression (engine-driven) cycles, with a possible cooling COP of greater than 1.0 and a heating COP of greater than 2.0.

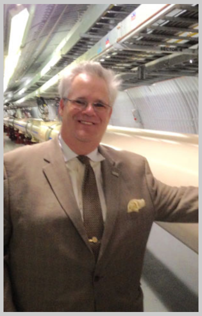
Benefits / Market Implications

The technology developer estimates that lifetime fuel savings of a GVHP over a condensing furnace can be as high as $9,760, with the potential for cooling-season cost savings as well. Using a benign working fluid (helium) with cost-effective design to accommodate higher working pressures (~1,450 psia), the GVHP may offer a premium gas heat-pump product with compelling emission and cost savings for gas ratepayers.

Technical Concept & Approach

Phase 1 efforts focused on helping design, evaluate, and improve the overall performance of the GVHP hot end. The unique operating regime of the system required new burner material, air-fuel mixing, and heat-recovery methods to be assessed, with the project team’s recommendations ultimately being integrated into subsequent system prototypes.

Laboratory testing.



"This technology represents a new class of ultra-low carbon heating and cooling appliances. ThermoLift has created a new category of heating and cooling appliances. A single unit (heating, cooling, and hot water across a wide temperature range) that supports the goals of deep de-carbonization through the highly-efficient direct use of energy. This new category of gas heat pump paves the way to use 100% renewable energy sources, including renewable natural gas derived from waste and green hydrogen derived from renewable power."

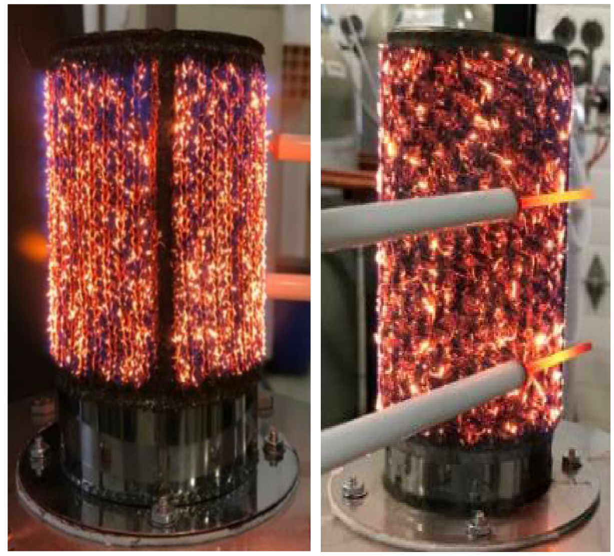
- Christopher A. Cavanagh
Engineering Manager - Low Carbon Energy National Grid

In the current Phase 2, researchers provided support on optimizing the design of the hot-end assembly and field certification of the initial prototypes. In addition, an entire pre-production prototype will be laboratory tested using standard rating procedures. This information will be used to assess the energy efficiency and technical potential of the system.

Results

In Phase 1, the project team:

- Identified air-fuel preheat limits for a recuperator that would help the GVHP reach its performance targets
- Defined design guidelines for air-fuel mixing strategies for the GVHP
- Engaged with five burner manufacturers to find a compatible burner for the operating regime



Initial air-preheating test setup with example burners.

- Validated hot-end heat-exchanger design
- Demonstrated overall hot-end efficiency consistent with initial design estimates, and
- Identified subsystems that needed redesign to reach target performance levels.

Current Phase 2 efforts include:

- Provided technical support to redesign and further optimize the combustion system and novel combustion controls
- Performed a codes-and-standards review to help with field certification of initial prototypes, and
- Testing of the full system prototype is to be completed. In preparation for whole-system testing, a comprehensive test plan for the system was prepared and the test apparatus was constructed.

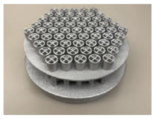
Status

The research team is currently awaiting a prototype to be provided by the technology developer to complete testing. Testing has been delayed until at least the fourth quarter of 2024.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Advanced Nozzle Burner for Commercial Water Heaters



Researchers are developing and demonstrating an economical, compact and advanced 3D-printed nozzle burner for commercial water heaters to increase efficiency, deliver ultra-low emissions, and provide good turndown with superior stability in order to benefit the environment and light commercial end users.

Project Description

Current commercial water-heater burner designs are limited in their ability to achieve all the technology targets of ultra-low emissions, high efficiency, good turndown, and attractive first costs. They also often cannot typically be readily retrofitted into existing equipment, and the fundamental designs are often capacity-specific and not scalable to multiple product platforms.

In Phase 1 of this project, researchers successfully developed and tested a 3D-printed burner by integrating advanced nozzle prototypes with the blower, controls, and fuel inlet of a commercial water heater. In the current Phase 2 of this project, researchers are testing a beta prototype version of this robust, smooth- and safe-operating advanced retention nozzle in a commercial water heater (~200,000 Btu/hr capacity), offering improved efficiency, turndown, emissions, stability, and compactness.

Goals for Phase 2 include improving efficiency by 2%-4% for the same emissions, demonstrating NO_x emission of <5 ppm and CO emissions of <20 ppm corrected to 3% O_2, and achieving turndown of 10:1.

Benefits / Market Implications

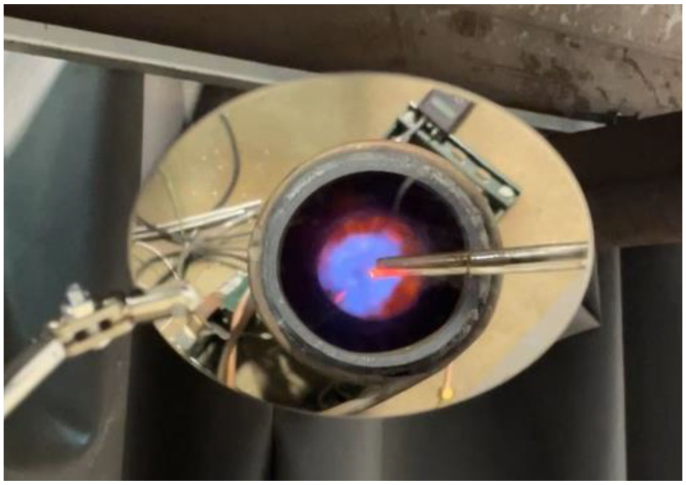
Forty-four percent of the 225,000 commercial water heater units sold annually in the U.S. are gas driven, with associated positive impacts on source-energy efficiency. Similarly, data shows that 42% of commercial buildings heat water with natural gas. Low-cost, low-emission, compact commercial gas-driven burners could further reduce source-energy use.

The technology to be advanced in this project can substantially reduce energy consumption in commercial buildings. Of the 40 quads used by U.S. buildings, 9% are used by the water heaters. An average 3% improvement in efficiency will lead to at least 0.12 quads of annual energy savings.

Other benefits of the advanced, patented nozzle burner technology are expected to be:

- Scalable to multiple designs and capacities
- Significant reduction in NO_x emissions >75%, with turndown of 10:1 with CO emissions of <20 ppm
- Simple and robust, with potential lower first costs
- Installer- and manufacturer-focused

Complete test setup of β-prototype design



Ignition testing for 150K Btu/h

- Reduced weight and size of the water heater; hence, lower cost and easier installation in tight locations
- Improved manufacturing ease and significantly reduced time to market
- Reduced noise (hence, more comfort), and
- Capable of integrating smart controls for smart-building applications.

Technical Concept & Approach

In Phase 2, the project team will design and fabricate prototypes of a nozzle burner. This design will consider the key features to be adapted for the prototype (e.g., flame stability within the water heater and smooth ignition). Two to three design iterations will be fabricated by Oak Ridge National Laboratory.

After designing the prototypes, researchers will install the burner in a commercial water heater. The dimensions will be matched to have a drop-in design to replace the current burner. The design of the igniter may have to be modified.

The team will perform multiple ignition tests to ensure that the burner ignites reliably and smoothly at variable firing rates. This will determine the reliability and repeatability of the ignition process, even though the water heater usually operates at a constant firing rate. This will provide greater confidence in the ignition process.

After successful ignition testing, performance testing will be conducted. This will help determine the operability and turndown characteristics of the advanced nozzle burner. The testing will be performed for different firing rates and different air-fuel ratios to evaluate the emissions and efficiency characteristics. The firing rate will be varied to ensure operability and oxygen concentrations will be varied for evaluating emissions and efficiency performance.

Results

Researchers designed, developed, and tested a 3D-printed advanced nozzle burner on a benchtop setup with the controls and blowers of a commercial water heater. Multiple design iterations were manufactured to improve operating characteristics and combustion performance and adapt the burner into the water heater for long-term steady and robust operation. Benchscale testing showed the burner can be adapted to a commercial water heater and is able to provide ultra-low emissions of <5 ppm NO_x and <20 ppm CO at 3% O_2 and turndown of at least 8:1.

The novel burner was further developed to provide a design that could easily retrofit existing in-field equipment as well as be used in new water-heater installations. Design changes were made to the nozzle diameter and the number of nozzles were customized and designed to match the water heater chamber. Multiple design iterations of the advanced nozzle burner were 3D printed. A Phase 1 Final Report was issued in November 2020.

In 2021, the project team reviewed different integration methods for the burner within the water heater. The blower and the burner were installed and different firing rates were evaluated. The impact of the burner on upstream components such as a premixed air/fuel blower and the combustion dynamics, mixing, and emissions were evaluated.

In 2022, burner designs were further reviewed for adaptation and flame stability within the water-heater prototype. Researchers reviewed various methods for adapting the burner within the water heater. Testing showed that ignition was intermittent and the flame was not stable and, hence, further changes were made to the ignition scheme to ensure that the burner can be retrofit without any other modifications. The emissions testing showed that <9 ppm emissions can be achieved.

In 2023 the β-prototype burner was 3D-printed and the team prepared the test setup for ignition and emissions testing of the nozzle.

The team is in the process of ignition and emissions testing.

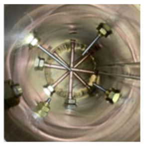
Status

Phase 2 efforts are continuing. The project team is evaluating performance of the B-prototype nozzle for ignition and emissions.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Mitigating Methane Emissions from Residential and Light Commercial End-Use Equipment



Research is being conducted to quantify the emissions and determine the conditions under which residential and light commercial end-use appliances release unburned hydrocarbons into the atmosphere, in order to identify best practices or design features to reduce methane emissions.

Project Description

Residential and commercial appliances are coming under increased scrutiny due to field-measured emissions of unburned hydrocarbons. However, field-derived emissions measurements are difficult to perform accurately and often lack the data resolution or flexibility to gain a full picture of emission events. This project generates laboratory measurements of methane emissions from appliances with the goal of generating greenhouse gas (GHG) emission factors, understanding the conditions leading to emissions, and identifying best practices or design features to reduce methane emissions. UTD's scientific research can help inform public dialogue on this topic.

In the first phase of this project, the team focused on assessing emissions from tankless water heaters (TWHs), which modulate directly in response to end-user loads. The high-input compact burners in TWHs frequently cycle on and off, which may increase their methane emissions.

Phase 2 and Phase 3 efforts expanded this project to examine residential furnaces, storage tank water heaters, and ranges, which have also been included in various field studies focused on residential methane emission measurements. Phase 4 builds on the work of Phases 1-3 in quantifying and identifying methane emissions in Res/Com equipment, and adds analysis of the effect of hydrogen blending.

Benefits / Market Implications

The results from this study will support the continued improvement of residential natural gas appliances and the understanding of post-meter methane emissions. This includes standard residential gas appliances such as tankless/storage gas water heaters, furnaces, and residential ranges.

The ability to clarify and mitigate the impact of gas appliances on GHG emissions will support the continued improvement of this technology and help address end user concerns. Efforts to reconcile bottom-up estimates of methane emissions with atmospheric measurements will benefit from reliable data that is otherwise sparsely available.

Technical Concept & Approach

Phase 1 focused on measuring unburned methane release from TWHs, and the results are summarized below.

A laboratory test setup from Phase 1 was adopted for Phase 2 to quantify methane emissions in furnace exhaust. In addition to steady-state testing, a control program was developed to operate the furnaces at a variety of part-load conditions to observe the impact of varying operation on emission profiles.

Researchers will use the laboratory measurements taken in Phases 1-3, supplemented with emission factors from literature where needed, to create a tool to estimate total residential appliance emissions based on selection of appliances in the home and adjustable operating patterns for space heating, water heating, and cooking over a range of climate zones.

In Phase 4, the team will conduct a literature review, install and test Res/Com appliances, and test industrial/large commercial burners.

Furnace test bay with final modulating furnace installed for testing.

Electrochemical sensor - ECOM J2KN analyzer with a hydrogen sensor

Results

In Phase 1, the project team engaged with a major university to develop a test plan as a complement to field sampling of TWHs. Input was also solicited from TWH manufacturers regarding system operation, compact burner modulation/ignition methodologies, and system controls with respect to the emission of unburned fuel.

Researchers developed methods to accurately measure the dynamic emission rate of methane from a modulating TWH and used various dynamic tests to simulate end-user behavior. Three TWHs were tested – representing a range of combustion system designs and the most popular models and manufacturers. The units were tested using steady-state, “step ramp-up”, and simulated-use patterns to establish typical methane emissions across products and combustion system designs. Through data analysis, researchers identified tankless designs, features, and operating conditions that can produce methane emissions. A list of recommendations for detection and mitigation of such conditions was developed.

Phase 1 findings showed that the tested TWHs produced measurable methane emissions through “puffing” at ignition/extinction, during modulation (depending on the burner design), during steady-state operation (depending on the burner design and firing rate), and during off periods. Both steady-state emissions and ignition/extinction emissions generally showed similar order of magnitude results as in prior field studies. Phase 1 findings were presented at the ACEEE Hot Water Forum conference on July 22, 2020, and in other venues to university researchers and other organizations.

In Phase 2, researchers performed a number of shakedown tests to address issues with the methane analyzers, instrumentation, control programs, and data acquisition. Furnaces were tested in 2021-2022. Total hydrocarbon emissions data were collected for both steady-state and part-load tests to generate a full picture of the emission profile for typical furnace operation. The final report and public dissemination are currently in preparation.

In 2023, furnace steady state testing and part load cycling test was conducted with seven part-loads ranging from 40-100% with one-hour cool down period in between each cycle. Methane spikes can be seen at ignition and extinction of the burner and is sub-atmospheric during combustion, indicating complete combustion of the gas during steady state operation.

In Phase 3, after completing the test plan and job safety analysis, the team installed a A.O. Smith water heater with a capacity of 50 gallons, operated at 40 MBH. The water heater was equipped with a gas meter, flow meter, and thermocouples to measure the gas consumption, hot water delivered flow rate, city water temperature, hot water discharge temperature, and tank temperature at different heights. The energy efficiency and emissions of the water heater were measured using the high-usage draw pattern recommended by the US Department of Energy. The experimental measurements were verified by performing the first hour rating (FHR). The energy efficiency was measured using the 24-hour Energy Utilization Factor (UEF). During the UEF test, the methane concentration in the flue gases was measured using a gas analyzer.

In Phase 4, the team conducted a literature review of existing methods for measuring small concentrations of H2. Based on methods developed and used in the automotive industry, several hydrogen analyzers that could be used to measure slip through the combustion system were identified. These options included: mass spectrometer-based analyzers, which are very robust and accurate but very expensive, and electrochemical sensors, which are accurate but require more frequent calibration. The team ultimately settled on an electrochemical sensor due to its ability to incorporate O2, CO2, and CH4 sensors and its lower cost.

The team has completed the shakedown and initial calibration of the H2+CH4 analyzer and has begun using the system in residential and industrial combustion systems experiments. Testing has been completed with one industrial burner and one water heater, and testing is ongoing with a residential furnace.

Status

For Phase 2 the team continues work on data analysis of all furnace testing and will then complete the final report.

For Phase 3 the team is continuing the literature review for cooking appliance emissions measurements and completing shakedown testing of low-efficiency storage tank water heater to validate emissions sampling protocol using a new gas analyzer. A conference paper draft has been submitted to ASHRAE Winter 2025 conference.

For Phase 4 the team is working to complete analyzing data for industrial burners and the water heater, and finish methane-hydrogen testing with a residential gas furnace.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Economical High-Efficiency Residential Gas Absorption Heat Pump with Integrated Cooling

This project focuses on adding cost-effective cooling to a new low-cost gas absorption heat pump product that currently provides only heating and domestic hot water. An economical, integrated single unit offering both air conditioning and high-efficiency heating can help more end users benefit from this exciting new product.

Project Description

A gas absorption heat pump (GAHP) can provide low-cost whole-house heating with significant improvements in efficiency over condensing furnaces and boilers. In addition to cost-competitive Therm savings of up to 45% over conventional residential gas heating equipment, the GAHP delivers stable, comfortable temperatures without the need for auxiliary heating or backup and is projected to be ultra-low-NOx compliant with all combustion occurring outdoors. This project builds on other UTD efforts to bring to market a new heating-only, low-cost GAHP for the residential market, in coordination with Stone Mountain Technologies, Inc. (SMTI).

One issue that might limit adoption of SMTI's first Anesi GAHP product is that it cannot currently also provide cooling. The heating-only GAHP's economics (sized at nominal 80 MBH output) are generally suitable in cold climates and for large, single-family homes. However, the economics worsen in mixed or cooling-dominated climates, especially in the U.S. Southeast. As a result, cost-effective cooling is necessary for this product to succeed and serve many ratepayers broadly.

While GAHPs offer high efficiency and low emissions, existing commercially-available GAHPs tend to be costly and have seen limited adoption in North America. The approach in this project will advance a new hybrid arrangement, wherein the GAHP would have an electrically-driven compression cycle, and may share internal heat exchangers with the absorption heat-pump sealed system. In this project, a research team seeks to demonstrate an economical GAHP with integrated cooling that could offer a simple payback of less than three years for a hybrid system.

This UTD project leverages co-funding from the Natural Gas Innovation Fund (NGIF) and from the Propane Education and Research Council (PERC), and advances technology development from the development/design stage to a laboratory version of a packaged alpha prototype.

Current Phase 3 efforts are building on previous phases to support and optimize component development, bench-scale evaluation, and preliminary techno-economic analysis.

Benefits / Market Implications

The hybrid GAHP with cooling is intended to broaden the GAHP's energy and emissions savings potential, expanding the benefits of this technology for end users by providing applicability for mixed and cooling-dominated climates.

Of all U.S. single-family homes, 73% have central air condi-

Prototype GAHP hybrid (left) and paired prototype air-handling unit (right).

tioning (A/C). Early feedback from contractors and homeowners on the heating-only GAHP is that very few homeowners will permit having two large pieces of HVAC equipment outdoors. The advantage offered by operating with a chilled-water loop for A/C, using the single indoor coil, is that this is not a direct expansion system. This significantly reduces the refrigerant charge volume as it is only contained within the hybrid GAHP unit. In addition, many HVAC manufacturers are looking for refrigerants at higher pressures or with moderate flammability, which is challenging for conventional split A/C systems.

Technical Concept & Approach

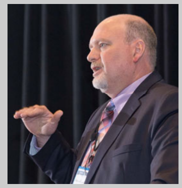
Phases 1 and 2 of this effort initially examined the potential to integrate a cooling cycle that used ammonia as a refrigerant into an alpha hybrid GAHP, perform a techno-economic assessment to establish an estimate of hybrid GAHP technical potential, and address some product operational and reliability issues. In the current Phase 3 efforts, the project team will focus on a) successful integrating a low-GWP EAC module into an "alpha" prototype with heat recovery capability for combined space cooling and water heating (sized at nominal 40 MBH output) and b) experimental evaluating this prototype in steady state and simulated conditions, including a limited assessment of the viability of a "four-pipe" design for simultaneous space cooling and heat recovery for water heating. Low-GWP refrigerants likely to be evaluated include R-32 and R-452B. The production units of the 40 MBH GAHP with integrated cooling are anticipated to be offered with options for being fueled with propane or natural gas

Results

In 2020, the scope of the hybrid GAHP device was defined for the purposes of modeling. A modeling plan (assumptions, boundary conditions, etc.) was developed and simulation was executed. Researchers agreed on the operational parameters of the GAHP hybrid as it pertains to the initial building energy modeling task, using the heating GAHP modeling assumptions developed under prior efforts and absorbing modeled performance curves.

The project team ran models of single-family homes for several representative metropolitan areas, covering multiple climate zones and housing types (size, construction, occupancy) and performing annual energy assessments of hybrid GAHPs. Investigators are considering multiple baseline scenarios (all-electric, high/low efficiency, etc.). This modeling exercise will be extended to key U.S. regions, including Chicago, Salt Lake City, Fargo, St Louis, Minneapolis, Portland, Rochester, San Francisco, Albuquerque, Atlanta, Los Angeles, and Tampa.

In 2021, the project team made upgrades and additions to the laboratory thermal heat pump test station, developed a test plan, and modified the test stand for the heating-only GAHP.



- Michael Garrabrant
Founder and CEO
Stone Mountain Technologies, Inc.

"UTD provides an invaluable contribution towards the advancement of innovative, very high -efficiency products within the gas and energy industry.
Without UTD's support on numerous projects over the prior 10 years, SMTI would not have been able to prove out and de-risk our family of affordable thermally-driven heat pumps, a critical first step before investors will step in to support commercialization activities.
Our Hybrid GAHP/ AC heat pump model will help move gas heat pumps from a solid niche to the mainstream HVAC/water heating market."

In 2022, after resolving several installation and unit issues, steady-state cooling tests and heating and dynamic tests were completed. Results of Phase 1 and 2 efforts were reported to UTD members in a November 2022. Results were publicly reported in a technical paper presented at the 14th IEA Heat Pump Conference held in May 2023 in Chicago, IL.

Key highlights from this test program included defining this alpha prototype's seasonal heating and cooling performance with an AFUE of 121.6% and an estimated SEER of 8. The seasonal cooling performance is lower than the target and is influenced by the compressor selection; this estimated SEER rating would not be acceptable by conventional standards (min. SEER = 13, soon to be increased). For heating operation, the performance degradation is mainly due to the cyclic operation of the hybrid system and the standby electric load. For this first-of-a-kind prototype, the project team has published these key results and findings in addition to modifications/improvements to meet targets. Concerning GAHP emissions, the CO emissions ranged from 11.5 to 101 ppm air-free, and NO_x emissions were Ultra-Low (7 to 8 ng/J), both of which are already below performance targets.

Status

The team continues to coordinate with SMTI to support the technical development of hybrid 40k GAHP with an integrated cooling system to provide both HVAC and water heating, and offer end users an exciting new economical product that provides very high efficiency fuel-fired heating and electric-driven cooling in a "one box" solution.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Gas Heat Pump RTU Cold-Climate Performance Assessment

This project demonstrated a gas-engine-driven heat pump incorporated in a packaged rooftop unit to quantify its cold-climate performance, reductions in peak electric and peak gas demand, and environmental benefits.

Project Description

Gas-engine-driven heat pumps (GHPs) are an important gas cooling and heating option for commercial buildings when considering electric-demand reduction initiatives. Previous studies demonstrated that GHPs can reduce peak electric demand by 6 kW to 15 kW, compared to electric variable refrigerant flow (VRF) systems, or conventional rooftop units (RTUs), respectively.

GHPs can also reduce peak gas demand. GHPs have high heating efficiency due to the use of engine heat recovery to boost performance during the winter. This increased heating efficiency will reduce peak gas demand, generate energy savings, and reduce full-fuel-cycle greenhouse gas (GHG) emissions when compared to a baseline standard-efficiency RTUs.

Compared to electric heat pumps, GHPs have two key advantages in heating operation for cold climates. GHPs use engine heat recovery to: 1) avoid a defrosting cycle and 2) maintain heating capacity and supply temperatures during very cold ambient temperatures. Electric heat pumps require periodic defrosting at ambient temperatures below 40˚F. Conventional defrosting uses reverse cycling, which results in an inherent energy penalty because it removes heat from the indoor air during the defrosting period. GHPs avoid the need for a defrosting cycle by controlling the flow of the recovered waste heat from the engine and maximizing the heat-recovery process.

A second advantage is to avoid supply temperatures which can result in the “cold blow” effect (delivery of air at less than body temperature) that compromises indoor thermal comfort. GHPs use engine heat recovery to supplement heating output in order to maintain both indoor supply temperatures and heating capacity, which can be a problem with current electric heat pumps. In cooling and moderate heating mode conditions, engine waste heat can also be directed to an optional supplemental water heater, maximizing system efficiency.

This field study quantified the performance and benefits of the packaged natural gas engine-driven heat pump rooftop unit for (PGHP) high-efficiency space conditioning for commercial buildings in cold climates. This rooftop configuration is a unique GHP design with potential for wide adoption and lower installation costs by using the same footprint as conventional packaged rooftop units. Although this model successfully demonstrated high-efficiency cooling performance and reliability in very hot climates, this field study was one of the first cold climate demonstrations of the packaged GHP. The objective of this study was to validate cold climate performance and identify any design changes needed to optimize this technology for cold-climate applications.

This project was conducted in partnership with the New York State Energy Research and Development Authority (NYSERDA) and National Fuel Gas Company, with NYSERDA providing the prime funding for this research.

Image credit: Blue Mountain Energy

Blue Mountain Energy’s packaged rooftop gas-engine-driven heat pump.

Benefits / Market Implications

GHPs can provide economic and resiliency benefits for commercial buildings and gas customers, such as life-cycle cost savings with favorable time-of-use rates or electric-demand charges, and infrastructure capital cost savings due to lower peak electric demands.

Technical Concept & Approach

- **Site Selection and Baseline Monitoring**

  Select a site representing a potential end user for GHPs, including facilities such as offices, schools, health clubs, gymnasiums, hospitals, retail buildings, and restaurants. A small gas station and grocery store in Buffalo, NY was selected for this demonstration.

- **PGHP Installation and Demonstration Plan**

  Develop the demonstration plan for the selected site, and then specified, installed, and commissioned the instrumentation and data-acquisition system.

- **PGHP Performance Monitoring**

  Monitor the performance of the PGHP from 2020 through 2021 to determine annual energy use and costs across the full range of operating conditions.

- **Data Analysis**

  Analyze measured data to determine heating and cooling delivered, energy consumption, reduction in peak electric demand, GHG emission reductions, and energy cost savings relative to baseline. Estimate simple paybacks.

- **Innovative Desiccant Proof of Concept**

  Develop at laboratory scale an innovative 3D-printed desiccant wheel with thermo-responsive desiccants to enhance energy efficiency and thermal comfort in buildings. UTD and partners National Renewable Energy Laboratory, Blue Mountain Energy, and TCPoly will design, build, and demonstrate a proof-of-concept prototype. Separating sensible and latent cooling by using desiccants have shown up to 30% savings of primary energy. Compared to conventional desiccant systems, the proposed design has potential to reduce energy consumption by reducing the additional sensible load due to desiccant regeneration.

Results

This field study confirmed significant peak electric-demand reductions, which may qualify for electric-demand response programs or non-wire initiatives. The measured peak demand during cooling was 4.38 kW, a significant decrease (76%) from the 18 kW summer peak demand associated with a conventional RTU using natural gas heating and electric cooling. A comparable electric heat pump would generate 22 kW peak demand during heating operation, excluding any supplemental heating at low temperatures.

The PGHP demonstrated high cooling efficiencies with a seasonal average of 1.19 COPg (Coefficient of Performance on gas use) which aligned with rated efficiencies of 1.12-1.24 COPg reported from laboratory testing. Although the PGHP demonstrated high heating efficiencies in laboratory testing (1.4 COPg at rated conditions), the heating efficiency measured at the field site was lower than expected. Some heating-performance issues were discovered at lower ambient temperatures that will require further investigation by the product design team; this type of anomaly is not unexpected for the first cold-climate demonstration. As noted, a key objective of this study was to identify design changes needed to optimize PGHP heating performance and effectively implement this design in colder climates.

Based on regional utility pricing, the PGHP can reduce energy costs up to 44% compared to conventional and electric heat pump RTUs due to high-efficiency operation, low-cost natural gas, and reduced demand charges. Further cost reduction of the PGHP design is needed to achieve more favorable paybacks. Upstream GHG emissions for the PGHP were similar to conventional and the electric heat pump RTUs based on regional non-baseload power-generation mix; however, engine operation generated additional onsite GHG emissions, highlighting the need for an engine design that can optimize performance while minimizing emissions.

The project team analyzed the experimental NREL data on new thermo-responsive desiccant samples. A computational model was developed to optimize the geometry of the thermo-responsive desiccant channels and the desiccant wheel based on the NREL experimental data.

A conference paper which summarized the results of the rooftop GHP demonstration was presented at the 2023 ASHRAE Winter Meeting on February 5, 2023.

Status

A public summary dated April 6, 2022 of the Final Report for Tasks 1-4 of UTD project 1.18.I is available on the Reports page of UTD's public website.

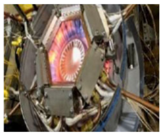
For Task 6, the project team is waiting to receive NREL's input data for the computational model. The modeled output will then be compared to the measured experimental data.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Integrated, Self-Powered, High-Efficiency Burner System



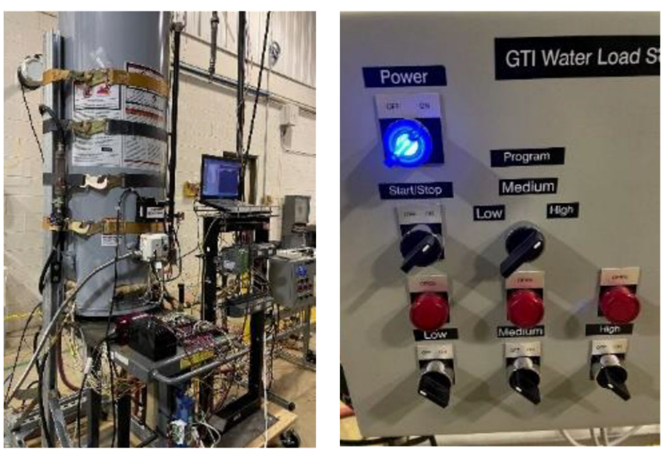
Researchers are developing a grid-resilient, self-powered, fuel-flexible, high-efficiency Advanced Burner Thermoelectric Generator that can be installed in many residential and commercial building space- and water-heating systems to improve their resiliency, reliability, and efficiency.

Project Description

The goal of this project is to develop and demonstrate a laboratory prototype of a grid-resilient, self-powered, thermoelectric generator (TEG) system integrated into a commercial water heater. Initial development efforts focused on demonstrating this at a 40,000 Btu/h capacity, while current efforts are scaling up development to ~200,000 Btu/h capacity.

Phase 1 demonstrated two key subsystems: 1) a 3D-printed high-efficiency, ultra-low-emissions, fuel-flexible, modulating burner integrated with 2) a commercially available low-cost, high-efficiency, high-operating-temperature TEG. The project seeks to demonstrate and advance towards commercialization a design that is drop-in retrofittable, self-powered, grid-independent and with fast payback (<2 years). The Phase 1 project successfully showed the following:

- Effectively integrated the TEG system with the water heater to maximize the power output, electrical and controls scheme and water integration
- Demonstrated 200 hours of continuous grid-independent operation via sufficient electrical self-generation (100 We) to exceed power demands for water heating systems
- Demonstrated that the water heater can operate without any external power for a wide range of hot water demand profiles.



Water heater with damper, data acquisition system and water load simulator for testing (left). Programmable water load simulator (right)

- Demonstrated ability to accommodate 10% hydrogen blending into natural gas.
- Showed how the design can be a drop-in solution for a representative product application with no substantial changes to the water heater installation process
- Performed techno-economic analysis to understand the additional cost for grid-independent operation which ranged from $50-100 for a storage water heater

Phase 2 will develop a larger-scale system and build upon the accomplishments achieved in Phase 1, which developed and demonstrated the core configuration of the TEG-integrated system. A larger scale 200,000 Btu/h storage water heater is being investigated for integration with the TEG.

Benefits / Market Implications

The primary target markets are new and retrofit installations of existing water heaters in the light commercial sector. The global commercial water heater market is projected to grow from $5.98 billion in 2021 to $8.69 billion in 2028. The largest shares of the market are in healthcare, restaurants, institutions and offices. A self-powered commercial scale water heater technology would offer a low cost option to continue hot water production during power outages as well use in remote areas and emergency situations without the need for external power. Reliable supply of hot water is essential for many key functions in both residential and commercial sectors, including such as community warming shelters, police and fire stations, urgent care medical facilities, etc.

The technology aims to ensure safe, reliable, and resilient operation and increase integration with renewable energy (RE) sources such as hydrogen produced from RE.

Technical Concept & Approach

In this project researchers will design, develop and test drop-in TEG burner, and develop commercial prototype designs for TEG-integrated self-powered water heater at 40,000 and ~200,000 Btu/h capacities. The following tasks will be performed in the current phase of the project:

Finalize system architecture

The team will finalize and assess integration of the TEG with the ~200,000 Btu/hr water heater including reviewing the installation of the TEG and its impact on the operation, reliability, and safety; and performing a trade-off analysis to ensure optimized electricity generation from the TEG. It is important to have a drop-in design with minimum modifications to the heating system. The team will evaluate the TEG's operational efficiency, location with respect to the burner, and impact of modulation. That evaluation will be used to optimize integration of the TEG and burner.

Integration of the TEG System with WH Controls

The team will design the controls and optimize the operational performance of the TEG module and integration components and integrate the module into the water heater to ensure minimum energy usage with the water supply. The design will accommodate stresses due to thermal cycling in the TEG materials and modules with multiple interfaces which could otherwise result in failure. The system will be integrated to maximize temperature gradients and achieve maximum power output with minimal design modifications. Thermal and emissions characterization with and without the TEG will be performed to ensure the TEG does not impact the burner performance. The team will build and test the TEG module, including heat sink and cooling, with the water heater burner to characterize its operation and fine tune its arrangement and positioning.

Integrate subsystems testing

The team will integrate the TEG module into the water heater and test over several days of uninterrupted operation at different water load profiles, covering from low to high water demand while ensuring continuous hot water management. Test data will be analyzed to assess integrated system performance. The team will then develop designs for TEG integrated self-powered water heaters. Finally, the team will estimate costs of the integrated system towards a commercial prototype and the scope of its potential market based on the developed design.

Results

The team performed a detailed analysis to down-select three different materials for the TEG. In addition, three different water heaters were reviewed.

In 2020, researchers performed Computational Fluid Dynamics (CFD) analysis for the fuel-flexible burner and generated a solid model, which was 3D-printed. Two water heaters were installed in the laboratory for power-consumption and thermal characteristics testing. A test rig was set up for operation with hydrogen including the appropriate interlocks and improved exhaust system. Testing and evaluation of the residential water-heater burner were performed, with temperature, emissions and electrical power demand analyzed. Different TEG integration methods and designs were evaluated. In addition, a preliminary model for hydrogen/natural-gas mixtures was developed for CFD analysis.


Commercial scale water heater

In 2021-2022, testing was performed on multiple TEG units of different power levels and physical dimensions to understand the power output. Initial CFD analysis of the burner and bench-scale setup for burner testing was completed. An analysis of an advanced 3D-printed burner was performed for hydrogen testing. Testing with the 3D burner demonstrated <5 ppm NOx emissions. Methods to improve the performance of the burner for pressure drop and air-fuel mixing were evaluated. Researchers also analyzed different single-nozzle burner designs. Further CFD modeling of the burner was completed, and key design improvements were identified and implemented. Testing results demonstrated that <5 ppm NOx emissions can be achieved for the entire firing range and with different levels of hydrogen blends with natural gas.

A Final Report which summarized Phase 1 results was provided to UTD members in October 2022.

In 2023-2024, the team reviewed power demand for the water heater and started evaluation of the integration design. They also presented a paper "Grid Resilient Self Powered Heating System" at the 8th High Performance Buildings conference in July 2024, at Purdue University, IN. A commercial size water heater was ordered for testing and integrating with the TEG.

Status

The team is currently working on the design to integrate the larger-capacity ~200,000 Btu/h TEG burner within a water heater, and continuing to discuss and evaluate this technology development with major water heater manufacturers.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

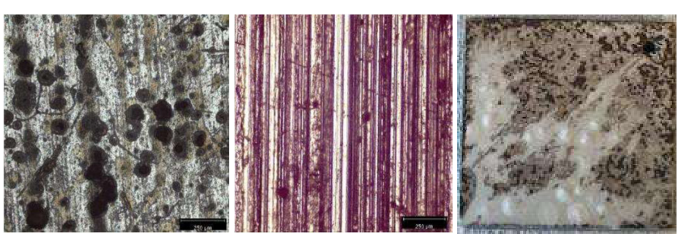
Sequestering Non-Condensable Gases for Enhanced Gas Absorption Heat Pump Reliability

Researchers are developing technologies to enhance the long-term system performance, economy, and reliability of any type of high-efficiency gas absorption heat pump, while also reducing maintenance requirements and costs, to benefit end users and accelerate market transformation.

Project Description

A significant factor that influences the cost effectiveness of high-efficiency gas absorption heat pumps (GAHP), which represent the most technologically mature option for thermally-driven heating and cooling systems, is the need for corrosion protection. The ammonia-water or strong salt absorbent/refrigerant working fluids used in absorption cycles typically create high-temperature, high-pH environments that have a tendency to form hydrogen (a non-condensable gas that degrades system efficiency), and can attack steel surfaces, promoting stress corrosion cracking and failure.

To successfully advance the use of GAHPs, it is important to minimize the impact of non-condensable gases (NCGs) on long-duration performance and reliability, and make other cost reductions. The goal of this project is to design and develop NCG isolation (NCGI) modules and provide research and development support to employ novel, low-cost aluminum heat exchangers to increase long-term system efficiency and reliability and safe operation, and reduce the cost of any GAHP. Phase 1 of this UTD project provided co-funding to a prime contract funded by the U.S. Department of Energy (DOE) with the general goal of reducing the cost and improving the reliability of residential and light commercial-sized GAHPs. Specific goals for the current Phase 2 work are to develop a prototype bench-scale NCGI module, demonstrate its operation in venting and storage modes, integrate several NCGIs into operating GHPs, and demonstrate successful operation, maintaining < 5% loss in COP over simulated one-year of operation.



***(Left)** Alloy AA3003 at100x after 60-day immersion in 28-30 wt% ammonium hydroxide solution. The micron marker is 250 µm*

***(Middle)** Alloy AA6061 Sample 1 at 100x after 60-day immersion in 28-30 wt% ammonium hydroxide. The micron marker is 250 µm*

***(Right)** Alloy AA5052 Sample 2 after 60-day immersion in 28-30 wt% ammonium hydroxide*

Ref: Garrabrant, M., Newland, J., Glanville, P., Spicer, K., and Frankel, G. (2022) Improving Reliability, Weight and Cost of Gas-Fired Absorption Heat Pumps. United States: N. p., doi:10.2172/1886933

Benefits / Market Implications

High-efficiency GAHPs are strategically important to achieve energy efficiency and decarbonization goals. This project seeks to ensure optimum long-term performance, economy, and reliability of these new product categories for end users.

The efficiency of GAHPs that use ammonia-water or strong salt absorbent/refrigerant fluids can slightly decline over time as NCGs are created within the system. An economical and effective NCGI module will increase the long-term efficiency of GAHPs while simultaneously enhancing their reliability and reducing periodic maintenance expense.

Current GAHP heat exchangers use corrosion-resistant steels, in part because more common materials (e.g. copper) are not compatible with ammonia-water solutions. As such, the evaporator coils of GAHP systems are the heaviest and most expensive part of the system. By shifting to an aluminum-based evaporator (provided that corrosion issues are within control), the GAHP may be significantly lighter and less expensive. The evaporator coil in a standard 80 kBtu/h GHP weighs about 150 pounds; however, an all-aluminum coil could weigh just 25 pounds and might save $375.

Laboratory setup assembly.

Technical Concept & Approach

Both building on experience with gas absorption heat pumps (GAHPs) and their corrosion control and leveraging technology developments in chemical processing, the team will develop and demonstrate solutions to handle NCGs through isolation, storage, or both. The current project phase will perform the following tasks:

"Succeeding today's gas furnace and water heater are highly-efficient gas heat pumps (GHPs) — the future for space- and hot-water heating. However, to gain customer acceptance, GHPs must be highly reliable, similar to a gas furnace with extremely low maintenance. One of the critical issues for long-term reliability of absorption GHPs is the removal of non-condensable gases.

We're very pleased that this UTD-funded technology development, in partnership with U.S. DOE, will further enhance GHP reliability."

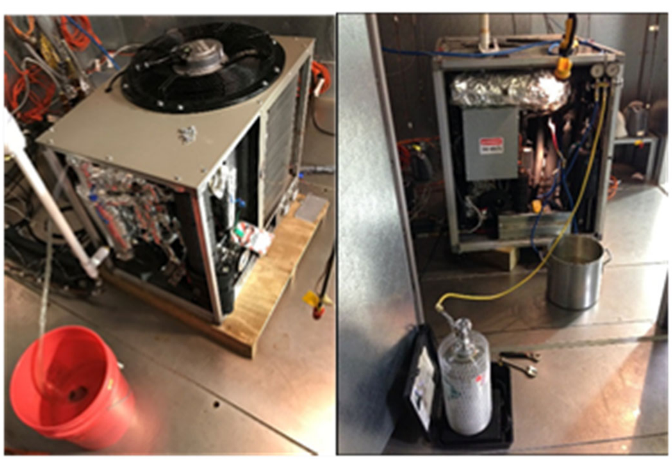
- Aqeel Zaidi
Manager, Technology Development
Enbridge Gas Inc.

Corrosion Inhibitor Evaluation and Non-condensable Gas Isolation Analysis and Final Design

Aggregate findings from 25+ GAHP field demonstrations and long-term laboratory testing to further characterize NCG development and the impact/benefits of removal/isolation. Finalize the design NCGI module specification, compatible with GAHP units from Robur, SMTI, Vicot and other leading OEMs. Finalize the selection and preparation for the H2-selective membranes using a membrane system developed for nuclear fuel applications, building on prior literature survey and bench-scale data collection during Phase 1. In parallel, novel approaches to corrosion control as a chemical inhibitor will be explored, using emerging technologies not explored in prior RD&D efforts.

Bench-Testing of NCGI

Perform bench testing on multiple versions of the NCGI module, using a modified NH3/H2O Corrosion Test Station to provide a simulated environment for each module. The NCGI module will be in communication with an NH3/H2O mixture at representative conditions (concentration, temperature, pressure), while a controlled amount of H2 will be fed into the volume to come into contact with the NCGI module to quantify H2 selectivity, transfer rates, and need for module thermal management.



Removing NCGs and Adjusting Charge with Laboratory GAHPs

Results

In 2020-2021, the project team completed rounds of corrosion testing with the alloy samples using a custom-built corrosion test stand. In parallel, university researchers initiated atmospheric pressure testing. Testing included bare metal (baseline) and various coatings – in total, 96 alloy and 16 low-carbon steel samples. The project team reviewed the results and shifted towards the next set of alloys for testing. Tests were completed in 2022 and a Phase 1 Final Report was issued. This last round of testing included an evaluation of a range of corrosion-protection solutions for proprietary aluminum alloy coupons from a third party and several baseline coupons. Each coupon test was at two ammonia concentrations, mid (50%-75%) and high (90%-95%), and the coupons were tested in pairs with duplicates for each run – in total 64 test points for this project.

In Phase 2 efforts, the project team performed preliminary analysis using corrosion simulation software to evaluate the corrosion mitigation capabilities of degassed water against normal water when mixed with 10% NH3 solution. Unlike as learnt from previous literature, the use of degassed water did not have a significant impact over corrosion mitigation of carbon steel. The dissolved gases in the normal water are helping to reach the safe pH levels where passivation of carbon steel is possible.

To better understand this, the project team has decided to perform a few preliminary tests to evaluate the validation of the results obtained from the software. Results had significant drift between values which made it difficult to infer anything from the weight loss observed. So, the project team decided to repeat the preliminary tests with 3 coupons in each test vessel for a monitoring period of 2 weeks. The project team has ordered additional ammonia and carbon steel coupons for continued testing efforts.

Status

The project team continues to make progress in securing samples. All inhibitors, coupons (coated and uncoated), and other materials have been ordered and the team awaits their receipt. All of the reagents/coupons have been received for testing.

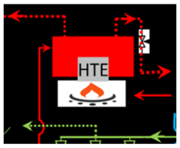
Preliminary tests are underway, with final seal tests of the two oven vessels at pressure and temperature (350°F).

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Gas-Fired Binary-Fluid Ejector Heat Pump Water Heater



Research is being conducted to develop and demonstrate a prototype gas-fired binary-fluid ejector heat pump water heater that provides 12,000 Btu/hr (3.5 kW) capacity, achieves a UEF (Uniform Energy Factor) of 1.4 or better, and shows an attractive value proposition for gas consumers.

Project Description

This project involves modeling, designing, building, and testing a prototype of a gas-fired ejector heat-pump water heater (GFEHP). This first-of-a-kind heat pump uses a novel cycle that combines a binary-fluid ejector and sorption subsystem into one high-efficiency cycle. The technology integrates several components that are thermally and hydraulically coupled. The overall objective is to develop and demonstrate GFEHP technology at 12,000 Btu/hr (3.5 kW) capacity in the laboratory and achieve a gas Coefficient of Performance (COP) of 2.0 (equating to a UEF>1.4).This project is taking a ground-up approach for designing and building the novel GFEHP prototype, starting with system specification, modeling, and breadboard prototyping, then culminating in a full system prototype construction and testing.

The project is a collaboration among UTD, the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory, the University of Missouri (MU), and ThermAvant Technologies. UTD's funding is being leveraged by approximately $1.9 million in prime funding provided by the DOE.

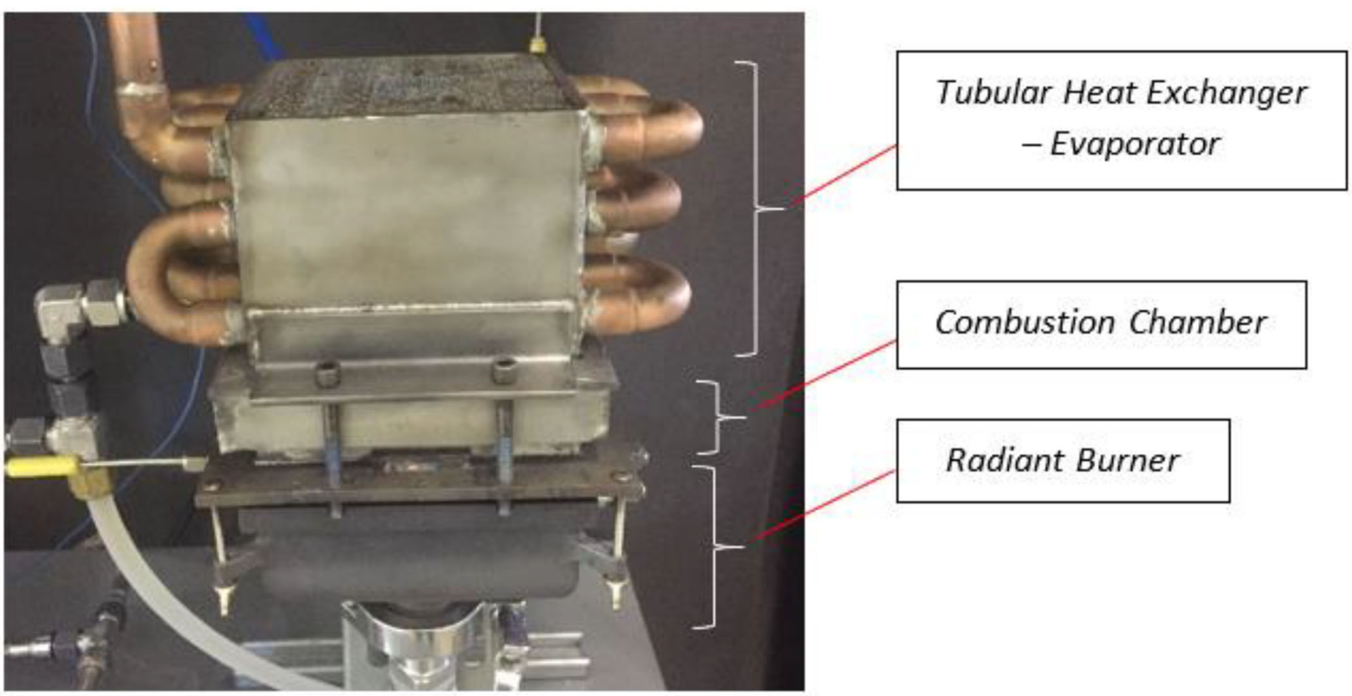
Benefits / Market Implications

The primary target markets impacted by GFEHP will be residential, multifamily, and light commercial water heating.

The GFEHP has a target gas COP of 2, which translates into an energy factor (EF) of at least 1.4 if the burner is non-condensing and its storage tank is not well insulated. With a well-insulated tank and condensing burner, the GFEHP can have an EF of 1.8. State-of-the-art gas-fired water heaters have a thermal efficiency of 0.98, which translates to a <1 EF.

The GFEHP is expected to be twice as efficient as the state-of-the-art product on a primary energy basis (e.g., tankless water heaters and electric heat pump water heaters). Compared with an electrically-driven vapor compression heat pump water heater, the GFEHP replaces the compressor and the expansion valve with an ejector, additional heat exchangers, and an oscillating heat pipe. A cost comparison indicates that it is possible to meet cost targets of $4,000.

Water heating is a source of significant primary energy consumption in U.S. (second in buildings only to space heating). There are approximately 60 million minimum-efficiency gas



The laboratory-scale heat-transfer system was designed, fabricated, assembled, and tested.

"Innovative next-generation technical solutions like the gas-fired binary-fluid ejector heat pump water heater can double the efficiency of standard water heaters while greatly reducing related emissions. UTD's partnering with the U.S. DOE, MU, ORNL, and ThermAvant brings a strong team to deliver significant efficiency gains from this exciting technology, while ensuring cost-effective solutions for the customers we serve!"

- Steve Roberson
Technical Analyst
Spire Energy

water heaters in U.S homes (EF<0.67), responsible for 2.86 quads of primary energy consumption and an annual consumer expenditure of around $32.6 billion. As improving building envelopes reduce space-heating loads and more high-efficiency warm-air furnaces are installed, water heating represents a growing proportion of the residential gas load. The GFEHP technology will provide high efficiency as a retrofit option to all existing gas water heaters and the 9.1 million homes that currently do not use natural gas in water heating but have gas availability. As new houses become more efficient, innovative gas solutions such as GFEHP water heating can provide low-cost, high-efficiency heating options.

Technical Concept & Approach

Specific tasks for this project include:

Identify System Architecture and Product Specifications

Develop a conceptual design of the GFEHP. Conduct thermodynamic modeling to ensure that the targeted thermal efficiency metrics are feasible. Develop a system architecture that specifies the required components, their efficiency target levels, and how they are integrated.

Design, Manufacture, and Test of the Combustion System

Develop an ultra-low-NO_x, high-efficiency, low-cost manufactured burner that will be used in the prototype system.

Assemble the Prototype Combustion System, Characterize its Performance, and Validate the Model

Integrate combustion sub-systems with other required components to form a breadboard prototype of the proposed GFEHP. The breadboard will provide valuable information on the characteristics of the GFEHP as a system.

Support the Design of an Alpha Prototype

Design a alpha prototype of the GFEHP using the validated system model and information gained from the breadboard evaluation.

Techno-Economic Study

Support commercialization by assessing the value proposition and the potential of a GFEHP water heater. To do so, estimate the first cost at maturity of the GFEHP (based on the alpha design).

Results

In 2020, the project team provided guidance on burner design. Researchers recommended a radiant-type burner, which is the only technology to achieve ultra-low-NO_x emissions without sacrificing efficiency. Other off-the-shelf and prototype burners considered included a metal fiber mesh burner, a permeable metal matrix burner, and volumetric and flat-metal foam burners. Investigators also analyzed the option of using a thermoelectric generator (TEG) in combination with a radiant burner for self-powering of some components of GFEHP.

A report titled *Product Characterization Criteria Brief* was compiled that summarized the applicable efficiency standards and emission requirements for commercialized and pre-commercial gas and electric water heaters. Recommendations related to target cost and physical characteristics of the GFEHP water heater were provided.

In 2021-2022, the project team modified the existing design and test stand to test the system at conditions closer to what would be seen in the full prototype system. A preliminary engineering design of the laboratory prototype combustion and heat exchanger system for the GFEHP was completed.

In 2022-2023, the team designed, built, and tested a breadboard prototype with the anticipation of building and testing an alpha prototype in early 2024.

In 2024 the team has been working with MUST and ORNL to analyze the breadboard prototype test results. The team iterated on the design of the fluid ejector-compressor in order to improve on the performance of the initial design, the geometry and fluid selection have been changed several times. The team at Missouri University of Science and Technology completed its testing and prepared a workable design for the GFEHP's alpha prototype.

Status

The team is resuming work on designing the high-temperature evaporator, which is a critical component that drives the entire thermodynamic cycle.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

High-Efficiency Combination System Integrating PV and Self-Power

Researchers are demonstrating hybrid residential combined HVAC and water-heating systems that use novel controls to integrate gas/electric systems with micro-combined heat and power, energy storage, and renewable energy in order to increase resilience and reduce operating costs and greenhouse gas emissions by up to 50%.

Project Description

Integrated energy systems (IES) are an emerging approach to provide high-efficiency, self-powered HVAC and water heating by integrating fuel-fired and electrically-powered equipment with distributed energy resources and energy storage. This project is developing and demonstrating hybrid residential HVAC and water heating systems in a laboratory that use off-the-shelf appliances and novel controls to integrate gas/electric systems with micro-CHP (mCHP), energy storage, and renewable energy in order to reduce operating costs and GHG emissions by up to 50% and achieve COPs up to 1.5 while retaining superior resiliency. The initial phase of this project demonstrated that the integration of a residential scale mCHP system with a tankless combi and an electrically-driven air source heat pump (ASHP) could achieve highly-efficient, self-powered HVAC and water heating.

Goals for this project include developing an mCHP retrofit solution with an existing furnace and ASHP to achieve self-powered fuel-fired space heating with COP>1.0, and integrating a ~5kW mCHP with an air-to-water combi heat pump to achieve self-powered fuel-fired HVAC and water heating with COP>1.5.

UTD is partnering with the Propane Education and Research Council (PERC), which provided co-funding to this project.

Laboratory facility used to demonstrate and test novel integrated energy systems.

Benefits / Market Implications

The target markets to be impacted include single-family and multifamily residential markets (retrofit or new, including affordable housing markets) where NG/LPG-fueled furnaces and/or ASHPs are used and small commercial applications with moderate HVAC and water heating loads.

Benefits of this project include reducing GHG emissions by: increasing integration of PV renewable energy; using significantly more efficient NG/LPG-fueled equipment; increasing HVAC system operational resiliency for ratepayers through on-site power generation/nanogrids; and the opportunity to rapidly implement the innovations since they integrate and control off-the-shelf appliances in novel ways.

Technical Concept & Approach

Continuing to move from research implementation to technology development, UTD will conduct this project in the laboratory and use Virtual Test Home (VTH) methods for simulated-use evaluations.

The current phase of work will complete the following tasks:

Prepare Overall Test Plan and Procure all Equipment

The project team will procure equipment for a prototype integrated system, mCHP retrofit and air source heat pump and develop a project test plan to address key research questions.

Develop Cloud-based Smart Fuel Switching Control

BKR Energy has developed an innovative cloud-based smart fuel switching controller that uses data on weather, energy rates, and emissions factors to make fuel switching decisions. Working with BKR Energy, the team will develop control strategies to help answer and address the research questions.

Implement hardware-in-the-loop test protocol

The team will implement hardware-in-the-loop test protocols inside the laboratory, and perform EnergyPlus™ modeling to co-simulate building models and hardware interface capabilities. This functionality will enable co-simulation of a building model as the hardware operates, permitting "real-time" interaction between the building model and HVAC system.

Design and Build Residential Hybrid and mCHP IES

The team will design, build and test the prototype integrated solution, an additional mCHP retrofit solution, and an integrated 5kW mCHP with an ASHP system. VTH data will be reduced to 24-hour load versus efficiency profiles. As with all VTH data sets, they will be used to develop performance curves that can be used in building energy modeling software to predict energy, GHG, and cost savings from the various IES systems.

Results

In Phase 1, a residential nanogrid testbed was built, and a prototype system achieved key performance markers such as: self-powered HVAC water heating on- and off-grid for superior resiliency for ratepayers; annual hybrid space-heating efficiencies >100%; predicted annual GHG reductions based on IES performance of >30% in cold climates; and annual operating cost savings of >40% in several regions.

The prototype matched the best-in-class advanced combi system's performance. More importantly, the prototype has led to the development of a complete IES where an electric heat pump and onsite power are already installed, and the control logic is developed for integration.

The VTH performance-based modeling efforts determined that significant energy, cost, and emissions-related savings are possible with the hybrid self-powered system compared to a traditional 90%-efficient furnace, 0.62 EF water heater, and 15 SEER HSPF air conditioners. Modeled estimates for seven different climates were developed.

Additional findings indicated that specific IES designs (particularly with integrated PV) can achieve self-powered space heating/cooling and water heating at annual COP >1.5 on a source energy basis with 30-50% lower operating costs and similar GHG emissions reductions than with separate code-compliant equipment in various climates.

Researchers also determined the nanogrid system can operate entirely off the grid and power the HVAC and water heating loads but with substantial battery storage, thus demonstrating resiliency.

To communicate these important findings and concepts to building HVAC design professionals, results from this project were presented at the ASHRAE 2022 Winter Conference in Las Vegas, NV, in January 2022 and the World Gas Conference 2022 in Daegu, Korea in May 2022. Additionally, a paper was presented at the Purdue 2022 Refrigeration & Air Conditioning Conference in West Lafayette, IN, in July 2022. Two papers from this research were also presented at the ASHRAE 2023 Winter Conference in Atlanta, GA, in February 2023.

Enginuity E-ONE Micro-CHP System (image credit: Enginuity)

In Phase 2, the project team took a modeling approach to evaluate the performance of a variety of resilient IES to support outage events due to snowfalls in the winter seasons. Part of the IES included implementing battery energy storage systems, PV, emergency backup systems, mCHP, and backup generators in homes with furnaces, fully electrified with heat pumps or hybrid heating systems. Modeling outputs such as emissions, cost, and payback were assessed for homes with 60, 80, and 100 MBH peak heating capacities. The duration of outages was also evaluated, with a number of continuous days ranging from 1 to 3 annually for a span of 1 to 15 years.

In addition to the modeling efforts, the team procured a mCHP appliance that is targeted for residential applications, along with automated electric and thermal load banks, to perform simulated use testing of the appliance in a laboratory nanogrid testbed. In 2024, the team worked closely with the manufacturer of the mCHP appliance to evaluate it and to model it in order to understand control options and quantify cost/GHG emission benefits. Commissioning and thorough testing of the mCHP appliance in a matrix test plan identified several opportunities to refine and optimize the system and product, such as to optimize runtime cycles as a function of thermal bandwidth, further reduce noise and emissions, and add a closed-loop heating loop for space heating integrations.

Status

Phase 2 activities remain underway. The project team continues to support the mCHP appliance manufacturer as it further optimizes its product and technology. When completed, it is anticipated that the next version of this mCHP appliance intended for nanogrid and other applications will be tested and evaluated in a laboratory nanogrid testbed using a Virtual Test Home approach.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Hydrogen-Blended Gas in Residential/Commercial Combustion Equipment

This project is adapting and demonstrating solutions to use hydrogen blends in residential and commercial combustion equipment in order to reduce GHG emissions. Researchers will demonstrate multiple solutions in a controlled laboratory environment and leverage findings from other researchers globally.

Project Description

While hydrogen as a fuel presents a number of challenges to existing combustion equipment, an emerging consensus suggests that low blends (e.g., <20% by volume) are suitable for existing equipment. Technology demonstrations are under way in Europe, where natural gas is predominantly used for heating. Through these efforts, several products are undergoing development and demonstration, from domestic boilers to cooking ranges and their associated combustion components, that can safely and efficiently utilize up to 100% hydrogen fuels.

Under Phase 1, this project seeks to build on these European efforts through extended technology transfer, while developing an R&D roadmap for hydrogen-blend-compatible equipment in North America, with an initial focus on >50% hydrogen blending by volume.

The concurrent Phases 2 and 3 of this project seek to support the potential deployment of up to 30% hydrogen-blended gas in North American buildings by assessing the performance, emission, safety, and qualitative impacts of hydrogen blending on widely-used residential gas-heating appliances. Phase 2 focuses on high load gas appliances such as furnaces and water heaters, while Phase 3 focuses on widely-used but low-load peripheral gas appliances such as gas lights, space heaters, and indoor fireplaces.

Table-top hearth hydrogen-blending test setup

Benefits / Market Implications

This project initiated a significant technology-transfer and research effort with several leading global technologists to demonstrate high-hydrogen-compatible equipment and lay out a path for wider utilization of hydrogen in North America. Subsequent phases of the project are aiming to assess the compatibility of existing appliances with hydrogen blends to quantify net benefits of hydrogen blending at different levels. If successful, broad ratepayer benefits are anticipated to include achieving up to 100% reduction in the onsite carbon emissions associated from natural gas consumption, and reducing or eliminating carbon-based emissions.

Technical Concept & Approach

Specific tasks for Phase 2 include:

Testing of Standard Gas Appliances Under Rating and Adverse Operating Conditions

Working with appliance manufacturing partners, researchers will perform standard rating and simulated-use tests with several typical furnaces and condensing water heaters in "as-shipped" condition to quantify any changes in efficiency and emissions of criteria pollutants when operating on hydrogen blends up to 30%. Additional tests will focus on adjusted appliance tests and operating under adverse operating conditions to determine if hydrogen use will cause existing appliance to lose compliance with ANSI standards.

Specific tasks for Phase 3 included:

Qualitative Impacts of Hydrogen Blending on Aesthetic Burners

The team will build a test apparatus for evaluating the qualitative and aesthetic output of fireplaces, radiant space heaters, and gas lights based on changes to flame size, shape, color, luminosity, and radiant output.

Results

In 2020, researchers coordinated with manufacturers of key hydrogen-capable components and combustion systems. Within this group, several appliance manufacturers discussed

"Clean hydrogen will be key to helping consumers take advantage of the reliability and resilience of the gas system, while aiding us in reaching our decarbonization goals. This project will help assess the compatibility of existing appliances with blended gas and demonstrate the next generation of hydrogen-ready equipment."

- Neil Navin
Vice President, Clean Energy Innovations
SoCalGas

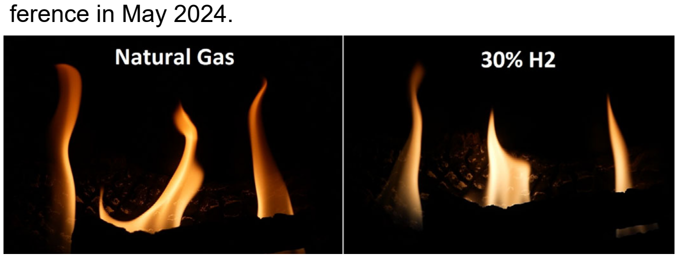
approaches to operating with hydrogen blends, up to 60% in most cases and 100% in some cases. Hydrogen-compatible flow sensors were acquired and project representatives developed a hydrogen/natural gas automated mixing station.

In 2021, the project team developed a comprehensive review of hydrogen demonstrations in Europe and Asia that included end-use customers, including materials from the EU-based *THyGA* project, adapting some of the timely findings for a February UTD member webinar. Additionally, researchers actively coordinated with other North American hydrogen studies and testing efforts.

In 2022, test stands were built and/or modified for standardized testing of furnaces and water heaters. As part of the R&D roadmapping and outreach efforts under this project, the team prepared a summary paper for the World Gas Conference held in May 2022. Researchers demonstrated that methane emissions decrease with added hydrogen. The response to results was very positive, in particular with high interest from organizations in Latin America.

In 2023, the team completed commissioning the test stand for Phases 2 and 3, and initiated initial tests with hydrogen blends in a hearth and gas furnaces. Results to date for this project were presented at a seminar at ASHRAE's Winter Conference in February 2023.

In 2024, the team conducted furnace tests, which are ongoing. The team completed testing for an Ultra-low NOx furnace, including steady-state and Virtual Test Home (simulated use) tests using natural gas and 30% hydrogen blends. Results show a 1.4% decrease in efficiency under simulated use tests and a ~50% reduction in NOx emissions. The team has also commenced testing of conventional residential water heaters with H2-methane blends. The team is performing UEF-like tests to investigate the impact of 30% H2 blends the annual rating. Additional project results were presented at a seminar at ASHRAE's Winter Conference in February 2024, and also at the International Gas Research Conference in May 2024.



Hearth testing with Natural Gas (left) and a 30% H2 blend (right)

Test Setup. 1. Fireplace, 2. Camera & black globe meter, 3. Cylinder cart with regulator, 4. Emissions analyzer, 5. Gas flow meter

Phase 3 is complete and a final report for Phase 3 was issued to UTD members in August 2024. Results showed that natural gas produced the largest and brightest flame, followed by 100% methane and a blend of 30% hydrogen and 70% methane. The effect of hydrogen on luminosity was especially noticeable when operating at a lower firing rate. Testing of radiant heat output showed a 20% decrease in differential temperature when using hydrogen blends compared to natural gas and methane. Changes in both the luminosity and the radiant heat were at levels which could be detectable by a user.

The effect of hydrogen on flue gas composition and emissions of carbon monoxide and NOx was inconclusive. As was expected, the 30% hydrogen blend consistently resulted in the lowest carbon dioxide and the highest oxygen in the flue gases, consistent with the de-rating due to changes in the Wobbe Index of the fuel blend. Differences in CO and NOx were within the uncertainty bounds of the measurements for the experiment.

No flashing of the flame to a point upstream of its normal position (flashback) up to 30% H2 was observed for the burner operational performance.

Status

The project is nearing completion, with work under Phases 1 and 2 anticipated to be completed in Q4 2024. Additional opportunities to publicly present the findings of this research work at scientific conferences or in scientific publications are being sought.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Integrated mCHP System for Multi-Family Buildings

A project team integrated a micro-combined heat and power (mCHP) unit with best-in-class electric heat pumps, thermal storage, photovoltaic (PV), and other commercially-available equipment to serve a simulated multifamily application scenario. This advanced system provides annual gas efficiencies greater than 130% for heating, cooling, and hot-water loads while increasing resiliency and using more renewable energy. Gas customers can immediately benefit.

Project Description

This project demonstrated and optimized the integration of a near-zero emission (NZE) mCHP unit coupled with best-in-class electric heat pumps in multi-unit application scenarios such as a multi-family building. By integrating this commercially-available equipment with thermal storage, PV, and smart management capabilities, this advanced integrated system achieved annual gas efficiencies greater than 130% for heating, cooling, and hot-water loads, while providing high resiliency of on-site power generation, and substantially reducing operating costs and greenhouse gas emissions particularly in cold climate zones. Specific project objectives were to: integrate communications functions with variable-speed compressor electric heat pump operation and an mCHP system power lead-mode for space heating and cooling; right-size thermal storage and manage hot-water production for the mCHP system; characterize space and water-heating and space-cooling part-load performance; and communicate results to facilitate market transformation.

UTD partnered on this project with the U.S. Department of Energy (DOE), in which part of this UTD project supported a DOE-funded Connected Communities research program aimed to expand grid-interactive, efficient building communities nationwide to reduce carbon emissions and energy costs. UTD also partnered on this project with the Propane Education and Research Council (PERC), which provided co-funding to UTD.

Benefits / Market Implications

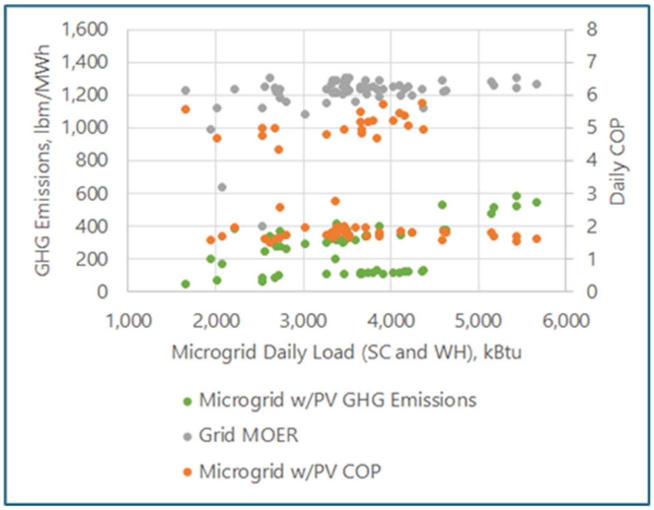
Optimization of an mCHP unit integrated with cold-climate air source heat pumps (ccASHPs), thermal storage management and PV will help increase low-cost, reliable energy solutions for consumers. Applications beyond multi-family housing include other multi-unit buildings, low-rise suburban office buildings, smaller strip malls/plazas, distributed thermal microgrids, etc. While NZE buildings can employ HVAC and domestic hot water produced by all-electric heat pumps powered in part by on-site PV power generation, advanced mCHP integrated systems can provide similar or lower emissions at lower operating costs with superior energy resiliency while also directly integrating PV energy. A reliable and efficient mCHP system, when cleverly integrated with best-in-class heat pump heating/cooling, can provide numerous benefits to meet thermal demands while also providing clean backup energy to power EV charging stations when PV power is insufficient. Demonstrating its feasibility helps inform consumers, homebuilders, manufacturers, and other stakeholders about the benefits of integrated energy systems for end users and the environment.

The mCHP integrated system indoor installation.

Technical Concept & Approach

Under Phase 1, the project team developed a test plan and subsequently built a prototype microgrid testbed to represent a 4-townhome multifamily building. This microgrid testbed included the EC Power 24 kW mCHP with four 3-ton best-in-class electric heat pumps. This microgrid was evaluated using a Virtual Test Home (VTH) load-based evaluation methodology, to optimize microgrid integration and control strategies. The microgrid performance was characterized for building energy modeling to develop sizing guidelines for multi-unit building sizing and location, including utility operating costs and region of transmission marginal operating emission rates (MOER). Researchers quantified the microgrid's MOER and operating cost reduction relative to commercially available all-gas and all-electric baselines.

Under Phase 2, the project team installed a PV array and EV charging stations in the microgrid and develop integration



GHG emissions of microgrid with integrated PV vs. local grid MOER during heating season

"We thank UTD and GTI Energy for partnering with EC Power to advance efficient new distributed generation technologies, demonstrating in this project its integration with PV and electric-driven equipment as well as providing prior technical support to help meet key emission requirements. Our new PowerHeatPump product for gas end users builds upon this important research."

-Bjarne Bogner
CEO
EC POWER A/S

strategies to cascade power prioritization, starting with solar, on-site cogeneration, and the grid. An automated load bank simulated realistic EV charging station loads and captured the effects on the microgrid performance. The project team also developed performance curves, evaluated microgrid performance with EV charging stations and PV in multiple climate zones, and developed design guidelines.

Results

During Phase 1, the project team developed a test plan and microgrid testbed design, integrated microgrid components, and evaluated its performance over the 2023 heating season in Chicago, IL. The test plan encompassed the microgrid testbed design and component selection. The EC Power 24 kW mCHP and four 3-ton ccASHPs were selected for this microgrid. Hydronic integration strategies were developed to leverage on-site cogeneration to prioritize water heating loads while supplementing space heating loads with the ccASHP's heating output. Power integration strategies were also considered to modulate the mCHP as a function of the ccASHP's power demand. The mCHP heat production was designed to be distributed to individual dwellers' indirect tanks and hot-water coils for water and space heating.

A hybrid approach to couple actual weather conditions with simulated loads was implemented using the VTH test rig and building energy modeling to evaluate the microgrid performance. Simulated loads were crafted to optimize performance via simplified energy modeling, which showed that four-unit townhouse homes with peak heating loads of 60 MBH at design conditions were needed to maximize microgrid performance.

Results indicated that this microgrid can operate at COPs between 1.0 and 1.8 across the heating season. The resulting carbon footprint rate of the microgrid was an average of 300 lbm/MWh, which is 25% of the national average MOER of the current electric grid and approaches many 2050 emission targets! This project demonstrated that advanced mCHP technologies integrated with best-in-class electric ccASHPs can operate with only 14% of the net power requirements, reduce electric loads by 27%, reduce installation costs by 43%, and reduce greenhouse gas (GHG) emissions by 47% of fully-electrified multifamily building HVAC&WH systems.

During Phase 2, the project team designed and implemented power integration strategies for PV and EV charging stations. A 13 kW PV array, two dual-pole 40 A level 2 charging stations, and an EV charger simulator were added to the microgrid, and performance data was collected over the 2023-2024 cooling and heating season. This microgrid demonstrated the reduction power consumption that can be displaced for plug loads relative to a fully-electrified scenario while leveraging electric-driven technologies for space and water heating in a cold climate. In addition to providing superior resiliency, the microgrid reduced GHG emissions by 25% relative to the fully-electrified scenario even at operating conditions favorable to ccASHP operation, and demonstrated an overall COP of 1.8.

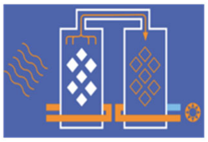
Status

This project is complete. Final reports for Phases 1 and 2 were issued to the utilities participating in UTD in July 2023 and November 2024, respectively. Phase 1 results were summarized in a technical paper presented at the ASHRAE 2024 Winter conference, and public reporting of Phase 2 results is planned at upcoming industry conferences. Results were also communicated directly to industry stakeholders, including building design professionals and hybrid residential HVAC solution manufacturers. EC Power's new PowerHeatPump product leverages the integrated energy system concepts that were validated by the technical development and results demonstrated in this project.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

HeatAmp Adsorption Thermal Heat Pump



Researchers are advancing the development of an innovative, high-efficiency, and robust gas-fired thermal heat pump technology by optimizing, designing, building, and testing a cost-effective alpha prototype burner/boiler and combustion system and integrating it into a complete alpha prototype water heater.

Project Description

The technology being developed in this project is based on a proprietary chemisorption sorption system from HeatAmp Sweden AB. The primary target use is for domestic hot water applications, with options for combined space/water heating or pool-heating.

The fuel-fired heat pump operates on novel adsorption process and system integration that is expected to result in a cost-effective, robust, and scalable appliance design with few moving parts. The Chemisorption unit is compact and efficient and without the corrosion management or sealing requirements of standard absorption machines. The driving force of the technology is a compact gas-fired heater desorbing the refrigerant, with an efficient integrated backup boiler and a fuel-flexible combustion system projected to be compatible with renewable natural gas and/or hydrogen. Desorbed refrigerant heats the buffer tank, then the refrigerant flows to a receiver/evaporator.

HeatAmp's cost-effective thermal heat pump (THP) technology has potential for market transformation by virtue of its high efficiency (projected >33% energy/emission savings vs. standard fuel-fired equipment) and the opportunity for increased reliability and operating life relative to other sorption-type heat-pump technologies.

The goal of this project is to optimize an alpha prototype burner/boiler assembly and then evaluate the technology in an alpha prototype of a complete integrated water heater. UTD is partnering with the Northwest Energy Efficiency Alliance (NEEA), which provided co-funding to this UTD project.

Benefits / Market Implications

This appliance uses ammonia as a natural refrigerant with zero ozone depletion and zero global warming potential, suitable for all climate zones. Additionally, the sorption components are integrated into the tank, reducing thermal losses and safely isolating the refrigerant charge.

By 2030, the US residential fuel-fired heating is projected to be 2.7 Quads/year per DOE's BTO Market Calculator. With a target COPgas of 1.30, this chemisorption heat pump and similarly-efficient products have the potential to reduce US 2030 energy consumption by approximately 830 TBtu/year.

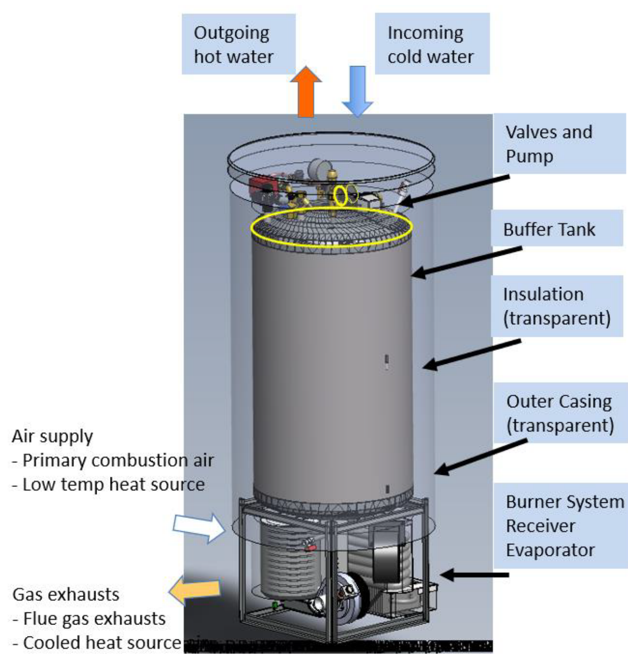
Technical Concept & Approach

Researchers are developing design/specification recommendations for an alpha burner/boiler, including the combustion system (burner, blower, fuel/air mixing, combustion controls) and boiler module (combustion chamber, heat exchangers, venting/flue, overall burner/boiler controls).

The system will be fabricated and evaluated using bench-scale testing and a simulated load test rig to recreate demanding hot water draw profiles consistent with residential use. Performance/emissions/safety testing will be performed (steady state, ramp up/down, etc.), results reviewed, and recommendations for optimized burner/boiler developed.

A final optimized burner/boiler system will then be evaluated within the alpha prototype THP unit. Performance will be analyzed and estimates of manufacturing costs will be generated.

Researchers will compare performance of the THP system to baseline and emerging technologies, as both water heater and whole-house heating systems, using extrapolative modeling to establish the North American technical potential.



Alpha prototype (XBTI-10) CAD rendering

"Gas-driven Heat Pumps with energy efficiencies over 100% will be key for residential users to reduce energy costs and GHG emissions, but also to meet future energy standards. By maintaining heating appliance capacity we ensure the same end-user experience as for current products. UTD has provided and continues to provide valuable technical support for important developments of HeatAmp's technology including 3rd party support from GTI Energy to accelerate the steps needed to commercialize the technology."

- Magnus Ekblad
CEO
HeatAmp Sweden AB

Results

In 2021, the research team prepared a simplified dynamic modeling of the heat pump water heating design to assess its ability to meet standard and extreme hot-water demands.

After an extensive design process, the burner/boiler testing in the lab indicated that an operating efficiency of up to 96% was feasible, though not at full-fire. The project team identified design modifications necessary to reach this target at full-fire. NOx emissions ranged from 3 to 15 ng/J, with modifications identified to assure the 14 ng/J target is met at full-fire.

A calibrated simulation tool was developed and used to estimate performance against the standard simulated use test pattern, leading to recommendations for the full "alpha" prototype design and controls strategy. Burner/boiler system testing completed in 2022-2023 met the targets of 10 kW-13.5 kW firing rate with $\lambda = 1.7$, although the team encountered system challenges with flame stability under certain conditions.

During initial testing of the Alpha GHPWH, the boiler was able to deliver steam at >140°F, however, the team noticed heat losses between the boiler and tank, where the steam delivered to the reactor was less than 120°F. As a result, the salt matrix couldn't achieve the optimization desorption temperature of 90°F in the desorption period. A manufacturing flaw in this prototype was identified as a root cause.

After resolving these issues, multiple tests were conducted to evaluate the direct-fire and sorption cycle efficiency. The team technically supported HeatAmp's team in Sweden and provided recommendations based on the testing and evaluation of the second alpha prototype in this project. Accordingly, HeatAmp made significant design advancements and simplifications, with the aim of improving overall efficiency by minimizing thermal losses and reducing the potential cost of the unit by removing components. These efforts resulted in the fabrication of the Beta prototype.

The project also included a comprehensive review of North America's current codes and standards governing domestic water heating equipment for both commercial and residential applications to identify potential barriers to the commercialization and adoption of Gas Heat Pump Water Heaters (GHPWHs). Several aspects relating to domestic water heating equipment focused mainly on different types of GHPWH were extensively reviewed, including but not limited to testing standards, safety standards, performance and energy efficiency standards, environmental impacts, market maturity status, and operation limitations. Both mandatory standards and voluntary standards are reviewed in this report.

The "Alpha" prototype during laboratory evaluation

Status

The project is complete. Final reports that summarized Phase 1 and 2 results for the utilities participating in UTD and to NEEA were completed in August 2023 and November 2024, respectively. Project results were publicly presented in a technical paper at the 14th IEA Heat Pump Conference in May 2023 and a presentation at the ACEEE Hot Water Forum in March 2024. The project team anticipates that it will continue to provide technical development support to HeatAmp under potential follow-on efforts funded by UTD in 2025.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Technical Support for Residential & Light Commercial Gas Equipment Testing, Performance, and Safety

This project provides technical information and support to technical committees that by consensus develop, refine, or update codes and standards to improve safety for natural gas end users and increase the energy efficiency, reliability, and resiliency of gas equipment and integrated systems.

Project Description

Advanced technologies are often developed to address problems with existing alternatives in the market; however, new technologies are typically evaluated using existing criteria, which may misrepresent performance and necessitate costly engineering redesign that delays market introduction. In many cases, advanced technologies will not be included in codes and standards unless they are updated. When existing technologies advance from lower- to higher-performance levels, there is often a gap in test protocols and rating procedures to capture the full benefit of the advancement. This project helps address that gap.

Through this project, researchers provide technical support to industry groups and professional societies that develop codes and standards by consensus in open technical sessions. Researchers provide analytical test results, laboratory test results, and field test data to develop and improve test methods to more accurately reflect real-world conditions.

Benefits / Market Implications

This project provides information to improve safety for end users and accelerate the use of new advanced gas technologies for space conditioning, water heating, and micro-combined heat and power (mCHP).

These advanced gas technologies can help utilities meet the goals of energy-efficiency programs while reducing individual ratepayer costs. Other important benefits include:

- Expanding customers' competitive choices of product offerings that can save energy and costs
- Ensuring safe and reliable operation of gas appliances
- Developing accurate and consistent equipment ratings for consumers to compare cost, efficiency, and the environmental impact of available products and fuel choices, and
- Expanding choices of product offerings that support ZNE initiatives.

Target markets impacted by this project include current equipment such as furnaces, water heaters and mCHP, as well as new cost effective, high efficiency, gas-fired technologies for all residential and commercial space-conditioning markets, such as gas-fired heat pumps.

Technical Concept & Approach

The project team provides technical information to support the development and consensus review of water-heating and combination system energy codes, as well as methods used to model the performance of new technologies.

In 2024, examples included:

- A project team member participated on the technical committee of NFPA 2,Hydrogen Technologies Code.
- A team member participated on the technical committee of NFPA 54/ANSI Z223.1,National Fuel Gas Code, 2024 Edition. The team participated in reviewing, commenting, providing suggested edits and, voting as applicable, over seventy-five proposals.
- A team member chaired the committee of CSA/ANSI Z21.40.4,Testing And Rating-Fired,Pump Appliances.team

provided technical contributions to relevant safety and performance requirements and, methods of test and rating procedures,the standard issued in late 2023 in time for a number of emerging gas-fired heat pump products. Team members continue to chair the CSA/ANSI Z21.40.1 and Z21.40.2 committees, concerning the safety and performance of heat and work-activated gas-fired air-conditioners and heat pumps, to modernize these standards to reflect emerging technologies.

- The team worked in 2023 within the newly formed ICC H2 Working Group to influence the full 2027 cycle of "I-Codes", providing up-to-date research/data to the newly formed ICCWorking Group, informing the 2027 Code Cycle for the Fire, Building, Mechanical, Fuel Gas, Residential codes, with a focus on safety and performance impacts.worked was successfully completed and the team continues its leadership within multiple hydrogen-related technical committees within CSA Z21/83 umbrella of safety and performance standards for combustion components and equipment.

Results

Project team members have supported technical discussions on various committees, such as:

- ASHRAE Technical Committee 4.3, *Ventilation Requirements and Infiltration*
- ASHRAE Technical Committee 5.10, *Kitchen Ventilation*
- ASHRAE Technical Committee 6.1, *Hydronic & Steam Heating Equipment and Systems*
- ASHRAE Technical Committee 6.3, *Residential & Light Commercial Forced Air Heating and Cooling Systems*
- ASHRAE Technical Committee 6.9, *Thermal Storage*
- ASHRAE Technical Committee 6.6, *Service Water Heating Systems*
- ASHRAE Technical Committee 6.10, *Fuels and Combustion*
- ASHRAE Technical Committee 8.03, *Absorption and Heat Operated Machines*
- ASHRAE Standards Project Committee 40, *Methods of Testing for Rating Heat-Operated Unitary Air-Conditioning and Heat-Pump Equipment*
- ASHRAE Standing Standards Project Committee 41, *Standard Methods for Measurement*
- ASHRAE Standards Project Committee 118.1, *Method of Testing for Rating Commercial Gas, Electric and Oil Service Water Heating Equipment*
- ASHRAE Standards Project Committee 124, *Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances*
- ASHRAE Standards Project Committee 154, *Ventilation for Commercial Cooking Operations*
- ASHRAE Standards Project Committee 155p, *SPC 155P Method of Testing for Rating Commercial Space Heating Boiler Systems*
- ASHRAE SSPC 154, *Ventilation for Commercial Cooking Operations*
- Proposed New Standard, Z21.85 - *Alternative Connection Means for Use in Gas Appliances*
- Proposed New Standard, Z23550 - *Safety and control devices for gas and/or oil burners and appliances*
- *Meeting of the Z21/Z83 Technical Committee and, CSA Gas Appliances & Related Accessories Technical Committee Joint Meeting*
- Proposed New Standard, Z23551-4 - *Safety and control devices for gas burners and gas-burning appliances*
- ANSI Z21.40:23/CGA 2.94:23 DRAFT STANDARD, *Performance Testing And Rating Of Gas-Fired, Air Conditioning And Heat Pump Appliances*
- New Edition - ANSI Z21.20-2014 - CAN/CSA C22.2 No. 60730-2-5-14 - *Automatic electrical controls for household and similar use control systems,* and
- NFPA 54/ANSI Z223.1, *The National Fuel Gas Code.*
- *NFPA 2, The Hydrogen Technologies Code.*
- *NFPA 54/ANSI Z223.1, The National Fuel Gas Code, 2024 Edition.*
- *CSA/ANSI Z21.40.4, Performance Testing And Rating Of Gas-Fired, Air Conditioning And Heat Pump Appliances.*

Status

Representatives participate in relevant technical committees and prepare conference papers and presentations of value to the HVAC and built environments community. Members of the team have joined a steering committee to guide CSA's future strategy/approach to adapting standard and certifications to H2-ready combustion equipment/components. Phase 4 efforts are in progress.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

CleanO2 CarbinX™ Carbon Capture

Research is further advancing the performance and applicability of CleanO2's CarbinX distributed carbon capture device by extending operation to higher-efficiency condensing appliances. This builds on prior product development research support including to validate claims of avoided CO2 emissions, and average cost savings and energy savings.

Project Description

This project is advancing the performance of CleanO2's CarbinX™ latest available carbon capture device by validating carbon capture and heat-recovery rates in a laboratory test stand and identifying potential areas for further technical refinement.

This project builds on efforts since 2018 by the research team partnering with CleanO2 under additional separate funding provided by UTD members, including to test CleanO2's CarbinX v. 3 unit and provide technical development support. While the intent of the first phase of this UTD project was to investigate CleanO2's next-gen CarbinX v. 4 unit, the development of that unit was delayed and therefore extended laboratory testing was instead conducted on an earlier prototype to identify potential areas for product improvement, such as: addressing the possibility of moisture accumulating in the reaction chamber; optimizing the reaction chamber to maximize carbon capture; adding sensors to indicate progress or completion of reaction process; and easing the process to load the caustic potash and extract the pearl ash.

CleanO2's latest CarbinX v.4 system will address some of these areas by: adding powered dampers on the CarbinX inlet vent ducting to alternate flue-gas and fresh-air intake; adding temperature sensors and controls to automate the operation of the dampers; and adding wireless communication to notify the building owner of the reaction progress - - amongst other improvements. The addition of powered dampers to the venting extends the compatibility of the CarbinX v. 3 to condensing appliances by introducing a new operating mode for drying the chemical inside the reaction chamber.

The current Phase 2 of this project is focusing on advancing CleanO2's next-gen commercial carbon capture unit (CarbinX v. 4) to apply to higher-efficiency condensing appliances. The team seeks to demonstrate in a laboratory setting carbon capture efficiency ≥50% and payback period =5 years. This will enable condensing boilers, water heaters, or other condensing appliances, to provide high-efficiency and low-carbon operation to residential and commercial building operators. UTD is partnering in this effort with the Propane Education & Research Council (PERC), which is providing co-funding to this UTD project.

Benefits / Market Implications

Implementing distributed carbon capture technology will reduce greenhouse gas (GHG) emissions in the residential and light commercial/industrial markets while retaining customer choice options to use gas in zero net energy buildings. The team is targeting a 50% reduction in GHG emissions compared with the ~15% which has already been demonstrated. An eventual goal may be to approach 100% GHG emissions reduction for future technology beyond the next-gen unit.

This product will save consumers money through fuel savings and pearl ash rebates with an estimated payback period of 4.8 to 7.5 years. The project has a specific goal of a 5-year payback period without a carbon levy, although the

Experimental test stand with carbon capture unit (left), water-heater simulator (middle), and recirculation loop (right).

Interior of reaction chamber after operating unit for a few hours with ~25 kg of caustic potash

"UTD and its utility members have been essential partners in advancing our carbon capture technology. Their support has helped us to develop a cleaner, more sustainable energy future. We are grateful to their partnership and look forward to continued success in carbon capture and utilization with our disruptive technology along with help from our partners at GTI Energy.

- Jaeson Cardiff
Chief Executive Officer
CleanO2 Carbon Capture Technologies Inc.

technology may also reduce carbon levies owed by customers in jurisdictions that have a carbon-pricing program.

The primary target markets impacted will be residential and commercial buildings (e.g. multifamily, assisted living, hotels, schools, offices, shopping malls) and commercial boilers >250 MBH and <1,500 MBH.

Technical Concept & Approach

The current efforts will study and investigate different technologies for improving the carbon capture efficiency and waste heat recovery effectiveness of CleanO2's CarbinX v. 4 prototype. Scaling of the carbon capture unit for larger fuel-fired appliances will also be addressed. The following tasks will be performed:

Design Optimization of Carbon Capture Reaction Chamber

The team will develop a numerical model of CleanO2's cartridge-style reactors for CarbinX v.4 using design and performance data provided by CleanO2 and optimize reactor design for improved flue gas flow path and carbon capture efficiency.

Design Optimization of Waste Heat Recovery System

The team will perform modeling of hot water demand for standard installation sites of CleanO2's technology and determine baseline waste heat recovery of current CarbinX storage tank configuration. Various tank designs and configurations will be investigated to optimize waste heat recovery while minimizing the CarbinX footprint.

Advanced Simulated Use Testing of CleanO2's Latest CarbinX Prototype

The team will complete baseline testing of CleanO2's CarbinX v.4 to assess carbon capture efficiency and waste heat recovery using standard draw profiles, such as DOE's Uniform Test Method for Measuring the Energy Consumption of Water Heaters. All testing will be completed with a 500 MBH condensing commercial water heater. Multiple tests will be performed at various water heater turndown ratios to determine effect on carbon capture and waste heat recovery performance and extrapolate findings to firing rates >500 MBH. The CarbinX will be tested with both natural gas and propane combustion and determine any changes to carbon capture rate and waste heat recovery effectiveness and possible implications on payback period.

In coordination with CleanO2, the project team will modify CleanO2's prototype based on their findings in order to evaluate potential improvements to carbon capture efficiency and waste heat recovery.

Results

This project builds upon prior efforts by the research team working with CleanO2 to support its technology development since 2018. CleanO2 made significant commercial progress during 2023-2024, for example by placing a number of current-version units in initial field installations and by showcasing its product for the first time at the AHR Expo, a leading industry trade show, in January 2024.

Recent results under this UTD project included making major upgrades to an experimental test stand to provide more exhaustive testing of the CarbinX units over a variety of conditions. Most of the changes were made to the recirculation/ heat rejection loop, which now allows for more efficient charging and evacuation of air. New temperature-limit controllers were installed on the water-heater simulator and flue-gas venting to cut off gas supply to the burner if temperatures exceed a specified threshold. New gas analyzers were purchased to allow for more accurate assessment of carbon capture rate. Testing of the pitot tubes was completed to ensure accurate measurement of velocity pressure. Multiple shakedowns were performed with the water-heater simulator to test for performance stability.

Final tuning of the CarbinX unit, water heater simulator, and heat rejection loops was completed to confirm stable operation of the burner with the activation of the CarbinX inducer. Multiple weeks of continuous operation of the CarbinX unit has been completed while collecting carbon capture data. Final rounds of testing for the CarbinX unit's carbon capture efficiency have recently been completed.

Status

The team is wrapping up experimental testing under Phase 1 efforts, and a Final Report for Phase 1 is being prepared. Phase 2 has kicked off and is in the early stages of planning. Discussions are currently ongoing with CleanO2 to plan the delivery of a CarbinX v.4 unit for laboratory testing, validation, and further optimization.

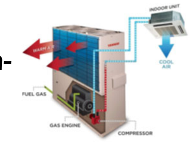
For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD
Utilization Technology Development

Gas Engine Heat Pump Modeling, Testing, and Implementation

This project is refining gas-engine-driven heat pump performance models based on actual field data for variable refrigerant flow systems operating across a range of conditions. These efforts will optimize benefits for end users through more advanced techno-economic assessments, performance validations and enhanced energy models for system designs as well as compliance-based energy simulations.



Project Description

The performance of all air-source heat pumps – including electric- and gas-engine-driven – varies significantly with ambient temperatures. In addition, the complexity and customized design of variable refrigerant flow (VRF) systems make it costly to accurately measure real-time performance and efficiency. As a result, estimates of energy savings are often calculated using simplified energy modeling based on steady-state laboratory data obtained under controlled conditions, rather than actual installed performance.

EnergyPlus™ gas-engine heat pump (GEHP) models were typically based on published electric VRF models adapted to GEHP manufacturer performance data and a limited number of measured datasets. Manufacturers' performance data is typically only available for part-load operation at 60% and above; however, researchers know from previous demonstrations that GEHPs typically operate at much lower part-loads. Furthermore, in some cases the measured field data used for the model was from a single installation, corresponding to a limited range of operating conditions.

Example of a Yanmar Gas Engine Heat Pump being analyzed, with a gas meter to monitor gas consumption

In summary, a more complete dataset of GEHP measured performance data is required to enhance EnergyPlus models and improve their accuracy to better predict energy savings, greenhouse-gas (GHG) reduction, and economic benefits for facility owner/operators, designers, and others.

Recently, a number of GEHP equipment options were also introduced to expand the applications for GEHP and/or VRF systems. This project investigates options such as:

- An AHU Integration Kit that incorporates an expansion valve and controller enabling the VRF system to integrate a non-VRF air handling unit (AHU) in addition to, or in lieu of, multiple VRF AHUs
- The Yanmar Hydrobox and Blue Mountain Energy (BME) Sierra AWS System that transfers heating or cooling from the heat pump VRF system to a facility's hydronic heating and cooling system

This project is being done in collaboration with National Research Council Canada (NRCC) and will validate performance for VRF systems across a range of conditions with the goal to support end users with superior analysis tools and information through:

- Enhanced GEHP energy models using measured performance data
- Validation of new methods for testing for new GEHP performance metrics
- Techno-economic assessments to assess best use of new GEHP equipment options.

Benefits / Market Implications

GEHPs are increasingly cost-competitive with electric VRF systems; recent pricing reduced the incremental cost to $500-$1,000/ton. Equipment options are expected to expand potential applications to include both hydronic or forced-air installations.

This project provides benefits for ratepayers, society, and the environment such as:

- Expanded options for reducing both gas consumption and electric demand response (approximately 10kW reduction in peak electric demand per unit)
- Targeted 20%-40% savings in energy costs, along with lower life cycle costs
- Reduced GHG emissions via high performance end-use gas equipment that is more affordable and more efficient
- Improved comfort in multi-zone facilities compared to conventional HVAC system.

Examples of end-users that can benefit include:

- Multi-zone commercial buildings (offices, schools, retail, etc.)
- Markets with electric constraints and/or high demand charges
- Both new or retrofit installations.

This project will also support commercial building designers and owners/operators who use EnergyPlus software.

Technical Concept & Approach

This project will support the development of enhanced energy models as well as validate new test standards for GEHPs.

Researchers will enhance existing EnergyPlus models by publishing GEHP models developed directly from field data and disseminating the information widely. This task includes collaboration with NRCC to share data, validate performance curves, and approve GEHP models for use in compliance-based energy simulation.

The research team will work with manufacturers and testing agencies to validate new GEHP methods of test and compare these ratings to the measured seasonal performance observed in the field. This effort will provide valuable feedback and insight on how well the new performance standard matches seasonal performance, with the long-term goal that comparable GEHP performance ratings can be directly compared to other HVAC technologies, such as electric heat pump VRF systems.

Technical feasibility and economic assessments will be performed on GEHP options (AHU Integration Kit, Hydro-Box) to determine the potential energy savings of these options, the economic benefit and payback, limitations in performance, and the range of potential applications. This assessment will identify the most promising technologies and application options that warrant further investigation or demonstration. A preliminary technology assessment of current GEHP ancillary products will determine the energy or economic benefits of these options and configurations and estimate the potential market for these applications.

Results

For Phase 1, the project team developed GEHP performance curves based on four GEHP field datasets in both warm and cold climates. The team shared data and ia collaborating with NRCC staff to develop and validate these heating and cooling performance curves with respect to outdoor ambient temperatures and part load operation. In addition, NRCC also supported this effort by monitoring an 8-ton Yanmar GEHP VRF unit installed at their test facility and has commenced data collection.

An ASHRAE technical paper describing the modeling approach and the development of GEHP heating performance curves based on measured field datasets was presented at the 2024 ASHRAE Winter Conference, January 22nd in Chicago, IL.

For Phase 2, the team monitored a Yanmar GEHP with an AHU Integration Kit installed at the Middletown Recreation and Community Center in Middletown, CT, to validate performance, best practices, and economic benefits. Based on preliminary results, the system performance approached the rated GEHP cooling efficiency of 1.0 COPg during design day temperatures of 95ºF. Higher cooling efficiencies were observed during periods with greater part loads and more steady state operation.

Status

The team has completed its analysis of the collected data and is developing the final report.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Commercial Heat Pump Water Heater Field Performance Comparison

Researchers will directly compare the performance of commercial fuel-fired and electric-driven heat pump water heaters in a commercial installation and also via laboratory testing to an applicable ASHRAE standard, to provide end users with validated cost- and energy-savings, help inform customer choice, and advance high-efficiency products.

Project Description

Commercial water heating end users are seeking higher-efficiency equipment options. Both fuel-fired and electric-driven heat pump water heaters promise efficiencies well above 100%, leading to energy and fuel-cost savings and reduced greenhouse gas (GHG) emissions. In recent years, Stone Mountain Technology, Inc. (SMTI) developed and introduced a gas-fired absorption heat pump water heater (GHPWH). Past projects funded in part by the U.S. Department of Energy (DOE), California Energy Commission (CEC), UTD and others have played important roles in advancing SMTI's product development.

Due to differences in the respective technologies, the standard measure of heat-pump performance – Coefficient of Performance (COP) – does not provide a sufficient metric to compare gas and electric heat pumps. While COP is a good measure when comparing traditional technology of the same fuel, it does not provide a useful comparison when evaluating cost savings or GHG emission performance between electric and gas heat pumps.

Researchers will directly compare the performance of commercial fuel-fired and electric-driven heat pump water heaters in a commercial installation and also via laboratory testing to an applicable ASHRAE standard, to provide end users with validated cost- and energy-savings, help inform customer choice, and advance high-efficiency products.

The Tennessee Department of Environment and Conservation (TDEC) is leading the DOE-funded project, through TDEC's Office of Energy Programs. UTD is partnering with DOE, TDEC, the National Association of State Energy Officials (NASEO), the Tennessee Advanced Energy Business Council (TAEBC), and SMTI by providing co-funding to DOE's prime funding. The Propane Education and Research Council (PERC) is also partnering in this project, by providing co-funding to UTD project 1.21.F.

Benefits / Market Implications

Key benefits that GHPWHs provide customers are to save consumers money, save energy, and reduce GHG emissions. Cost savings occur from reduced peak electric demand costs, low gas prices relative to electricity on a per-therm equivalent basis, and overall reductions in energy use. Prior research has shown that total natural gas savings and GHG emission reductions of 16% to 26% (with the potential of up to 53% savings is achievable if the gas heat pump is right-sized) versus conventional water heating technologies. Similar fuel savings are anticipated when fired with propane.

Other important benefits that GHPWHs provide include better cold-weather performance, with ability to operate to -40° F, as well as the resiliency and reliability of the underground gas delivery system. Propane-fired versions provide options for areas not served by gas distribution infrastructure. Gas heat pumps maintain high efficiency, compared to electric heat pumps, even when ambient temperatures decrease.

Indoor indirect water heating tank plumbed in parallel with the existing water heating loop.

New GHPWH product and technologies provide gas utilities and propane distributors with more high-efficiency options to include in their energy-efficiency incentive programs.

GHPWHs can also be beneficial for end users in areas where the electric supply may be constrained, and upgrades to the electric distribution grid may not be feasible within the end-users' timeframe.

The scientific data that evaluates the impact of deploying various types of heat pump water heaters may also aid public dialogue regarding energy efficiency and energy source options.

Examples of gas customers that can benefit include commercial water heating with a high hot-water use (>1,500 gallons per day), multi-family housing, restaurants, hotels, assisted-living facilities, and health and fitness centers.

Heat pump outdoor unit installed.

Technical Concept & Approach

The project will provide measurement and verification (M&V) support for the DOE-funded field demonstration project. Comparable models of both the SMTI Anesi gas-fired heat pump water heater and a commercially available electric-driven heat pump water heater will also be tested in a laboratory, to provide end users with an additional direct performance comparison.

The research team will:

- Develop an M&V plan and specify instrumentation for baseline and field demonstration of one SMTI 80 kBtu/hr GPWH
- Develop an interface for baseline and demonstration data to provide near real-time access to collected data and analysis
- Collect, monitor, and analyze baseline and demonstration data
- Prepare interim and final field test data analysis report for inclusion in DOE reports
- Assist in report development and disseminating results
- Install and test the SMTI gas pump water heater following ASHRAE 118.1 standard test for water heating with natural gas
- Install and test a commercial electric heat pump water heater following the ASHRAE standard test for water heating, and
- Provide energy and cost-saving analysis based on testing compared to traditional technology.

Results

The facility that initially planned to host this project ultimately declined from participating in this field study, which resulted in a project delay. A new host site, Kings University in Bristol, TN was identified and onboarded. An engineering analysis was performed to validate the applicability of installing the heat pump, and a measurement and verification plan has been developed.

In 2024, site visits were performed to verify M&V installation points, a M&V plan was finalized after addressing and confirming install ability at the site, and a M&V installation information was provided to the contractor for a revised quotation.

Status

Both heat pump water heaters have been commissioned and are operational. Measurement and verification data loggers and other instrumentation have been installed at the host site, and comprehensive performance data is being generated for analysis. Data collection and analysis is expected to continue through 2025.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Ionic Liquid Absorption Heat Pump for Commercial Water Heating

Researchers are designing and demonstrating in a laboratory environment an early prototype of a low-cost, ultra-high-efficiency gas-fired commercial heat pump water heater with a novel semi-open absorption cycle that uses a benign ionic liquid and provides integrated latent cooling to further maximize efficiency.

Project Description

In the water-heating industry, significant attention has been given over the past decade to the development of high-efficiency water heaters for residential buildings. Much of this attention has concerned the tankless water heater, electric heat pump water heaters, and even the development of gas-fired heat pump water heaters (GHPWHs). However, hot water in commercial buildings has not received similar levels of attention, where despite greater numbers of residential water heaters sold per year (with approximately 36 times as many residential storage water heaters sold as commercial storage water heaters), commercial buildings can consume 10 to 100 times the hot water as a typical home. Prior research efforts in UTD project 1.16.I demonstrated the potential for high-efficiency GHPWHs using an ammonia/water closed absorption system, which has performance advantages but also some challenges by using ammonia.

UTD project 1.21.I advances a different technology for commercial hot-water applications – a novel semi-open absorption cycle (SOA-GHPWH) that uses a benign ionic liquid and which provides integrated latent cooling to further maximize efficiency. UTD is partnering with the University of Florida (UF), their partner Micro Nano Technologies, and with potential support from a leading commercial water heater OEM. All experimental work will be conducted with natural-gas-fired regeneration; however, findings should be directly relevant to propane-fired regeneration as well. The Propane Education and Research Council (PERC) is providing co-funding to this UTD project.

Test stand construction starting in May 2024

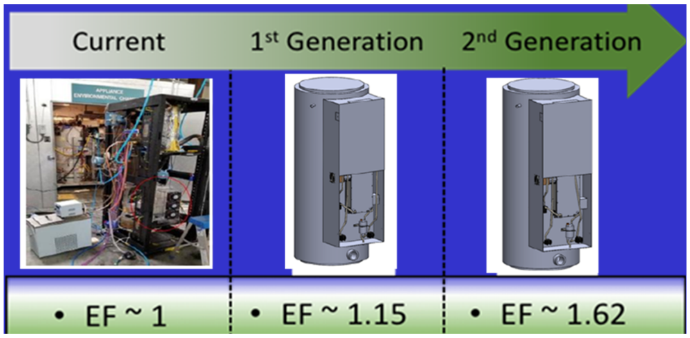
The heat pump design being developed in 1.21.I has several potential advantages over the closed ammonia/water GHPWH. First, the system operates at the atmospheric pressure, thus the lack of up to ~400 psig pressure allows simpler designs and low-cost components – with only small hydrostatic pressures and thin heat-transfer walls, enabling inexpensive low-thermal-resistance materials such as polymers to be used. Second, an inexpensive non-hermetic plastic solution pump is used.

In summary, the objective for this project is to design and demonstrate in a laboratory environment an alpha working prototype of an SOA-GHPWH targeted for commercial water heating applications. The project team will leverage the unique benefits of the GHPWH design, including a) environmentally-benign and safe working fluids, b) supplemental latent cooling via dehumidification, and c) the potential for long-term reliability and avoidance of costly corrosion-resistive materials and approaches. Research work in project 1.21.I is being coordinated with the work in project 1.20.I, which is applying this technology to rooftop units.

Benefits / Market Implications

The benefits that GHPWHs provide customers are primarily higher resiliency and efficiency, and reduced operating cost due to: reduced peak electric demand costs and total energy consumption; the resiliency of gaseous-fuel vs. electric-driven energy delivery; superior cold-weather performance; and lower purchased energy costs on a per-therm equivalent basis. The development of an SOA-GHPWH can provide another robust and attractively-priced fuel-fired GHPWH option for commercial end users.

The current product focus is a 145 kBtu/hr output system with a 100 gallons storage tank and a firing rate of 90 kBtu/hr, which allows this product to have the highest hot-water output in the market while only using a one-half-inch gas connection. The project team's simulations suggest that this GHPWH will have a recovery rate of 220 gallons per hour at 70°F rise. For a system installation with integrated controls, including a conventional water heater in series to support peak demand, the projected economics are very attractive.



Conceptual rendering. Source: University of Florida

For a 5,000 gallon-a-day hot-water demand – typical for full-size restaurants or mid-size hotel, dormitory, or multifamily buildings – the SOA-GHPWH system is projected to reduce natural gas consumption by 5,655 therms (42%), with associated annual operating cost savings of $6,390 ($1.13/therm assumed). The projected cost of the GHPWH system in this example, including the peak demand conventional water heater is $11,950. Thus, the simple payback period is estimated to be 1.9 years. Note that this estimate is conservative with respect to the project, as the GHPWH operation will be more efficient in hot/humid climates and the economic benefit of supplemental dehumidification, reducing overall site HVAC operating costs, will further improve the value proposition.

Technical Concept & Approach

A research team will develop a final design for the SOA heat pump module, including the desorber/condenser, conditioning equipment, combustion system, and other components. The module will then be fabricated and tested.

Researchers will perform a battery of steady-state tests, varying stored water and ambient air dry bulb/dew point temperatures for performance mapping. Ultra-low NOx performance will be demonstrated with simulated thermal loads. Cycling tests will be performed using extended draw sequences, varying the magnitude and clustering of hot-water draws per prior field observations. An optimized control strategy will be identified per cycling tests.

A manufactured cost estimate of the heat pump module will be developed and researchers will identify areas for cost reduction in subsequent efforts.

Results

In 2021, the project team continued to refine the product definition and consider codes/standards implications and controls specification options. In addition to defining the concept for the target application, the effort leveraged a parallel commercial HVAC effort using a hospital application to consider deep-dehumidification applications (defined as a separate sensible/ latent air-conditioning version) and a compressor-less HVAC version.

The team finalized the design of the desorber, which included shifting the type of overall heat exchanger (HX) design. In addition to these desorber design exercises, the team continued to solicit and evaluate custom premix burner options in open-air testing from multiple burner manufacturing partners.

Final simulations of the desorber design were performed to screen for potential hot spots and other issues. A package of drawings was prepared, bids were secured from local fabricators, and a fabricator was selected.

The desorber setup and testing were completed (with a water boil test and using peanut oil to simulate ionic liquid). These tests yielded results that were used to calibrate parallel computational fluid dynamics (CFD) modeling and a general analytical approach to heat transfer estimated. Results from peanut oil were analyzed and extended to the ionic liquid. Finally, a Multiphysics CFD simulation was performed, where gas phase (flue gases) and shell-side fluid (peanut oil / ionic liquid) were combined for the first time.

Using the data collected, the local heat transfer coefficients were estimated using standard non-dimensional analysis yielding an estimated Nusselt number of 46.3 and HTC of 315 W/m2K, within a 5% error from experimental results.

Progress and results to date from this project were communicated in technical papers that were delivered at the 14th International Energy Agency (IEA) Heat Pump Conference held in May 2023 in Chicago, IL, USA.

In 2024, the team finalized the experimental test plan, with key details settled including a) the nature of the controls and physical interface, b) the optimal approach for steam heating the desorber with steam trap condensate control, with options including open versus closed loops, and c) the wide range of test points to be evaluated. The final test plan was updated in May as the team finalized purchasing key components and hardware.

The project team has been preparing a laboratory facility to accommodate the wide range of simulated process air conditions needed at the larger volumetric flow rates. Installation of the test stand has begun.

Status

Construction of a laboratory test stand is ongoing. The project team expects to soon receive the prototype system from UF.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

Hydrogen Blending End-Use Performance and Safety Field Demonstration

Gas utility personnel and energy researchers are partnering to demonstrate at a utility's training facility the safety, technical, and performance implications of using hydrogen-enriched natural gas in common equipment such as HVAC, water heating, cooking, and hearth products so that end users can safely reduce GHG, NOx, CO and other emissions.

Project Description

Blending hydrogen into natural gas for use by existing gas appliances has the potential to reduce NOx and CO emissions into the home while also reducing GHG emissions (depending on the source of the hydrogen). This project seeks to demonstrate the safety and efficacy of a hydrogen/natural gas blend for a variety of end use products including HVAC, water heating, cooking, and hearth products. This project will test multiple retrofit and mitigation strategies. Efficacy will be measured by:

- End user safety and performance
- Estimates of decarbonizations potential
- Reductions of NOx and CO emissions

The results of this analysis will be packaged into best practices for field service technicians during utility blending programs. Outreach will be provided to builders, equipment manufacturers, and code authorities. Best practices will be issued for equipment commissioning for field installers/technicians during utility blending pilots. A methodology to estimate customer decarbonization potential in utility territories will be developed and implemented. Findings will be showcased with trade allies, builders, policy/standards, and other stakeholders.

Benefits / Market Implications

Hydrogen blending into gas grids for use in buildings and industry has distinct benefits:

- It can provide a significant decarbonization/energy storage "win" in the near-term
- This scale up of hydrogen demand further stimulates scale up of hydrogen supply and distribution technologies
- Low concentration hydrogen blending can be a stepping stone towards 100% hydrogen distribution, which can contribute to net zero emissions by 2050.

Hydrogen blending research is being conducted worldwide. Many utilities have recognized the benefit of adopting hydrogen into natural gas pipelines and, with significant efforts on their parts, have initiated hydrogen blending in the field. While other countries have embarked on hydrogen/natural gas blending pilots (such as in the UK, Germany, or the Netherlands) this is only recently happening in the US and Canada, prompting governments and stakeholders to drive the development of safety/performance standards for gas-fired appliances, including the identification of suitable hydrogen limits on existing equipment.

This UTD demonstration project can catalyze similar developments in North America, while serving to address research gaps and develop best practices for in-field equipment commissioning in blending pilots, by industry outreach and by expanding the dataset of operating existing/standard end use equipment on hydrogen blends. This is needed in part since the design of combustion devices used in North America can often differ from those used in Europe.

Appliance Samples

Technical Concept and Approach

This effort will focus on assessing the impacts on common end-use equipment that are lightly maintained (i.e., in residential or light commercial building applications). Broadly, this project concerns fuel-fired equipment that are inside of the scope of typical efficiency programs (e.g. the EnergyStar® program) with specifications for residential and commercial-sized equipment. Physical testing will focus largely on residential-type equipment, however decarbonization modeling, best practices development, and outreach will concern the full range of building-owned end use equipment.

This project will focus on existing equipment and addressing technical gaps in product development, field servicing, utility training, and stakeholder education, in order to: expand this emerging dataset for a wide range of equipment types at a controlled demonstration for short-term and long-term effects; support the momentum behind utility blending pilots with development of best practices and mitigation techniques; and engage a growing group of multiple stakeholders through in-person and media pathways (e.g. OEMs, builders/contractors, utilities, codes/standards bodies).

The hydrogen blending test site will occur at a utility-owned demonstration site located in the greater Las Vegas region. Under this project, a proposed solar panel-coupled Polymer Exchange Membrane (PEM) electrolyzer with the hydrogen generation capacity of 2 kg/day is going to be adopted to generate and blend hydrogen into the natural gas system onsite. The field testing at a Southwest Gas demonstration site will select 30 representative appliances from the market to conduct hydrogen blending research.

Simulated Neighborhood at Demo Site

Equipment test rigs identified for this project include:

- Four automated test stands will operate and collect long-term and short-term data from: central warm-air furnaces, wall furnaces, storage-type water heaters, and decorative gas appliances
- Four manual test stands will operate and collect short-term data only from: indoor cooking appliances, dryer/indoor hearth products, space heaters, and outdoor cooking/patio heating appliances

Dataloggers and Process Controllers

Results

The project team developed and reviewed safety documentation in preparation for testing, including the Blended Hydrogen Field Demonstration Plan, the Manual Test Stand Design and Protocols, the Automated Test Stand Design and the Protocols, and the Preliminary Job Safety Analyses for all test stands. The Blended Hydrogen Field Demonstration Plan will for example involve both short term (manually operated) and long term (automated) testing of residential-type equipment with hydrogen blends.

The team completed the design of the test rigs and prepared a Bill of Materials for each rig. Prospective models have been identified for each of the 30 appliances to be tested.

In 2024, the team provided feedback to SW Gas on potential site infrastructure upgrades, including power, ventilation, gas piping, drainage, and the logic scheme for hazard alarms and automated test stand controls.

The project team used the 2024 Winter AHR Expo to meet with a range of prospective equipment partners. Through this engagement, and separate engagements with cooking appliance, lighting, and miscellaneous outdoor appliance partners, the project team has a full set of “first wave” appliances identified. The team has received these appliances.

Status

The team has completed assembling the system controls/data collection items for pre-shipment check out. Preparations are being made with the host site and UNLV to execute the test equipment installation and commissioning, provided that the above criteria are met.

For more information:

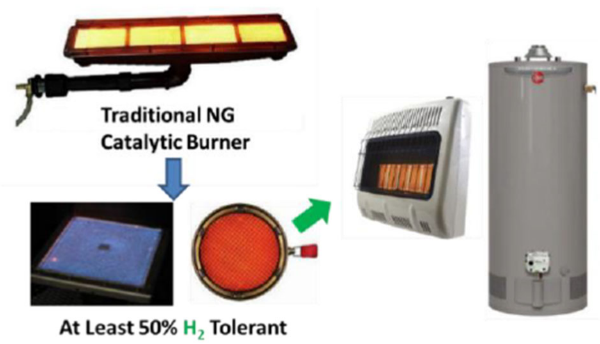
Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Fuel-flexible Ultra-Low NOx Catalytic Burners for ResCom Appliances

Researchers are developing, testing and demonstrating catalytic gas burners to use a blend of hydrogen and natural gas with up to 50% hydrogen, while achieving low NOx emissions. These advanced burners will enhance the safe, economical operation for end users and reduce GHG emissions by using fuels that contain more hydrogen.

Project Description

This project is developing and demonstrating fuel-flexible hydrogen-natural gas low-cost catalytic combustion gas burners for residential and light commercial applications that can accommodate up to 50% hydrogen while achieving NOx emissions superior to the current state of the art. Specific goals for this project are to demonstrate stable operation while accommodating fuel flexibility of at least 0-50% hydrogen, demonstrate at least sub 10 ppm @ 3% O_2 NO_x emissions, and quantify performance of the burner operating on different fuel blends.



Improved Catalytic Burners can provide Fuel-flexible Operation

Benefits / Market Implications

The primary target markets impacted will be residential gas water heating and furnace markets (over 61 million households in the US and Canada) and other domestic heaters with heating loads of less than 40,000 BTU/hr (outdoor heaters, etc.). Secondary target markets may include food service combustion equipment, including range top burners and ovens, and light industry heating devices.

Project success will have multiple benefits including:

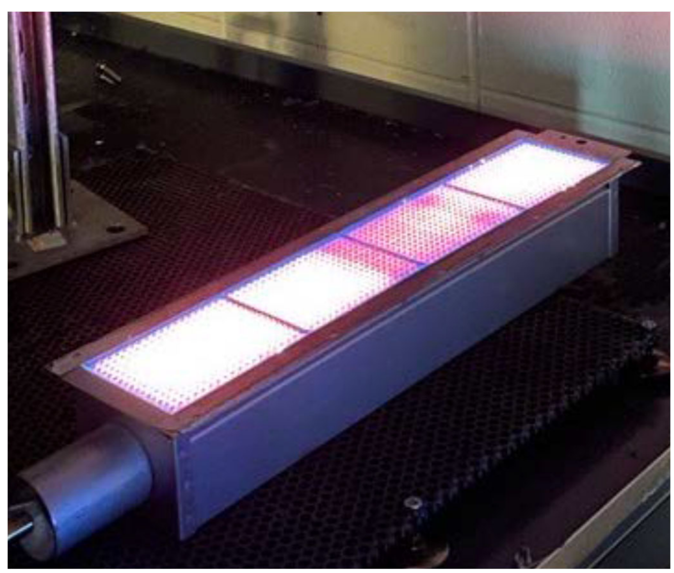
Saving consumers money: Hydrogen-natural gas burners would expand customer's competitive choices of product offerings (including fuel options from natural gas to H2 blends).

Expanding fuel flexibility of domestic combustion appliances: Ensuring safe, reliable, and resilient operation of end user's equipment and energy delivery systems allows fuel flexible gas burners to come to market.

Achieving superior environmental performance:

- Reduction in GHG emissions beyond current Ultra-Low NO_x domestic devices, including storage water heaters and furnaces, by adopting hydrogen in the pipeline natural gas.
- Reduction of NOx emissions under 10 ppm @3% O_2, which meets SCAQMD's Rule 1121.
- Expansion of choices of product offerings that support Zero Net Energy (ZNE) buildings.
- Provide scientific data to assess IAQ impacts of adopting catalytic burners in domestic appliances.
- Expand the integration of natural gas with hydrogen/power-to-gas in domestic, commercial, and light industry applications.

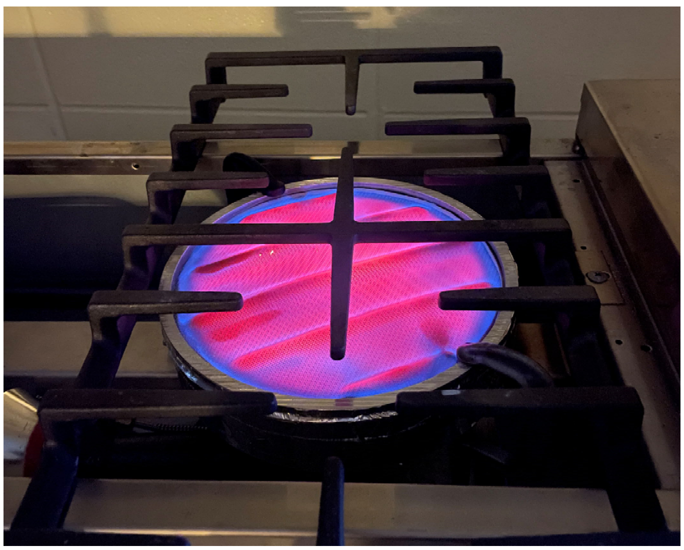
Combustion applications are the major appliance types for domestic water and air heating. For example, 32% of the domestic natural gas in California is used for space heating and 59% for water heating. Currently, more than 80% of space heating appliances and more than 90% of water heaters in California are fueled with natural gas.



Burner Testing, Rectangular Burner

As decarbonization efforts across North America and Canada, adopting H2-tolerant burners with Ultra-Low NO_x performance is of great interest to both gas consumers and utilities.

Adapting natural gas/propane catalytic burners to natural gas/hydrogen mixtures will assist energy transition to renewable hydrogen in residential and light commercial applications. A fuel flexible burner (up to at least 50% H2) which can accommodate varying fuel blends will aid the industry transition as the amount of hydrogen that can be manufactured and injected varies. Over 61 million households in the US and Canada would likely benefit from this alternative option of fuel flexible Ultra-Low NO_x device. This project may also help launch a key new product supplier and thus expand consumer choices for Ultra-Low NO_x combustion appliances. The research is also expected to help gas utilities achieve their Scope 3 GHG reduction goals, while manufacturers and consumers meet strict NO_x emission regulations (e.g., SCAQMD Rule 1121).



Burner Testing, Round Prototype Burner

Technical Concept & Approach

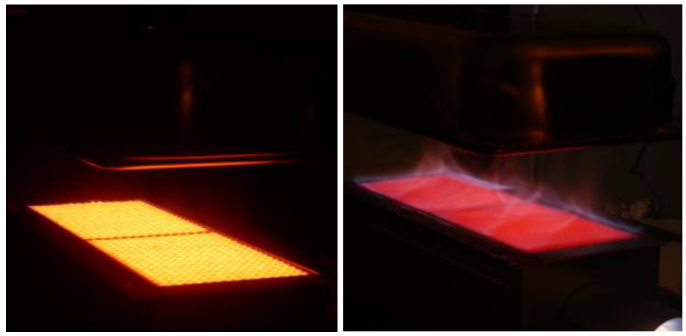
This project is broken down into three sequential tasks.

Investigate Prototype Burner H2 Tolerance levels

Conduct tests on at least five current off-the-shelf catalytic burners on various H2 blending levels to identify the tolerance levels of existing natural gas catalytic burners and examine combustion performance (NOx, CO, THC emissions, efficiency, etc.).

Optimize and Manufacture Prototype Burner

Down-select 2-3 of the most promising tested burners and work with manufacturers to evaluate potential burner re-design or optimization to better accommodate H_2. Manufacture and test the fuel-flexible burners (up to 50% H_2) to meet the sub 10 ppm @ 3% O2 NOx target.



Square burner with Natural Gas (left) and 60% H_2 (right)

Adjust and Test the Prototype Burner in Simulated Appliances

Install one or more optimized burners into a storage water heater and a room furnace. Evaluate the appliance performance and conduct further optimization if necessary.

Results

The literature review and burner technology review has been finished. The project team has collected/purchased a wide variety of catalytic burners from leading North American and global manufacturers. They have also partnered with UC Irvine and conducted burner testing using methane/hydrogen gas mixtures with 10%, 20%, 30%, 40%, 50% and 60% hydrogen. The team finished individual burner testing and burner in appliances (water heater, space heater) testing. The report is being drafted.

Status

The project team is finalizing data analysis and working to complete the final report.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

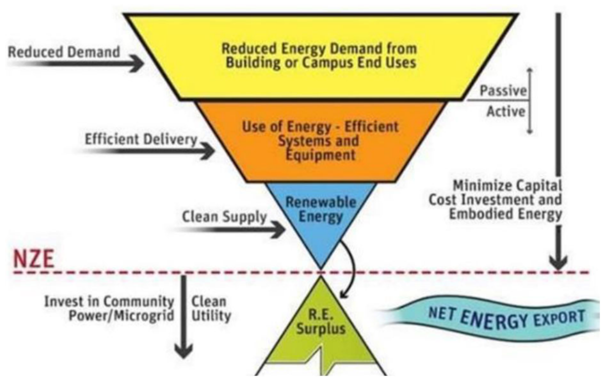
UTD
Utilization Technology Development

Deep Energy Customized Affordable Retrofits of Building Envelopes and Mechanicals

Researchers are advancing technologies that can rapidly integrate highly innovative building envelope improvements with next-generation HVAC equipment retrofits to reduce GHG emissions by ≥50%, while providing significant operating cost savings for homeowners, multi-family residences, income-eligible housing, and others.

Project Description

While much greater use of renewable natural gas, hydrogen generated from renewable energy, and other initiatives are key methods to support decarbonization efforts, whole-building decarbonization approaches will be most impactful if they first reduce energy demand through improved passive building envelope measures, especially when coupled with very-high-efficiency next-generation mechanical systems to efficiently use and deliver energy through the building. The image below illustrates one recommended priority of efforts to decarbonize buildings.



Decarbonizing buildings for net zero energy (NZE) Source: Affiliated Engineers, Inc.

The goal of this project is to advance the development and rapid deployment of innovative residential building envelope improvements coupled with directly-integrated next generation, high-efficiency space conditioning equipment to reduce energy use. Improvements will be developed and demonstrated in the laboratory and in field installations using multiple innovative methods. UTD is partnering with a number of entities, including providing co-funding to prime-funded contracts from the New York State Energy Research and Development Authority (NYSERDA) and the State of Illinois Environmental Protection Agency (EPA), as well as partnering with Hydronic Shell Technologies (HST) and Navien, Inc.

In Phase 2 the team will perform additional modeling and validation of HST's mechanical distribution system for space conditioning applications (which can tightly integrate with a retrofitted or new building envelope), test Navien's new Hydro-furnace low-load single-family mechanical system retrofit and develop an integrated gas-fired HVAC pod concept with space conditioning ventilation and potentially battery electric storage.

Benefits / Market Implications

Successful commercialization and deployment of the technologies being developed in this UTD "DECARB-EM" project will have a transformative impact on residential energy use. Customers will realize significant cost savings by reducing energy use, while GHG emissions will also be significantly reduced.

The primary target markets impacted will be buildings such as: single-family residences, or low-rise multifamily (e.g. 3 floors), or mid/high-rise multifamily residences (e.g. >3 floors), or income-eligible affordable housing; located in cold climate applications (generally U.S. climate zones Zone 4 and above); using either hydronic and forced air HVAC, and; primarily built more than 20 years ago (since this is the largest building stock by far).

The target is to achieve a 50% reduction in GHG emissions, with significant operating cost savings through reduced loads, higher part-load efficiencies with next generation gas technologies. This project will also expand customer's competitive choices of product offerings (including fuel options for decarbonization) while also addressing indoor air quality concerns by integrating mechanical ventilation into retrofits.

Technical Concept & Approach

Laboratory testing will validate a novel distribution system for all heating, ventilation, and cooling designed for an exterior envelope retrofit panel being introduced by HST. This technology provides ideal distribution for air-to-water heat pump systems, while addressing indoor air quality concerns by providing mechanical ventilation as part of exterior insulated panel retrofits.

This effort will develop a process roadmap to streamline high performance retrofit panels, minimizing on-site disruption for any deep energy retrofits. Performing retrofits in an exterior-only manner that minimizes occupant disruption and eliminates relocation is critical for mass adoption. To that end, this project will maximize offsite construction with digital support tools so that retrofits can be completed in days instead of weeks, at a more affordable cost.

Design guidance will also be developed to for gas-focused solutions that incorporate building envelope and mechanical technologies to deliver deep decarbonization objectives.

Point cloud image result from lidar scan of multi-family building

The following tasks will be performed for Phase 2:

Low-Load Gas Mechanicals

The project team will test a novel low-load single family mechanical system retrofit, such as the Navien's new Hydrofurnace, capable of low turndown and dual-fuel heating for deployment in deep energy retrofits. Results will be applied to various climate zones and evaluated in both standalone and hybrid dual-fuel scenarios.

Hydronic Shell Cooling Test and Applied Modeling

Validation tests of heat transfer for the hydronic shell mechanical distribution system (hydrobox and radiant convectors only) will be performed, as well as the system's ability to meet various cooling loads and maintain comfort setpoints using environmental chambers with varying sensible and latent cooling conditions. Integrated modeling from selected gas heat pump systems will be develop to model whole-building multifamily retrofits, coupled with results from the hydronic shell system. This will inform gas heat pump design applications for building retrofits with a modeling library item submitted to EnergyPlus.

Gas Mechanical Pods

Working with a commercial partner, the project team will develop an integrated gas-fired HVAC pod concept with space conditioning ventilation and potentially battery electric storage to provide resilience. The mechanical pod concept will be developed for a multi-family form factor and will be designed to work with hydronically delivered energy from a gas heat pump. A techno-economic assessment and design options for gas-fired envelope pod will be one of the deliverables.

Hydronic Shell envelope/mechanical panel

"UTD provided funding to build and test HST's first prototype panel at GTI Energy, validating our concept at a stage where our technology was too early even for most government grants. It's opened doors to new sources of funding and success in several prize competitions, totaling over $400,000 since testing at GTI began. We're now on a clear path to commercialization that's been enabled and accelerated by UTD's support."

– David Goldstein, Founder and CEO, Hydronic Shell Technologies (HST)

Results

Preliminary modeling on an existing 100-unit building in NY has shown over 70% GHG reductions when the hydronic shell is combined with gas heat pump technology. Results of UTD 1.22.E and related technical development work were presented during ASHRAE's Decarbonization Conference for the Built Environment which was held Oct. 25-27, 2023, in Seminar 15 entitled "Façade-Integrated Mechanical Systems for Multifamily Decarbonization Retrofits in Cold Climates". Results of UTD project 1.22.E were also used by HST in its application and successful award in November 2023 to receive a $3 million grant from the Housing Affordability Breakthrough Challenge.

The team completed laboratory installation of the hydronic shell interior wall, conducted testing against "real world" outdoor conditions, monitoring of the insulative properties and thermal capacitance of the interior "masonry wall", conducted analysis of the Lidar scan data of the multifamily building, and collected baseline temperature and water consumption recordings from the tankless water heater that will be the base of a hybrid advanced combi in the single-family home.

The project team installed and commissioned the Navien Hydrofurnace and developed the test plan for its evaluation. Testing operation under Stage 1 load conditions under the test matrix has begun.

Status

The team is finalizing a Final Report which will summarize Phase 1 results, and is working on two major tasks in Phase 2. First, they are working to complete the Navien testing, performance analysis, and evaluation of the Navien Hydrofurnace performance for residential applications. Second, they are beginning testing of the hydrobox and will evaluate hydrobox performance using the Virtual Test Home approach.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Safe Use of Hydrogen in Buildings

Researchers are developing experimental test data and analytical information to help inform the safe use of hydrogen blends in residential and light commercial appliances, such as hydrogen's potential propensity (in blends with natural gas) to leak from existing building gas distribution systems and appliances, and potential detonation risks.

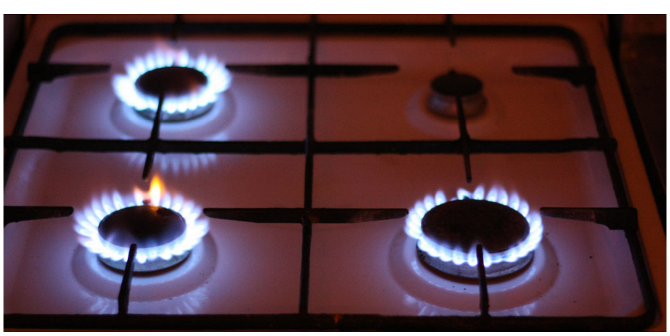
Project Description

Hydrogen, as a decarbonization means, offers only limited opportunity for GHG emissions reductions at low blends (e.g., up to 12% GHG emission reduction with 30% H2). The carbon reduction potential of hydrogen is reduced further if it is not generated from clean energy sources, if the appliance efficiency is reduced, or if its leak rate is significant in the existing gas infrastructure.

There are ongoing efforts in the industry and the academia to quantify preferential hydrogen leakage. Even if hydrogen blends up to 20-30% are permitted in buildings (currently it is not under NFPA 54), to achieve decarbonization goals of greater than 7-12% on the fuel side, higher concentrations of H2 will be needed. It is well understood that 100% H2 appliances and gas distribution systems need special design considerations and that appliances operating with low blends likely do not need many changes. However, the transition from where no changes are necessary to where significant changes are necessary is not well defined.

This project seeks to enable broad deployment of hydrogen-blended gas by proactively addressing consumer and regulator concerns about its safe use in buildings. To help achieve this, this project will characterize the propensity of hydrogen (in blends with natural gas) to preferentially leak from existing building gas distribution systems and appliance gas handling subsystems. Additionally, this project aims to address barriers for safe use of higher hydrogen blends (>30%) in Res/Com appliances.

Phase 2 specifically investigates questions about increased ignition hazards associated with low-medium hydrogen-natural gas blends as well as possible mitigation strategies.



A gas range is one appliance that has been shown to be susceptible to flashback and theoretical studies have raised a concern about detonation risk with blends above 45% H2 by volume

Benefits / Market Implications

This project will respond to growing interest and concerns about the use of hydrogen in buildings. As global efforts to revise codes and standards increase to enable the safe use of hydrogen in buildings (e.g., CSA formed a committee to enable 100% hydrogen use in appliances), this project will provide timely scientific data and information to help shape how hydrogen's use will be enabled or restricted in the near future.

The primary target markets impacted will be:

- Those served by low-pressure gas distribution systems (5 in wc – 2 psig), including low-rise residential, multi-family, and small commercial buildings.
- Appliances utilizing premixed combustion systems including gas heat pumps, mCHPs, tankless water heaters, condensing boilers, and ultralow NOx equipment.
- Hydronic and forced air installations.
- Gas-grid supply-constrained markets

Secondary target markets may include large commercial and industrial buildings served by high-pressure gas supply (>5 psig) and large commercial and industrial premix burners.

The development, distribution, and utilization of low and carbon-free hydrogen, produced from clean power-to-gas and methane reformation with carbon capture schemes, respectively, is an important strategic area for society to meet ambitious long-term decarbonization goals.

To that end, society must look beyond small-scale hydrogen blending demonstrations (typically limited to 5-10% H2) to achieve deeper GHG reductions. However, the use of higher concentrations of hydrogen inside existing buildings and appliances comes with additional questions and concerns. To permit even up to 20% of hydrogen in buildings would require building code revisions (e.g., NFPA 54 – National Fuel Gas Code), and none of the current appliance standards under ANSI Z21 series consider hydrogen specific requirements. This project addresses some of the current knowledge gaps about hydrogen leakage from building gas distribution systems, appliances, as well as potential new requirements in appliance standards for certification for hydrogen operation.

Technical Concept & Approach

The project will investigate the propensity of hydrogen to preferentially leak from blended gas in low-pressure gas distribution systems and appliance gas line connections. Going beyond the distribution system, the study will investigate the potential and risks for leaks inside the appliances, which could pose special risk due to being enclosed and potentially exposed to high temperatures and sparks. In a parallel task, the project team will investigate increasing detonation risks as the level of hydrogen blend increases for use with Res/Com combustion systems.

Tasks for phase 2 include:

Literature Review and Theoretical Assessment

The team will perform a background literature review on hazardous area classification, control, and mitigation theory. Based on the findings of this review, the team will conduct theoretical calculations to determine thresholds for ignition from common sources, such as electrical equipment, in an accidental fuel release. The objective is to identify knowledge gaps and best practices for determining the increased risk of hydrogen enriched natural gas.

Empirical Assessment, Prediction, and Mitigation of Fire Risks

The team will perform an empirical assessment using laboratory experiments and/or detailed numerical simulations to investigate risks and mitigation strategies for indoor spaces. Specific objectives for this task will include:

- Quantification of ignition probability after a fuel release indoors with increasing concentrations of hydrogen in natural gas and typical sources of ignition (such as lights, hot surfaces, and electrical switches)

Leakage test apparatus during shakedown tests.

Catastrophic gas fireplace failure during delayed-ignition tests with 30% H2 blends, otherwise not seen with pure natural gas (Image credit: www.thyga-project.eu)

- Modeling and/or testing of mitigation and remediation strategies, including leak detection, and catalytic/sorption devices for reducing the concentration of flammable gases in an emergency.
- Assessment of existing procedures around commissioning and performing maintenance on gas appliances and indoor gas lines.

Results

The research team completed a literature review on hydrogen-methane-air detonation characteristics with a focus on conditions relevant to industry and conducted a literature review on hydrogen/natural gas mixture leakage research.

In 2024, the team completed a comprehensive test plan and completed the construction of the leakage test apparatus. The team began leakage tests with hydrogen-natural gas tests. Preliminary results pointed to excellent sealing capabilities of factory-made pipe threads and standard pipe sealants. Surprisingly, the preliminary results also showed higher leak rates from compression type and o-ring sealed products, compared to factory-made test sections. The team is investigating potential sources of errors and more closely examining methods for assembling these connections.

As part of the dissemination effort, the team has submitted two abstracts to the ASHRAE Winter 2025 conference concerning leakage and safe use of H2 in buildings.

Status

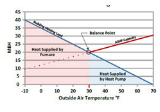
Phase 1 results were summarized in a Final Report issued in Dec. 2024 to the utilities participating in UTD, and will be publicly communicated in a technical paper at the 2025 ASHRAE Winter Conference. Phase 2 efforts are in progress.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Hybrid Fuel-fired and Electric-driven Residential/ Commercial HVAC Systems



Researchers are studying emerging or commercially-available hybrid gas furnace/ electric heat pump products in the North American market, in order to evaluate promising hybrid systems and develop installation and operation guides that can help end users accelerate their integration of electricity derived from renewable energy with fuel-fired equipment.

Project Description

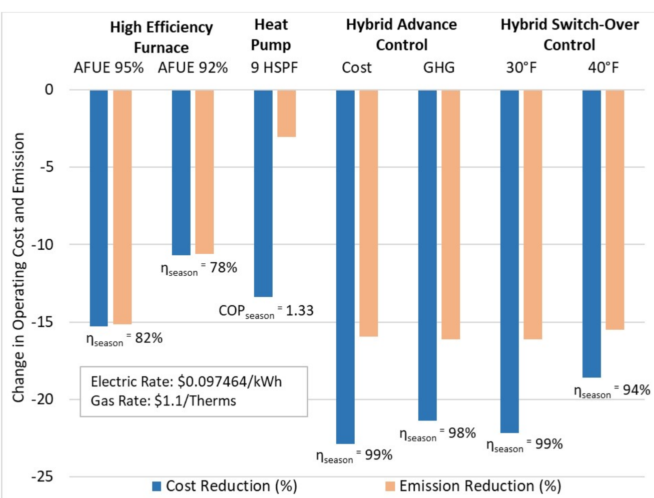
This project seeks to characterize the performance of hybrid gas furnace/electric heat pump products and quantify potential energy, operating cost, greenhouse gas (GHG) savings, fuel versus electric space heating contributions, and possible user comfort issues in all seven Building America climate zones. Phase 1 efforts in this project will be done in three steps: 1) Conduct a thorough market assessment of emerging or commercially ready hybrid gas furnace/electric heat pump products in the North American market. 2) Select and evaluate three promising hybrid systems. 3) Develop and publish design, installation, and operational guidelines for clean, efficient, and cost-effective use of hybrid forced air heating systems in various climates. Phase 2 efforts will build on the results from Phase 1 and seek next-step opportunities to advance relevant product innovations.

UTD is partnering with the Northwest Energy Efficiency Alliance (NEEA) and the Propane Education and Research Council (PERC), and both entities providing co-funding to this UTD project.

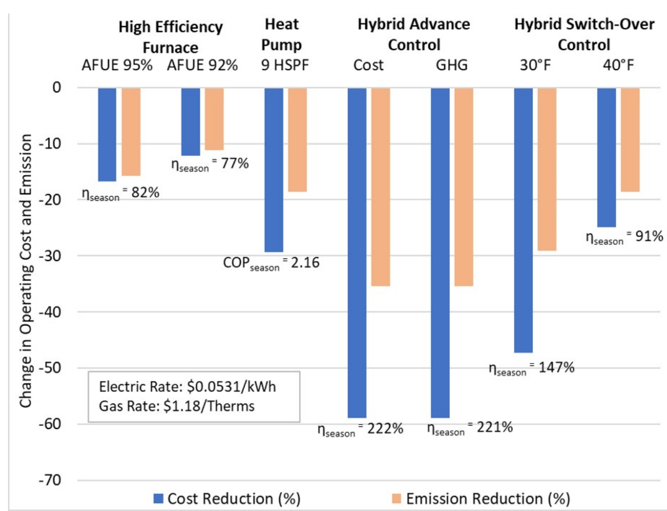
Benefits / Market Implications

Previous UTD research which characterized the full performance spectrum of fuel-fired residential space heating systems coupled with cold-climate and non-cold-climate electric-driven air source heat pumps (ASHPs) indicated that these custom-paired systems can generate energy, cost, and GHG savings by 15% to 30%. Due to recent market developments, these savings can be realized now by using off-the-shelf equipment that give customers choices in the energy sources used to heat their homes in a cost-effective, resilient, and environmentally-responsible manner.

Driven by ambitious goals to decarbonize the power generation systems, electrification is an emerging trend to switch end-use equipment from non-electric to electric sources of energy. Such societal shifts toward decarbonization, technological advancements and rapid R&D investments have contributed to an expanding North American electric ASHP market, which may dramatically increase building electric loads. Those loads, plus the potential effects of a nascent electric vehicle (EV) market as well as growing electrical demand from data centers, may strain the North American power grid.



Modeling result of 9 HSPF and 95% AFUE hybrid system compared with 80% AFUE furnace at Rochester, MN



Modeling result of 9 HSPF and 95% AFUE hybrid system compared with 80% AFUE furnace at Seattle, WA

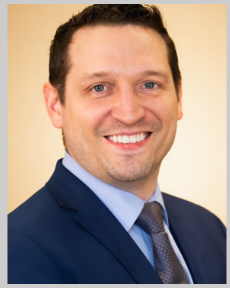
By employing hybrid systems, end users can maximize renewable energy while leveraging the very large underground gas storage capacity in North America (NA) for peak day energy needs. Hybrid systems also provide end users operational flexibility and enhance the operational resiliency of their equipment.

Technical Concept & Approach

Phase 1 efforts in this project will include developing, testing, and characterizing one or more simultaneous hybrid (dual fuel) gas furnace/electric heat pump systems and advancing the technology. The project team will develop a market assessment of residential dual-fuel technologies for forced-air systems using a thermostat, furnace and air-source heat pumps. A dual-fuel system will then be selected, installed, commissioned and evaluated over one heating season in a Chicago-area location. Its performance will be characterized in terms of energy efficiency, operating cost and GHG emissions and compared to simulated single-fuel systems, e.g. furnace or heat pump operation alone. The detailed performance curves will then be leveraged to perform building energy modeling across different utilities territories. Opportunities to publish the results at technical conferences will be sought.

Phase 2 efforts aim to develop and test a novel prototype product in collaboration with a major manufacturer. Tasks for this phase will include performing complete steady-state and load-based testing of the prototype in a laboratory, developing detailed performance curves, and quantifying through modeling the potential operating cost savings and energy/GHG savings in all seven Building America climate zones.

Simultaneous hybrid/dual fuel heating system in laboratory test stand



"The annual GHG emissions, operating costs, and source energy consumption of hybrid heating systems will depend on the local climate, regional electric grid fuel mix, system control logic, peak demand periods, and other factors. This project will help the design and contractor community to manufacture and install economical, effective hybrid systems, while enhancing real-time control options for customers to reduce overall GHG emissions, operating costs, or source energy use."

- Thomas Manjarres
Technical Lead – Energy Efficiency Programs
Peoples Gas and North Shore Gas

Results

For Phase 1, a market landscape of emerging or commercially-ready hybrid gas furnace/electric heat pump products in the NA market was created in 2023. A specific commercially-available hybrid system was identified and ordered. Testing infrastructure was designed. In 2024, the team designed and built a thermostat environmental emulator for hybrid load-based testing and a virtual test-home temperature emulator designed for communicating with thermostats for load-based testing. They also installed and commissioned a 5-speed high -efficiency Carrier heat pump and 90% AFUE high-efficiency furnace.

Status

The team is performing laboratory testing of Carrier's commercially-available hybrid system, and testing is expected to continue during the next 6 months under a continuation of Phase 1 activities. Its performance, operating cost and GHG emissions will be calculated and compared to that of two other hybrid systems. Upon the culmination of the 2024/2025 heating season and data collection, the project team will develop building energy models to evaluate the performance of this hybrid system in different utility territories and compare it with other hybrid and single-fuel system options. Phase 2 efforts in collaboration with a major manufacturer are also in progress, with laboratory testing planned for early 2025.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Emerging Distributed Methane Pyrolysis Technologies

Researchers are surveying emerging methane pyrolysis technologies to produce hydrogen ("turquoise" hydrogen), which allows siting hydrogen generation close to the point of use and potentially very cost-effectively for gas end users to decarbonize their operations.

Project Description

This project is classifying a range of emerging distributed methane pyrolysis solutions as good/better/best fit for gas ratepayers and consumers to decarbonize their operations, by combining application/process modeling with end user demand modeling and technology assessments. The research team initially conducted primary research via direct outreach to the leading technology developers in this space in order to create a landscape survey of options for distributed methane pyrolysis technologies. The survey included a techno-economic assessment (TEA) over a range of applications, with treatment of the underlying conversion process, hydrogen end uses, and handling of carbon outputs. Current efforts are expanding this analysis with additional direct outreach and refinement of the TEA.

Benefits / Market Implications

The primary target markets are in the large commercial and industrial sectors, but are likely to be quite cross-cutting. Initial applications could be commercial or industrial processes or boilers, where produced solid carbon may be readily collected.

With decarbonization pressures on utilities, their customers and society - coupled with a wave of investments in technologies for hydrogen production, distribution, and use - it is important to understand the advantages and disadvantages of different approaches for ratepayers to decarbonize their fuels. This need is further accelerated by incentives, such as the tax credits in the U.S. Inflation Reduction Act (IRA), which provide significant tax credits for investments and production of low carbon hydrogen or through carbon capture.

Different approaches to distributed methane pyrolysis will have a range of benefits depending on, among other aspects: the scale of their production (10 vs. 1,000 kg/day) and capacity factors, the ease of carbon utilization/disposal, process efficiency and emissions, and the avoided infrastructure modifications to reach the same overall decarbonization. This project directly addresses UTD goals to reduce GHG emissions while simultaneously accelerating an economical societal transition to increase the use of hydrogen as a low carbon fuel.

Full decarbonization of utility customers can be achieved through substitution of delivered natural gas with non-fossil gases, biomethane (RNG), hydrogen, and blends thereof.

The majority of hydrogen produced today is "gray", that is steam reformation of natural gas resulting in direct emissions of CO2. Some major emerging pathways are "blue" hydrogen, "gray" hydrogen with the addition of carbon capture and sequestration, and "green" hydrogen, hydrogen produced via electrolysis powered by renewable electricity. This research project focuses on "turquoise" hydrogen, a blend of blue and green, which is driven by methane pyrolysis.

Turquoise hydrogen has the distinct advantages over green and blue pathways by a) using a much lower cost feedstock (methane vs. water & electricity) and b) providing an ease of carbon capture via solid carbon, which is approximately 1,000 times denser than atmospheric CO2, sequestering nearly 4,000 times as much carbon. For these reasons, turquoise hydrogen production can be located physically nearby the end use customer, thus eliminating the otherwise-needed expense to transport pure hydrogen via a compressed gas "tube" trailer, as liquefied hydrogen, in a newly-constructed or re-purposed pipeline, or other manner.

There are estimates that turquoise hydrogen will provide more environmental benefits at a lower cost than green or blue pathways and the captured carbon may provide useful revenue streams. This project explores this potential with a techno-economic assessment, while grounding the analysis in technologies currently under development and with considerations of a range of use cases.

VulcanX 50-200 kg/day Demo Facility in Canada

"Low carbon hydrogen will play an important role in reducing the GHG emissions through deployment in heating, industrial and transportation applications to achieve a sustainable clean energy future. Methane pyrolysis offers a unique opportunity to produce hydrogen by using natural gas as a low-cost feedstock and leveraging existing natural gas distribution infrastructure. We're very pleased to support this project to help increase the awareness of this innovative hydrogen production technology, that could lead to scaling up of this technology."

- Aqeel Zaidi
Manager, Technology Development
Enbridge Gas Inc.

Technical Concept & Approach

The project team initially began application/process modeling by defining the approach up through developing a final system modeling plan, to couple with end user demand modeling and identified a range of distributed methane pyrolysis solutions (good/better/best).

This project performed a) a thorough modeling assessment of methane pyrolysis options with application considerations, b) provided analytical feedback to UTD members and select methane pyrolysis partners, c) provided a summary of R&D gaps for methane pyrolysis solutions – conversion technology and carbon handling, and d) a pre-feasibility analysis for a prospective demonstration. This was focused on the five or more application scenarios (e.g. boiler for space heating or industrial drying process) and five or more carbon output scenarios (e.g. disposal to soil, or as feedstock) identified in Phase 1.

Phase 1 results of this analysis will be used to refine the TEA to update assumptions based on both modeling results and any new information gathered. The project team will also collect data and information from industry scale-up efforts, as experimental and pilot-scale efforts are underway in a range of applications, providing this summary along with modeling results and recommended next steps.

Results

The team held information interviews with leading methane pyrolysis technology developers such as Levidian (UK), Molten Industries (US), Modern Hydrogen (US), H Quest (US), and Hago Energetics (US). These developers cover a wide range of pathways ranging from high-temperature thermal conversion (Modern Hydrogen) to use of biogenic catalysts (Hago Energetics), additional level of maturity varies where some are at the bench/lab-scale (Molten) while others have one or more demonstrations active with partners (Levidian).

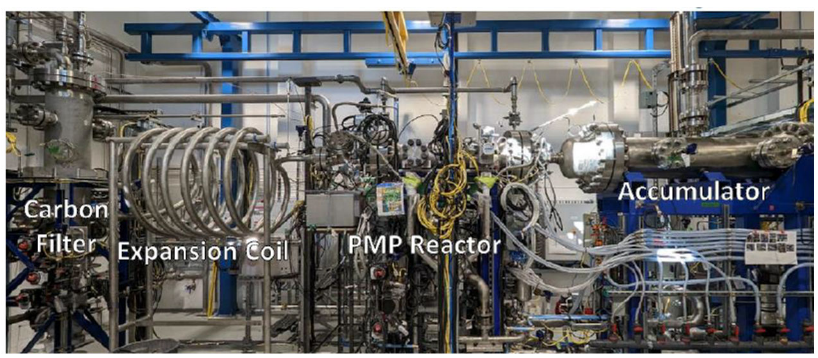
In 2024, the project team performed extensive due diligence on emerging technology developers and through these interactions have helped better place these developments in terms of technical maturity and market readiness. This has included site visits to pilot-scale facilities in the U.S. and Canada.

The project team has tentatively defined distributed methane pyrolysis as on the order of 1,000 kg/day, which would be suitable for utility customers as scoped in this effort, and the project team through this due diligence has sought to clarify which technologies (e.g. microwave-assisted cold plasma) are most suitable for distributed applications and appear to have substantial market potential in this market segment.

The project team started by developing the modeling plan. They started with an outline and internally refined it as new information came in from technology developers and/or published studies. The project team completed a draft developed for internal review based on enhanced representations of key technology groupings. A Final Report for Phase 1 was issued in August 2023.

Status

Current Phase 2 efforts are finalizing the draft of a simulation -focused Modeling Plan, which includes assessing impacts of distribution network architectures and analyzing industrial processes that appear poised as most likely adopt hydrogen-enriched fuels or pure hydrogen fuel in the near term (e.g. process heating in Food & Beverage applications).



Ekona Pulse Pyrolysis System (image credit: Ekona)

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Blue Frontier RTU AC System with Integrated mCHP - Laboratory Evaluation

This research project will develop a prototype of a revolutionary new packaged rooftop HVAC system that will integrate desiccant latent cooling, indirect evaporative cooling, thermochemical energy storage and mCHP, to provide commercial HVAC end users with efficient energy generation, high resiliency, and load-shifting control - - reducing peak electrical demand by up to 90%.

Project Description

UTD is partnering with Blue Frontier, Inc. to evaluate and test potential performance improvements to the regenerator subsystem of their liquid desiccant dedicated outdoor air supply system (LD-DOAS). Utilization of waste heat streams from commercial or near-commercial fuel-fired micro-Combined Heat and Power (mCHP) systems will be evaluated for potential regeneration system performance improvements. It is anticipated that the run-time, efficiency and payback of a right-sized mCHP unit can be maximized since Blue Frontier's novel technology also integrates thermochemical energy storage, and the resulting design with integrated power generation will also offer superior operational resiliency for end users.

Testing will be performed on the regenerator subsystem at an industrial laboratory at capacities and temperatures corresponding to the mCHP systems. Heating approaches will be evaluated and tested to identify optimal hardware and control strategies. A commercialized unit could provide an alternative for highly efficient, resilient, low GHG commercial HVAC applications that can offer minimal or zero external electrical usage.

Technical goals for this project include identifying solutions such as mCHP or Solid Oxide Fuel Cell (SOFC) that provide higher-grade heating to improve Blue Frontier's regenerator performance. Experimental results will allow Blue Frontier team to model and characterize impact of higher-grade heat on the Blue Frontier LD-DOAS. The project will also characterize potential energy, cost and greenhouse gas savings.

Benefits / Market Implications

Target customers for this technology include commercial building owners/operators that require 5 to 15 ton packaged rooftop units (RTU) for new building construction and retrofit applications. Customers in any climate served by electric utilities that offer energy efficiency, demand response, and energy storage programs are of particular interest. The technology may be scalable from 2 to 20 tons. This unit directly addresses key UTD goals, including saving consumers money, saving energy and reducing GHG emissions, enhancing reliability, and integrating more renewable energy.

Compared to a conventional NAECA compliant AC system, the Blue Frontier RTU can reduce energy use by at least 60% and efficiently stores and load-shifts energy, reducing peak electrical demand by up to 90%. Moreover, it uses a zero global warming potential (GWP) working fluid (essentially as refrigerant) thus improving its greenhouse gas reduction potential. Implementation of onsite mCHP would reduce electric load and potentially allow it to operate off-grid making it an economical, resilient HVAC option.

The integrated thermochemical storage (nominal 6- hour duration) allows the system operational flexibility, offering the user capability to shift heating requirements as needed and the potential of generating excess electricity during high demand periods. The size of the thermochemical energy storage can be easily adjusted depending on use case load profiles, since the fluid is contained in a simple plastic tank.

The Blue Frontier RTU in its initial go-to-market configuration is a liquid desiccant AC system, with thermochemical energy storage that can generate 10 MWh/yr energy savings per unit over conventional AC for electric utility energy efficiency Pro-

grams. Blue Frontier has publicly estimated that their total addressable market is 40 million units in the US alone.

When Blue Frontier RTU technology is combined with a mCHP system, it will provide a high-resiliency self- powered, high-efficiency decarbonization solution by eliminating the GWP impact of refrigerants; provide at least 4.4 kW of peak demand reduction per unit with fuel-fired equipment helping to reduce electrical usage during peak demand periods.

Technical Concept & Approach

Tasks for this project include:

RTU Integration with mCHP equipment

The team, along with Blue Frontier, will engineer the integrated system including specifications and anticipated performance metrics based on mCHP temperature and flow rate capacities.

Develop Test Plan of the Regenerator subsytem based on mCHP capability.

The project team will develop a test plan to determine regenerator performance at various operating conditions, evaluating performance using a hydronic loop to simulate mCHP integration.

Test setup, Installation and Testing

The team will install the integrated system in an industrial laboratory and evaluate efficiencies, emission levels, modulation and cycling capabilities.

Data Analysis, Reduction, and Reporting

The team will determine optimal regenerator performance at

Blue Frontier Rendering of Initial Product (non-mCHP configuration)

Blue Frontier regenerator section to be tested with an mCHP thermal load

various operating conditions to optimize the regenerator system. This will help develop the performance curves of the regenerator system for optimization using various heat sources.

Results

The project team and Blue Frontier are coordinating technical analysis relevant to the mCHP application. Various commercially-available and emerging small-scale power generation technologies were evaluated for best fit application. A laboratory test stand is being constructed and the experimental test matrix is being refined.

Status

The team is optimizing the integration strategy and assessing the mCHP options which appear to have the most promising characteristics for liquid desiccant regeneration.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Combustion Technology for Emerging Low Carbon Manufactured Gases

Researchers are accelerating knowledge for North American end users to use hydrogen-enriched natural gas and other low-carbon manufactured gases, by leveraging existing and recent technical and product developments from Asia and Europe. Leveraging best practices in safety, compatibility and efficiency will benefit N.A. gas customers.

Project Description

This project is conducting an experimental, technical, and safety evaluation of equipment using manufactured gases already on the market in non-North American markets, focusing on water heating and cooking applications. This includes performance and reliability tests to identify key principles which can be applied to natural gas-certified equipment in North America. The team will also conduct a review of emerging low carbon manufactured gases.

This work will build on a long history of manufactured gases (sometimes denoted “synthetic natural gas” or “town gas”) being used to provide energy as fuel, in North America in the 1800s and early 1900s, but is still in use today in some locations. For example, Hawai‘i Gas blends synthetic natural gas made from naphtha (a petroleum by-product) with renewable natural gas and up to 15% hydrogen, and distributes it to residential and commercial customers through its underground pipeline network on O‘ahu.

A Stove made by Tecno such as used in Singapore (image credit: Tecno)

Benefits / Market Implications

The project targets residential and commercial gas water heaters, ranges, ovens, and space heating. Manufactured gases offer a pathway to reducing greenhouse gas emissions, but their adoption relies on both supply and demand. Learning from markets using H2-rich manufactured gases can benefit North American OEMs and end users while utilities will benefit from understanding the current markets for manufactured fuels internationally and how those technologies might shape future demand. Lessons from existing markets on best practices for ensuring compatibility, safety, and efficiency will benefit North American gas customers.

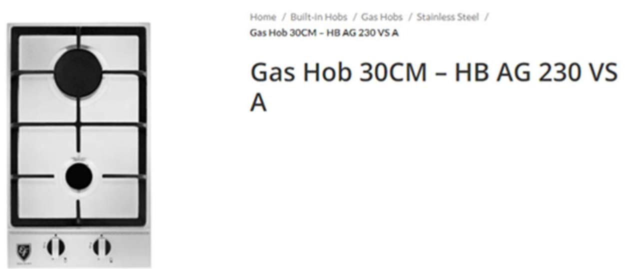
Technical Concept & Approach

Tasks for this project include:

Identify existing appliances

The project team will identify appliances sold outside North America that utilize manufactured gases. The appliances from

A instantaneous water heat made by Kuzzo such as used in Hong Kong (image credit: Kuzzo)



A Hob such as used in Singapore (credit: Embracing Finest Moments)

overseas are intended to mirror what the North American market commonly uses such as water heaters and stoves. Burner and component OEMs that the project team could develop partnerships with will be identified and sought out.

Acquire and test appliances in laboratory with blends of hydrogen

The project team will acquire and test appliances using hydrogen-methane blends for safety and performance. Baseline tests of the appliances will be performed using as close an approximation of the fuel gas blend they were designed for. Testing will include criteria for efficiency, emissions, and extended life.

Review Safety and Technical documents on emerging fuels

The project team will collect and review safety and technical documentation on emerging lower-carbon methane-substitutes including wider use of manufactured town gas and renewable hydrocarbons. This is in pursuit of safe and comparative alternative fuels outside NG and NG/hydrogen blends.

Results

The project team has started developing a plan to study appliances made for manufactured gases from regions outside North America. Singapore and Hong Kong were identified as two regions that actively use manufactured gases, composed of ~50% H_2, ~25-30% CH_4, ~15% CO_2, ~5% CO, ~5% N_2. The team also identified four manufacturers from the region.

Acquiring appliances from Singapore or Hong Kong was quite the challenge with most suppliers in the area refusing to ship out of their region, obviously their appliances are not designed for markets outside their region. An engineer on the project team traveled to the Singapore area and acquired 11 appliances to ship them back to a test laboratory in North America. This include five water heaters and six stove tops from numerous leading equipment manufacturers in Asia. The team is still working to acquire the last water heater through Rinnai Singapore.

A testing area and testing stand in an industrial laboratory has been prepared in order to begin testing these appliances, including on simulated syngas compositions.

Laboratory Stand to test Singapore appliance being commissioned

Status

The team is installing the newly-acquired appliances in a test laboratory in order to perform application and emissions testing using a Town Gas composition of 50% H_2, 25% CH_4, 15% CO_2, 5% CO, and 5% N_2. After application testing is concluded, the team plans to identify best design practices or innovations already in practice of the burners for each of the appliances.

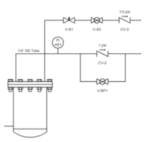
The team also reached out to contacts at several leading gas distribution utilities in Singapore and Australia to better understand their appliance test safety and energy efficiency standards.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Accelerated Life Testing of ResCom Equipment Components with Hydrogen-Blended Gases



Research is underway to better understand the potential impacts of hydrogen-enriched natural gas on the durability and performance of representative materials commonly used in combustion appliances and equipment in North America. Expanding the amount of this technical data will likely speed the safe integration of H2 derived from renewable energy sources.

Project Description

A significant challenge for hydrogen deployment in North America is the absence of inclusive fuel quality standards. Existing certification standards cover only natural gas and propane, and most installed equipment has not been tested with hydrogen. Manufacturers have expressed concerns about compatibility, with some recommending frequent replacement of components exposed to hydrogen.

This project aims to assess commonly used non-burner components in residential and commercial combustion appliances and equipment for compatibility with hydrogen-blended gas. The goal is to assist gas equipment and appliance manufacturers, gas utilities, and standards-setting organizations in understanding the potential challenges of using hydrogen in natural gas distribution networks.

Benefits / Market Implications

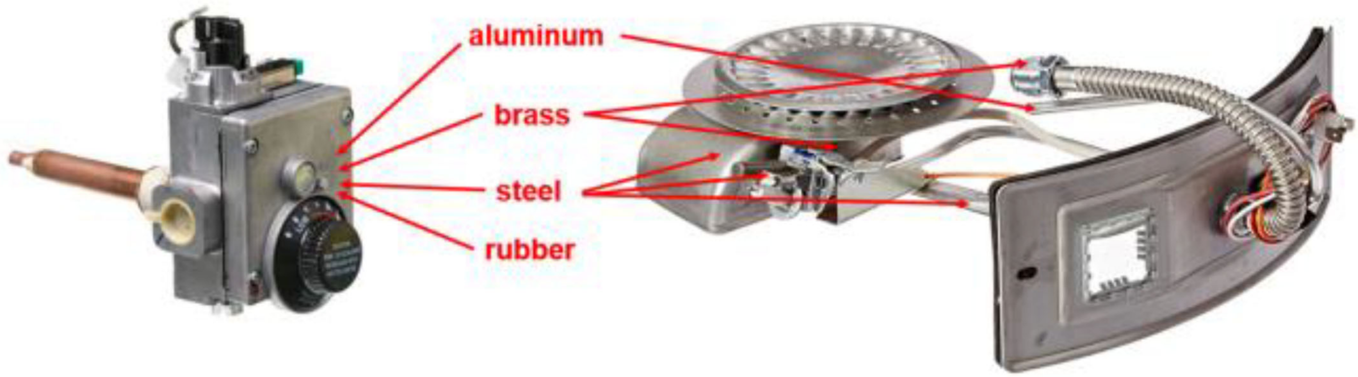
A number of gas distribution utilities, including those participating in UTD, envision a future distribution grid that may distribute hydrogen-enriched natural gas. Operations Technology Development, NFP ("OTD"), the U.S. Department of Energy's HyBlend initiative, and other researchers are conducting various tests focused on characteristics and performance implications for local gas distribution utilities themselves if they distribute hydrogen-enriched natural gas.

Some other researchers are performing durability and long-duration testing on burner and heat exchanger materials used in Commercial and Industrial equipment, but these typically focus on the effects of combustion products (e.g. increased water vapor) on components from the burner and downstream.

This project will complement ongoing studies by focusing on components upstream of the burner, addressing knowledge gaps which have not been covered by prior studies. It will build on earlier research such as the European THyGA project, which performed a literature review on the impact of hydrogen blending on existing gas-train components but tended to focus on metals, concerns around hydrogen embrittlement, and polyethylene. Fewer studies have examined potential effects on materials like natural and synthetic rubbers, valve stem packing materials, and lubricants.

In summary the results of this research will support the safe and reliable integration of hydrogen into the existing natural gas infrastructure.

Example Boiler Gas Train (credit: Dungs)



Example of Common Natural Gas Component Assemblies (credit: Robertshaw and Beckett Thermal Solutions)

Technical Concept & Approach

Literature Review and Component Selection

The project team will review the current state of knowledge regarding hydrogen compatibility through literature review and inquiries with OEMs regarding the past performance of their equipment or components in hydrogen-enriched gas service in Hawaii or other markets. Based on the results of the literature review, select components as having potential issues with hydrogen for testing.

Build Test Stand and Test Components

The project team will build a test stand to allow for accelerated life testing of components. The test stand will permit prolonged exposure of various gas train components to a hydrogen atmosphere until slightly elevated pressure. Multiple components will be tested at once. After a period of exposure, components will undergo simulated use tests to test for their function and any defects.

Results

The team has completed a literature review, focusing on prior work on gas-train components and material compatibility with hydrogen. Some completed studies focus on components found to have adequate compatibility, while others point to a lack of information and the potential for decreased product life due to a lack of optimization.

The team has also begun developing a test plan for the project, focusing on an approach where components of interest would be enclosed in a chamber, filled under low pressure to 100% H2 for a period of time. After exposure, the components will be tested for leakage and proper operation.

Status

The team is focused on completing the test plan and beginning the safety review of the planned testing. The team is concurrently working to procure components and assemble the test apparatus.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Impacts of Hydrogen-Blended Gas on Venting, Condensation, and Weatherized Equipment

ANSI NFPA

Researchers are seeking to develop vent tables similar to NFPA 54/ANSI Z223.1, Section 13, to incorporate the use of >30% H2 blends with natural gas, based on data from physical testing. Helping inform potential improvements to consensus-derived standards with scientific data can accelerate integration of H2 derived from renewable energy sources while addressing end user safety.

Project Description

The project aims to assess the impact of hydrogen blending, up to 30% or higher, on the compliance of existing gas appliances with the National Fuel Gas Code (NFPA 54) and other related global standards, such as ASHRAE guidelines, for flue gas venting, condensate management, and weatherized equipment. The project will develop new vent tables for hydrogen-blended gases and publish the findings in a technical paper or final report.

Goals for this project include:

- Through laboratory testing of at least three appliances or classes of appliances, identify the leading venting construction and design factors (alone and in combination) that impact good combustion (i.e., achieve <400 ppm CO Air Free) with good flame characteristics (no flashback or flame lift), and bad combustion (i.e., >400 ppm CO Air Free) or bad flame characteristics. Example factors may include vent diameter, vent height, vent length, input rate and vent environment, which drive with and without deleterious effects, CO emissions, stack loss, CO2 and NOx, and flame characteristics of flashback and lift.
- Develop vent tables similar to those in section 13 of NFPA 54/ANSI Z223.1 for the range of hydrogen blended gases that were tested.
- Publish the results in a technical paper or another manner for potential use by NFPA 54/ANSI Z223.1 Technical Committee or others.

Benefits / Market Implications

Replacing existing gas appliances while also replacing the existing vent system in the home can, under certain conditions, cause appliances to fall out of compliance with the certifications and codes to which they were installed. In particular, it is not readily known how compliance with Sections 12 and 13 of NFPA 54/ANSI Z223.1, The National Fuel Gas Code, may be affected by the detailed vent tables for Category 1 Appliances. These are appliances with negative or natural drafts, and flue losses greater than or equal to 17%. Moreover, it is not readily known how single appliance vents and multiple appliance vents, Type B double wall vents, Masonry Chimneys, and Single Wall Metal Pipe may be affected by blended Methane/Hydrogen operations. This project will provide information on those situations.

Advanced gas technologies require active participation in the standard and code writing process with dedicated support to develop sound engineering judgement and technical rationale for requirements. This project will provide engineering and technical expertise as well as analytical test results and laboratory test results to entities developing and revising Codes and Standards. In particular, advice and recommended guidance on the application of the venting requirements in NFPA 54/ANSI Z223.1, Section 12 and 13, for blended Methane/Hydrogen operations.

Technical Concept & Approach

Based on the application parameters of NFPA 54/ANSI Z223.1 (specifically, Sections 12 and 13 for Category 1 Appliances), the team will use a combination of experimental and numerical analyses to investigate potential venting issues due to H2 gas with blends up to at least 30% with Methane. If no significant issues occur at 30% blending (e.g. changes in flame and combustion characteristics, or CO emissions), the blending amount will be increased until significant changes in test results are observed. This will be in combination with test factors of vent height/length, diameter, type, appliance input rate and environment (wind). It will address single appliance vents and multiple appliance vents, Type B double wall vents, Masonry Chimneys, and Single Wall Metal Pipe.

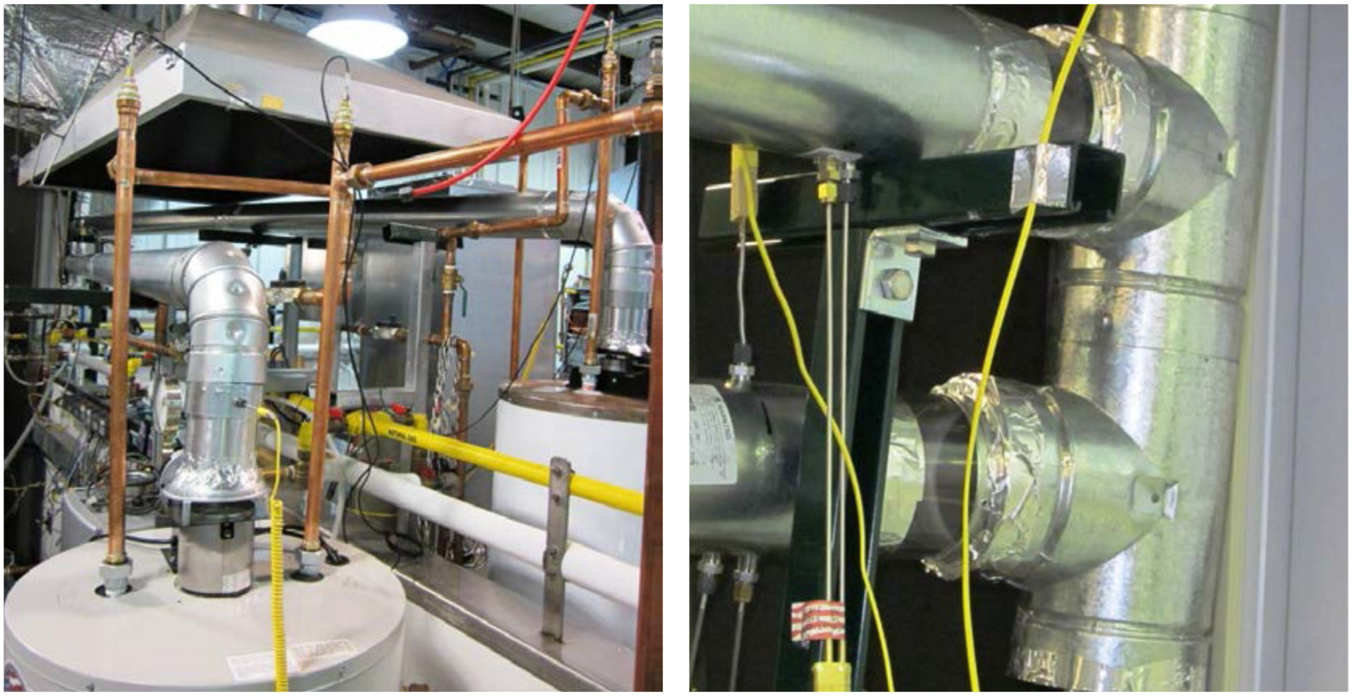
Tasks for this project include:

Determine Samples

The team will determine candidates of gas fired, residential class appliances for the testing, and will as a minimum test three appliance types of water heaters, furnaces or boilers.

"As our local gas distribution plans to decarbonize, a key enabler is the confidence that today's gas appliances will operate safely with blends of natural gas and green hydrogen as high as 30% by volume. The equipment must operate reliability along with the flue-gas venting systems they are connected to. In the 1990's, gas utility R&D and appliance manufacturers partnered to develop the gas venting analyses, procedures, and analytical tools now refenced in national and local fuel gas codes. Now is the time to update those standards for the low carbon fuels of today and tomorrow, and UTD has assembled the experience and expertise to meet the need."

- Chris Cavanagh
Engineering Manager - Low Carbon Energy
National Grid



Laboratory Test Setup Overview from earlier UTD project 1.10.B "Residential Venting Program" (informed VENT-II Software)

Test Samples

Candidate samples will be tested at various vent design and construction factors using accepted engineering practices.

Analyze the Data

Data will be analyzed using accepted engineering practices, (ie. cause/effect analysis, Pareto outcomes, statistical probability, etc.).

Development of Vent Tables

Vent tables similar to NFPA 54/ANSI Z223.1, Section 13, will be developed using the test data.

Results

The team has begun a literature and codes review regarding venting requirements for different appliances and fuels.

The team has also been reviewing an existing software called VENT-II that was developed in part with funding from UTD and has been extensively used in the industry for designing vent systems, but this software does not support fuels other than natural gas. The team reviewed background information on the VENT-II program and confirmed that the program could be used to assess the impacts of H2 blending if it is adapted to include hydrogen blend. Unfortunately, due to the dated technologies used to originally develop the program, it is not easy to update. The team is exploring options for updating the program.

Status

The team is working to identify the best approach to update the VENT-II program to include H2 blends and identify the model updates which will be needed.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Inherently Safe ResCom Combustion Systems for Hydrogen-Blended Gases

Researchers are developing and demonstrating combustion systems resistant to flashback when using H2-blended gas (5-50% H2 by volume) for common appliances. Integration of these innovations will help support the safe integration of lower-carbon fuels for end users.

Project Description

The goal of this project is to develop and demonstrate safe combustion systems for common gas appliances (furnaces, water heaters, ranges, etc.) and identifying inexpensive options to retrofit typical existing appliances when using H2-blended gas (5-50% H2 by volume). This will help gas utilities to demonstrate hydrogen blending levels well above 5% by volume and to broadly deploy blended gas in their networks.

Many entities in the North American gas industry have the goal of reducing greenhouse gas emissions and are taking steps towards replacing fossil natural gas with renewably sourced fuels, and these efforts align with UTD's goal to Save Energy and Reduce GHG Emissions. Multiple pilots using hydrogen are either starting or in the planning stages. Based on past research we know that many conventional gas appliances with atmospheric burners can tolerate hydrogen blends of more than 50%, and sometimes as high as 80-90%. If combustion instability or failure occurs, it typically occurs during an ignition process.

The underlying causes for inconsistent ignition problems with hydrogen blended gas are complicated, making them difficult to predict. More challenging yet is that the same burner may behave differently depending on the appliance or installation. What makes these events a problem is that the flame can stabilize at the gas orifice with the bulk of the flame inside the burner body, undetected by combustion controls. When this happens, it can result in unsafe levels of CO emissions, burner overheating and premature failure, and reduced or inconsistent appliance performance.

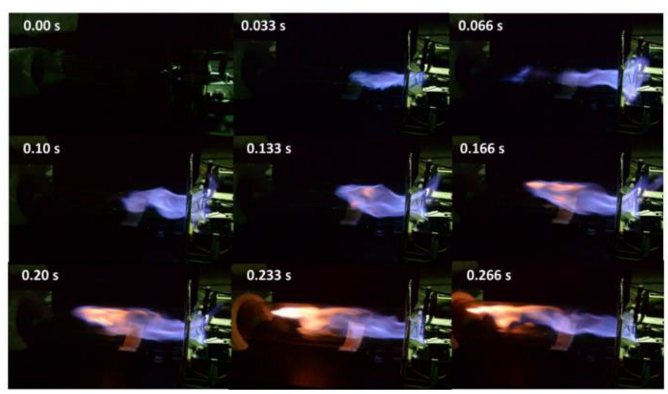
If successful, this project will for example:

- Demonstrate one or more practical, economical combustion system designs for new and retrofit applications that can either prevent flashback or detect flashback and shut down the burner safely.
- Demonstrate the technology in at least three common gas appliances (furnaces, water heaters, and ranges) in a laboratory setting
- Publish the results in a peer-reviewed journal or conference proceedings.
- Obtain expression of interest from a manufacturing partner to further develop and demonstrate the technology

Benefits / Market Implications

Hydrogen blending at a level of 5% by volume using green hydrogen will only result in a GHG reduction of <2%. To achieve deep decarbonization, much higher levels of green H2 are needed (e.g., at 30% H2, GHG reduction is still only 13%). While the early pilots with low blends are useful for developing the necessary blending infrastructure, if gas utilities and their customers are to reach their decarbonization goals, higher blend levels will need to be deployed sooner than later.

To ensure that existing and future appliances continue to operate safely in all conditions, the burners and combustion systems must be resilient to these combustion instabilities. While more robust certification standards for appliances operating with hydrogen-blended gas can help catch these issues before appliances are sold in the long term, for any hydrogen blending pilots with blends exceeding 5-10%, solutions that are inexpensive and that are ready to install are needed. This project seeks to develop new solutions to help ensure continued safe and reliable operation of customer equipment.



Images from non-uniform in-shot burner ignition in a simulator. Using H2-NG blends, this behavior may be causing unsafe ignition at the gas orifice.

Technical Concept & Approach

The project will design, manufacture and test in the laboratory several prototype solutions that either safely shut down or prevent flame instabilities during the ignition process in conventional partial premix burners. The purpose is not to strictly explain the intermittent ignition issues, but to instead focus on preventing the unsafe operating conditions that may result. By implementing a flashback resistant burner design, a self-extinguishing gas orifice, or more robust combustion controls so that if a flashback occurs, the burner will either safely shut down or push the unstable flame out of the burner body, resuming normal operation.

Tasks for this project include:

Design a flashback resistant burner(s)

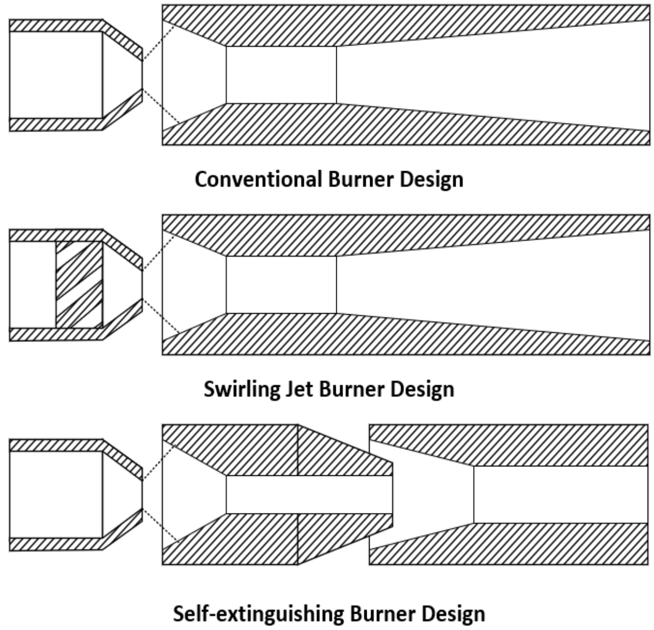
The project team will perform a detailed numerical design analysis using computational fluid dynamics to investigate flashback-resistant burner designs described in literature and suggested by theory, and identify one or more viable designs to test experimentally. Limited benchtop experiments may be performed to validate key model assumptions before full prototype testing.

Build and test burner prototypes

One or more leading designs from the first task will be built and tested under varying blend and load conditions to validate their resistance to flashback. Once validated, the designs will be installed in at least three existing furnaces, water heaters, or gas ranges. The appliances will then be tested under adverse operating conditions to force flashback and combustion instabilities to assure that the designs are able to either safely shut down or resume stable operation.

Results

The team has begun a literature review of flashback mitigation strategies in various combustion applications, such as fuel stratification and clever turbulence control. Project participants added to this research effort include an industry-leading computational fluid dynamics (CFD) software company, which will perform computational fluid dynamic simulations of various burner port designs to investigate controlling design parameters.



Conventional and self-extinguishing burner designs described by Prigg (1955)

Status

The team is working to complete the literature review and will then kick off work performing predictive simulations of various burner port designs and arrangements to determine design features that better prevent flashback.

The CFD company on the project team has completed initial simulations, validated against literature data, and is now focusing on simulations of various burner port configurations.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Hydrogen Flame Visibility and Colorants

This research project is enhancing safety for end users by evaluating the feasibility and implications of colorant additives to increase the visibility of flames when combusting pure hydrogen or hydrogen-blended fuels. This project can help advance the safe integration of lower-carbon fuels for end users and thus reduce GHG emissions.

Project Description

Flames of pure hydrogen can be nearly invisible depending on the lighting conditions, which can create a safety hazard for end users. In comparison, flames of natural gas are highly visible and thus provide a visible warning in addition to a thermal warning.

This project will evaluate and identify colorants for hydrogen-enriched gaseous fuel. The team will establish a matrix of hydrogen/methane mixtures to test visibility from 0% to 100% hydrogen and evaluate flame visibility using four common lighting conditions.

As part of this project the team plans to:

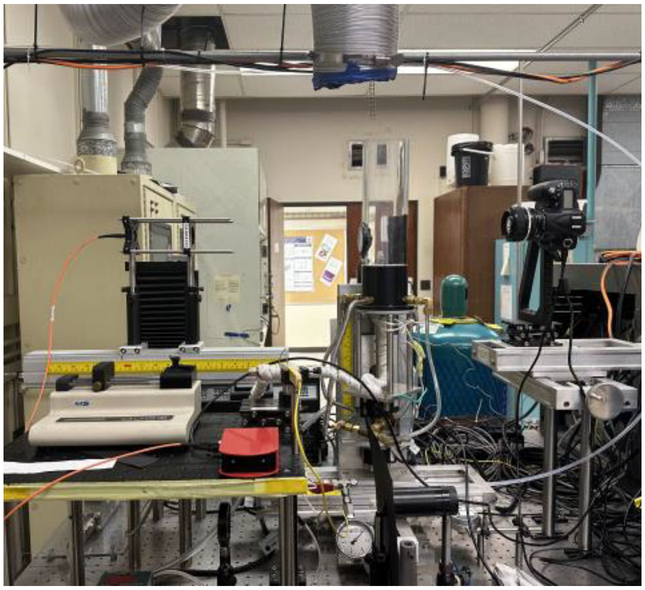
- Assess the flame visibility of hydrogen-enriched fuels from 0% up to 100% hydrogen addition and establish a flame appearance map.
- Conduct hydrogen combustion and visibility tests under at least four lighting conditions: candle, LED, fluorescent lamp, darkness.
- Identify at least two non-toxic and non-corrosive gaseous flame colorants that can be safely added into the gas transmission and storage infrastructure while enhancing hydrogen flame visibility.
- Publish the results in a peer-reviewed journal or conference proceedings.
- On a conceptual basis, evaluate how a colorant might be added into a gas distribution network.
- Publish results in a peer-reviewed journal, and presentation of results at one or more industry conferences.

Benefits / Market Implications

This issue has been identified by multiple industry sectors. The 2021 Tokyo Olympics provides an example from the recreation and entertainment industry. Renewable hydrogen created by solar-water electrolysis from Fukushima was adopted for the Olympic flame cauldron. To create a visible flame, sodium carbonate was sprayed into the hydrogen. A complicated valve design created a visible flame, but there was still a risk of clogging the burner, which makes this technology difficult to apply to residential, commercial and daily recreational hydrogen combustion applications.

This project will address a safety concern with the lack of visibility of hydrogen flame while minimizing adverse effects. The team will consider any impact to reliability and resiliency, CO and NOx emissions or other impacts to indoor air quality, and cost as they evaluate potential colorants.

Nearly Invisible Hydrogen Flames: North America Hydrogen Hut Field Testing on a Cooktop Burner (Left) and 100% Hydrogen Cooktop Burner Flame from HY Grove, UK (Right).



Experiment Setup

Colorants evaluated as a part of this project can be incorporated into ongoing and future hydrogen demonstration projects. This research will also provide background for future gas additive products to come into the market.

Technical Concept & Approach

The project will quantify flame visibility of twelve hydrogen enriched fuel mixtures under four lighting conditions. At least two non-toxic and non-corrosive gas colorants will be identified, and demonstration on burner prototypes will be conducted.

Task for this project include:

Quantify the Hydrogen Enriched Gas Flame Visibility under Various Lighting Conditions

Conduct flame visibility experiment test on twelve gaseous fuels, including natural gas, methane, 10% hydrogen/90% methane up to 100% hydrogen with 10% incremental steps. Vary the lighting condition (candle, LED, fluorescent lamp, darkness) to simulate real-life application situations.

Identify Potential Colorants

Investigate gaseous flame colorants (CO2, CO, CH4, C2H6, C3H8, etc.) impact on hydrogen/methane flame appearance. Generate flame color matrix for each colorant by quantifying the flame spectrum and compare them with the natural gas flame. Identify at least two gaseous flame colorants to enhance flame visibility.

Demonstrate their Use in Prototype Burners

Work with burner/appliance manufactures to test the colorants on prototype burners.

Results

The team identified a burner for the flame color visibility testing and replicated the burner based on CAD documents. They have finalized the testing setup and started flame color quantification testing.

The team also started reaching out to burner manufacturers about 100% H2 appliances to test the colorants.

Status

The team is working to complete flame color quantification testing and continues to engage with appliance manufactures to secure 100% H2 appliances.

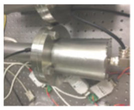
For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

LARGE COMMERCIAL AND INDUSTRIAL, INCLUDING CHP

UTD
Utilization Technology Development

Field Evaluation of Gas-Quality Sensor



Field evaluations were conducted to demonstrate a new, reliable, low-cost gas-quality sensor that can detect changes in gas quality (heating value, hydrocarbon, and CO_2 concentrations) in real time and provide valuable data to operators and end users.

Project Description

Natural gas is priced by total energy delivered (in Btus or therms). However, Btu content cannot be easily measured, so a common practice is to measure the volumetric flow rate at the point of use, and to determine total energy used by multiplying this number by the average energy content (Btu per standard cubic foot) measured at a central location. While this approach is economical and recognized as sufficiently accurate for billing residential, commercial, and most industrial customers, there are industrial combustion processes (e.g., processes for glass and fertilizer production) and power-generation equipment (e.g., dry low-NO_x gas turbines and lean-burn internal combustion engines) that have stricter limits on gas quality and composition.

Some large-volume end-user applications have in-line equipment to continuously monitor gas quality to obtain measurements that can be readily converted to heating value, methane number, or Wobbe Index. The introduction of shale gas and upgraded biogas from anaerobic digesters into the gas-transmission network is increasing the importance of more accurately and more regularly measuring the heating value of the gas for many of these large-volume customers.

The most common equipment used today for continuously measuring natural gas heating value is the gas chromatograph (GC). Although GCs provide accurate Btu values based on direct measurements and compositional data, they have several drawbacks, including:

- Long response times (often four minutes or more)
- High capital costs (in excess of $20,000), and
- Regular calibration required (a recurring operating cost).

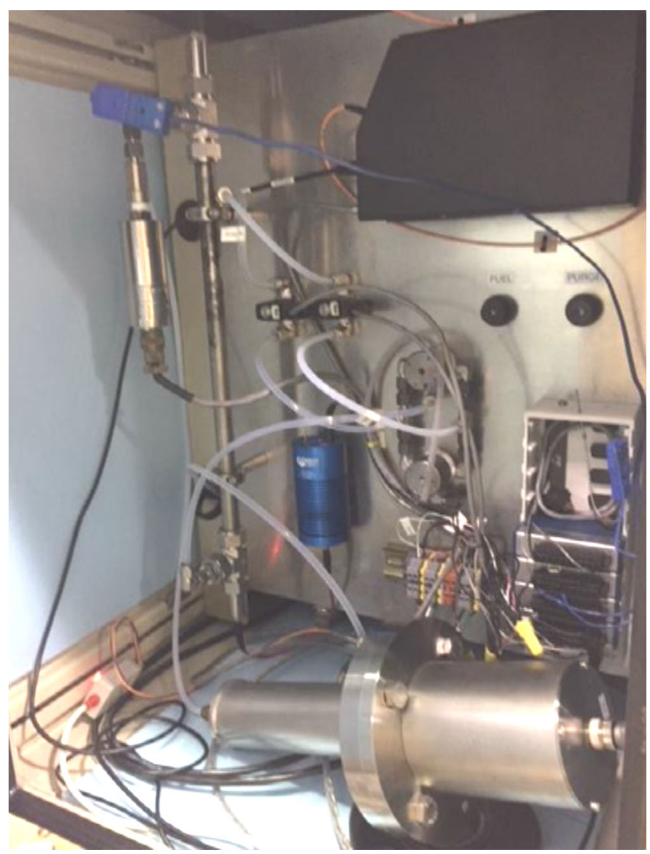
To address the issue, researchers developed and extensively tested in a laboratory a heating-value sensor on natural gas, biogas, and producer gas. The sensor is significantly lower in cost than gas chromatographs and will address other limitations of the GC.

The objective of this project is to continue to develop and demonstrate in actual field-operating conditions a practical, reliable, and low-cost gas-quality sensor (GQS) that can detect changes in gas quality (e.g., heating value, hydrocarbons, and carbon-dioxide concentrations) in real time and provide this data to natural gas pipeline operators, local distribution companies, and end users of natural gas.

The technology development that was advanced in laboratory testing and field demonstrations in this project supported the commercial introduction of the NIRIS NG GQS sensor by licensee CMR Group in 2019. The most recent phase of this project is supporting efforts by CMR to add capability to the GQS to also measure hydrogen content in natural gas, as well as make other improvements.

Benefits / Market Implications

Gas distribution companies and large-volume gas consumers that are sensitive to variations in gas quality will benefit from the faster, lower-cost new Btu sensor. Industrial customers can operate equipment more efficiently with lower emissions when real-time fuel heating-value data are available. Operators of natural-gas-fueled turbines and internal combustion engines can have enhanced control of equipment performance and protection.



The GQS in laboratory testing prior to the shipment to the field-test site.

Specific advantages of the GQS include:

- The sensor only needs to be calibrated just once for the application
- Simple to use; no special training is needed
- Measurements can be taken at high gas pressures
- Measurements can be taken continuously, allowing trending and controls operation, and
- In-line configurations are possible.

Technical Concept & Approach

The GQS uses the infrared light-absorption properties of hydrocarbon gases to measure the Btu content and composition of a natural gas mixture. It has been shown that this sensor technology can be used to measure the air/fuel ratio in air/hydrocarbon gas mixtures delivered to combustion equipment. The accuracy of heating-value measurements made by this new instrument can closely match those of a GC, but at a much lower cost.

Technicians prepared, calibrated, and installed a GQS prototype at a utility site in Tulsa, OK, to monitor the heating value and composition of natural gas for 12 months.

GQS measurements were conducted side-by-side with a gas chromatograph to verify accuracy of the GQS measurements. The gas-quality data can be provided to the pipeline operators and/or end users in real time.

The project team will provide support to the licensee of the GQS technology as production gas-quality sensors move through customer testing and will assess the capability of the GQS to also measure hydrogen content.

Results

Early project activities involved modifying software so that a new spectrometer could be integrated with the concentration determining algorithms. The new spectrometer was capable of reading high wavelength data and therefore was expected to be able to collect carbon dioxide data directly. Software was modified to collect and process this data. Changes were needed to meet the requirements established by the demonstration site, including the mechanism for data transfer.

An experimental apparatus was used to calibrate and test the GQS after upgrades and modifications. In 2017, testing of beta prototypes was performed using 12 gas mixtures with compositions covering the range of anticipated real-world biogas and natural gas. Calibration testing of 10 new prototype sensors from CMR was conducted in 2019.

GQS developments also included:

- The new spectrometer can read high wavelength data and, therefore, collect carbon dioxide data directly. Software was modified to collect and process this data.
- Details of the dimensions, utility requirements, and other aspects of the enclosure (inlet and outlet ports, temperature range, etc.) to hold the GQS for demonstration testing were made.
- The team completed assembling the GQS inside the enclosure. Two sensors were installed. One sensor followed a prototype design using a spectrometer and the other sensor is a commercial prototype built by the commercializing partner and using an interferometer.
- All sensors were installed in enclosures and prepared for testing per safety requirements of the host site.

The project team transferred several beta prototype sensors back to CMR. One sensor was transferred to a U.S. engine company for validation testing. Two sensors were returned to CMR in France so they could be sent to companies carrying out validation testing in real-world conditions.

Data from a demonstration test in Tulsa was retrieved, processed, and shared with CMR. The data showed more scatter than anticipated, which appeared to be a result of temperature variations during the demonstration period. Efforts were made to apply a temperature correction.

Status

Final Reports for Phases 1 and 2 of this project were issued to the utilities participating in UTD in 2021 and 2023.

Current efforts in Phase 3 have been paced by the CMR Group timing to make available the next-generation GQS unit which contains a hydrogen detector and other upgrades. The project team will conduct testing once they receive this latest GQS unit from CMR Group. The laboratory is already equipped with the needed blending station, mixing system, computer, and data acquisition system.

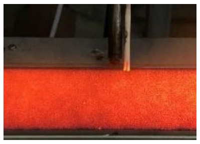
To support the development of this technology and CMR Group's commercialization efforts, an informational update webinar led by CMR Group was held on September 4, 2024 in order to bring more than 100 UTD, OTD, and other gas industry experts up to date on status of GQS development, capabilities, and commercialization efforts.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Next Generation Infrared Burner



Researchers are designing, building, and testing prototype high-performance, low-emission gas-fired infrared burners that use an advanced metal foam material to offer end users new high-efficiency products. The project team is collaborating with material and burner manufacturers. Field testing at a host site and durability testing at a laboratory is in progress.

Project Description

The goal of this project is to advance the development of a next generation, highly-efficient, low emission gas-fired IR burner for commercial and industrial use, in part by using a novel ceramic coated metal foam developed in Europe. Unlike conduction or convection, IR heating transfers heat through electromagnetic radiation (light). As IR light is absorbed by the load material, its surface is heated. This surface-heating phenomenon can be highly efficient by avoiding the unnecessary heating of surrounding air. Using gas-fired infrared (IR) heaters instead of electric-driven IR heaters can significantly reduce both source-energy emissions and end users' operating costs.

Phase 2 built upon Phase 1 results, in which the team successfully tested a range of IR burners from multiple Original Equipment Manufacturers (OEMs) to evaluate performance, durability and limitations of metal foam, ceramic, and fiber materials. The team also identified an OEM and material manufacturer with a patented improved metal foam material that looked promising during preliminary testing. Phase 2 evaluated the performance and improved the design of this prototype burner for IR applications. In Phase 3, the team put a near-commercial prototype at a customer host site for testing and demonstration. Current activities underway in Phase 4 include helping position this new burner to be ready to run on hydrogen-blended NG.

Benefits / Market Implications

Currently, nearly 75% of the IR-heater market in commercial and industrial applications is occupied by electric units. Development of an advanced gas-fired IR burner that can meet market specifications will increase customer choice, reduce operating costs, and save energy on a source basis in most locales.

Technical Concept & Approach

Tasks for Phase 4 include:

Test setup for firing NG-H2 blends

The project team will work with OEMs to design the experiments and make needed modifications to the burner and the test facility to enable blending of H2 with NG. The required hardware for installation and testing of the burner with up to 100% H2 will be fabricated and assembled.

Burner performance at different operating and process conditions with NG-H2

The burner will be tested with up to 100% H2 and with different firing rates, excess air and H2 blending levels to assess the performance of the burner for NOx and CO emissions, start-up times, radiant surface temperature and its uniformity, blow-off limit and safety (ignition, flashback, flame sensing).

Improve burner design for H2 operation

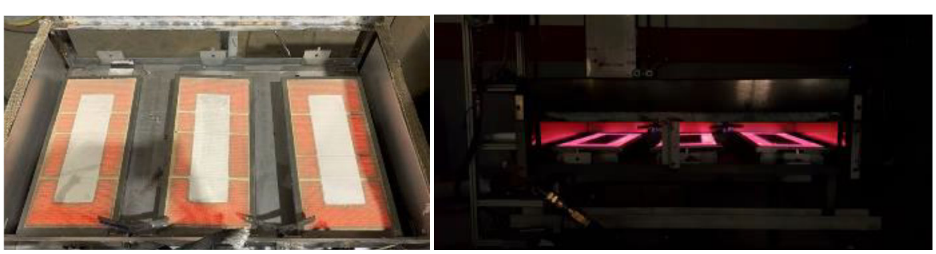
The test results will be analyzed and any needed modifications to the burner to achieve the desired performance targets will be implemented.

Evaluate prototype burner performance reliability

The assembled burner will be tested to evaluate its performance for various key parameters with different levels of H2 blended with NG, including ignition testing, performance testing, and reliability testingfor 100 hours with hydrogen-blended NG.

Results

Researchers selected and tested multiple commercial IR burners to evaluate operational and emissions performance. Different materials and original equipment manufacturers (OEMs) were chosen for the testing to provide a spectrum of performance data. The key performance indi-



Phase 3 burners at Solaronics (left) and in demonstration testing at host site (right)

Test setup used to perform IR burner evaluation with Solaronics burner installed on the test-stand

cators for the burner testing were to successfully achieve target goals for turndown, emissions, start-up and shutdown characteristics, and temperature uniformity.

Testing showed the advantages and key limitations of these burners. The high-throughput burners could provide high output; however, these led to high emissions and potential material degradation. Burner materials such as ceramics led to cracking due to thermal cycling and were difficult to form into different shapes. Other materials such as metal fibers lead to non-uniform mixing, non-uniform temperature profiles, and loss of fiber material due to high-temperature zones.

Metal foam materials testing showed promise in certain aspects, such as adapting to different shapes and layouts, more robust design, and improved thermal cycling characteristics. This material showed the potential to replace a majority of the materials and be able to provide a long-term solution to gas-fired IR.

Emissions and performance testing showed that the non-uniform mixing and high local temperatures led to increased NO_x emissions (>20 ppm @ 3% O2). In addition, the start-up time for a gas-fired IR was high (>7 seconds) with burner material choice making a significant impact.

In 2019, emissions and temperature measurement testing were conducted at different axial locations from the burner surface. A Phase 1 report issued in July 2019 summarized the differences in burner configurations tested.

In 2020, researchers teamed with a burner manufacturer and an advanced material manufacturer to resolve key issues to move the technology to the market. Emissions and temperature-measurement testing were performed at different axial and longitudinal locations from the burner surface. Test hardware was fabricated to reduce air entrainment and provide more data for comparison with previous data.

"This project is evaluating advanced materials for improved performance, increase efficiency, and durability. It is critical to evaluate these materials."

- Tom Martelle
Chief Engineer
Solaronics, Inc.

In 2021, the project team conducted performance mapping of the burner at different axial and radial locations. showed that emissions were below 20 ppm for NOx and CO dropped below 10 ppm, both corrected to 3% oxygen, from about six inches from the surface of the burner. In addition, improvements to the uniformity of the temperature and the oxygen concentration at a given plane (nine inches from surface of burner) were sought. A host site for a demonstration was identified and design criteria for testing was evaluated. A set of prototype burners was fabricated, assembled, and tested at a host site.

In 2022, heat-flux measurements were performed for the different conditions and were compared with the performance of traditional IR burners. The measurements showed this IR burner was in the similar range (8 to 10 Btu/ft2-s) compared to other industrial burner systems in terms of heat released.

In 2023, Solaronics and one of its customers are testing a pre-production version of the new burner at a host site in California and have collected preliminary test results. Simultaneously, durability testing at an industrial laboratory is in progress for multiple hundreds of hours to further evaluate the market-readiness of the material and burner unit. The project team is also setting up laboratory tests to fire hydrogen and has ordered instrumentation and controls to support that effort. A report issued in August 2023 summarized Phase 2 results.

In 2024, the team completed durability testing and received and analyzed Solaronics testing of the burner. A final report which summarized Phase 3 results was issued to UTD members in July 2024.

Status

The project team is supporting OEMs as they consider commercializing new products that will employ the new material. Under Phase 4 activities, the team is working on setting up test rig for hydrogen testing and assembling flow meters, instrumentation and controls for testing and data collection. Test setup and assembly is in progress with safety analyses being developed for the test skid.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Low-Emissions Efficient Burner for Ovens and Dryers – Field Evaluation

This project is validating the performance of a novel burner both in a laboratory and at an end-user host site. The goal is to advance the commercial introduction of a new burner that will reduce emissions, energy use, and operating and capital expenses for the many end users who use hot air in their process operations.

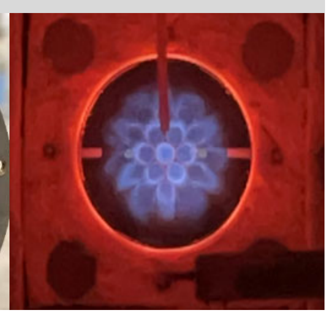
Project Description

In this project, researchers and manufacturers are advancing and refining a new burner that offers 9 ppm NOx emissions and < 50 ppm CO emissions. It uses 3D printing to manufacture the complete burner assembly as a single-step operation which reduces labor and tooling costs, and to fabricate internal geometries which cannot be achieved via conventional subtractive manufacturing. In addition, there is no need to braze the different nozzles together for further assembly.

The goal of phase 1 was to combine a novel burner technology previously developed with UTD's support with other product design improvements into a 3 MMBtu/hr burner-assembly system to heat process air.

Phase 2 will build on phase 1 efforts to develop a natural gas burner capable of operating efficiently and robustly for process air heating applications, by modifying it to provide the desired performance characteristics when firing NG-H2 blends. The technology has the potential to reduce NOx emissions by > 80%, CO emissions down from 300 ppm to 50 ppm, reduce blower requirements by 30%, increase efficiency by 4% and reduce CO2 emissions by 50% compared to conventional NG fired air heaters.

Phase 3 will focus on installing a commercial prototype in the factory of a major burner manufacturer.



Sideview and combustion air inlet ends of the fabricated Design II burner section housing the nozzle assembly

Benefits / Market Implications

Customer application segments for an improved process heater include applications in automotive manufacturing, and food-drying (such as milk-flash dryers). The technology has the potential to reduce NOx emissions by >80%, CO emissions from 300 ppm to 50 ppm, and blower requirements by 30%, while also increasing efficiency by 4%.

The innovative approach taken in this project can reduce emissions and equipment costs, and introduce another product in this market to expand ratepayer's choices and options.

Technical Concept & Approach

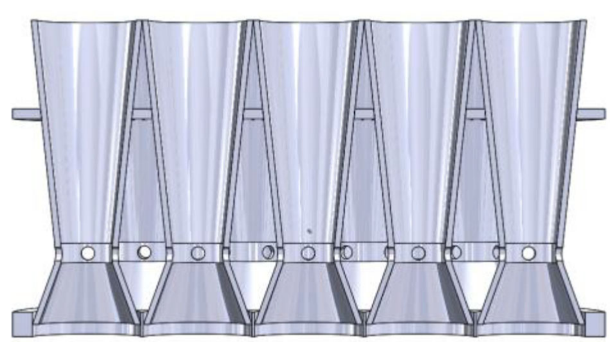
Tasks for phase 2 include:

Develop burner design to burn natural gas/hydrogen (NG-H2) blends

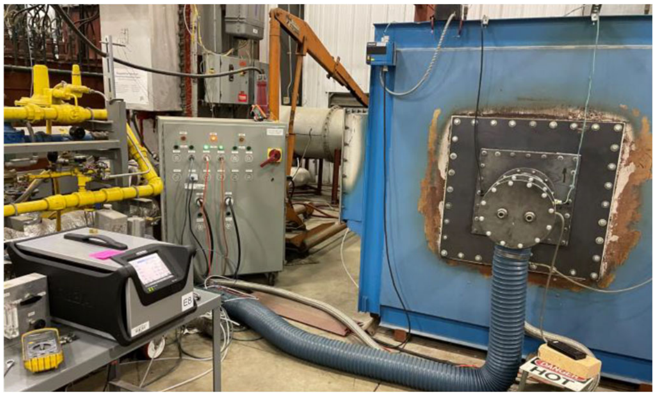
The team will perform design modifications to the improved NG air-heater burner to enable operation with NG-H2 blends up to 50% H2 to provide greenhouse gas reductions compared to NG alone, while maintaining or improving NOx and CO emissions, flame stability, and short flame lengths with no adverse impacts on controls, safety, and burner costs.

Evaluate NG-H2 burner performance

The team will test the NG-H2 burner over the range of 0 to 50% H2 in the fuel in a laboratory. Key parameters include emissions, turndown, reliable and smooth ignition, blower power requirements, and safety.



3 MMBtu/hr 3D-printed burner design



Simulated test rig for air-heating applications.

Data analysis and performance assessment

The team will analyze test data from both NG and NG-H2 firing and to compare ease of ignition, NOx and CO emissions, and operating range of flame stability for NG and NG-H2 firing.

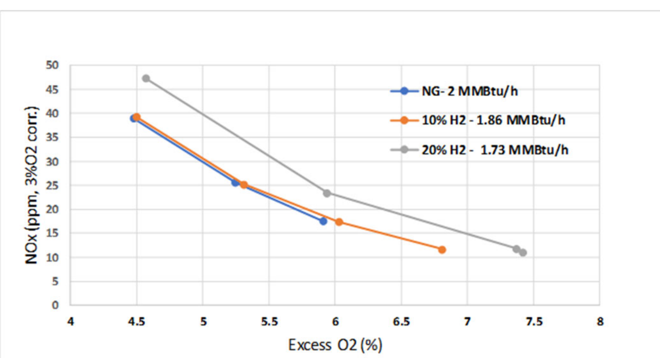
Tasks for phase 3 include:

Design and integrate burner assembly at host site

The team will work with the host site that manufacturers heaters to perform testing and evaluation and to generate design and drawings necessary to adapt the assembly into the host site process. The current hardware is fabricated taking into account the host site equipment and it is anticipated that minimum modifications will be required.

Evaluate prototype burner performance at different operating and process conditions

The team will perform ignition tests to ensure the burner ignites reliably and smoothly at various process conditions. Burner performance will be demonstrated and validated in a laboratory setting.



80%NG-20%H2 blend testing showing ultra-low NOx emissions for air heating applications

Results

A first prototype burner was designed and tested in 2021 to evaluate performance that resulted in lower emissions and

"There are ongoing efforts to implement transformative innovations in the process heating industry, and this novel 3-D printed burner design shows great promise. We appreciate the opportunity to partner with UTD and the project team to validate and advance its design and evaluate opportunities to expand our range of highly fuel-efficient, safe and environmentally friendly industrial heating technologies."

- David Schalles
VP-Technical Services
Bloom Engineering Co.

good performance in a certain firing range from 1 to 2 MMBtu/hr; however, further improvements were required to achieve the desired for the complete firing range from 1 to 3 MMBtu/hr.

In 2022 and 2023, an improved second prototype burner design was fabricated based on further computational fluid dynamics analysis and when tested on natural gas it demonstrated: operation at up to 6:1 turndown; very low CO emissions of below 10 ppm over the entire range of firing rates; robust ignition and stable flames; and superior NOx performance. Performance testing of both prototype designs were completed with < 9 ppm NOx (corr. to 3% O2) and < 10 ppm CO (corr. to 3% O2) emissions were achieved.

In 2024, the team performed burner design evaluation of four different burner designs. Testing showed that the baseline burner design can provide low emissions and good performance. The different burner designs showed < 5 ppm NOx emissions and provided good turndown.

The team also submitted a technical paper "Design and Development of Advanced 3-D Printed Burner for Process Heating Applications" at the American Flame Research Committee, September 2023, in Denver, CO, USA."

Status

Phase 1 results were summarized in a Final Report to UTD Members that was issued in August 2023.

The team is currently working on laboratory modifications for H2 operation. Discussions with a host site to demonstrate its performance at its location on natural gas are in progress. Separately, additional laboratory testing, evaluation and optimization of the burner to operate using up to 50% hydrogen blended into natural gas remains in progress.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD
Utilization Technology Development

High-Efficiency, Low-Emission Commercial Baking Oven Field Demonstration

A field demonstration is being conducted to validate at least 10% CO_2 emission reduction and 25% NO_x emission reduction in commercial baking settings by applying advanced ribbon burners coupled with optimized combustion controls technology.

Project Description

The gas-fired ribbon burner is a mature, low-cost technology that is widely applied in many industries, such as baking, drying, and surface-treatment applications.

The objective of this project is to demonstrate at least a 25% NO_x emission reduction by optimizing the combustion process in a multi-zoned commercial wholesale baking oven within the environmental jurisdiction of California's South Coast Air Quality Management District (SCAQMD). Carbon dioxide emissions are also anticipated to be reduced by 10% through combustion system optimization.

The project team is demonstrating the performance of a combustion system with advanced ribbon burners and a control system that uses an Integrated Flame Plasma Analyzer to continuously analyze and monitor the air/gas mixture being delivered to the burner to optimize the flame chemistry in each zone of the oven (called an Ecozone). This signal is used as input to operate a gas flow valve to maintain optimal flame chemistry. This ensures that the preset optimum air/fuel ratio is constantly maintained regardless of changes in temperature, humidity, or gas composition.

The advanced ribbon burner configuration to be demonstrated in this project successfully integrates both traditional ribbon and metal-fiber infrared options. Combustion performance is achieved with a simple changeover between infrared and blue-flame ribbon modes. The approach theoretically provides the means to minimize NO_x and CO_2 emissions while operating the burners at the most efficient firing rate possible at every moment of the baking process.

Testing and performance data will be collected over a wide range of operating conditions at a large commercial bakery operated by a leading U.S. grocery retailer to prove the anticipated energy savings and environmental benefits. Testing is being coordinated with a leading burner manufacturer and an independent measurement and verification contractor.

UTD is partnering with SCAQMD and SoCalGas in this effort by providing co-funding to SCAQMD's prime funding.

Benefits / Market Implications

There are more than 3,000 commercial and wholesale bakeries in the U.S., and the U.S. baking industry consumes more than $870 million of energy annually. Additionally, the baking industry in many air-management districts is subject to strict NO_x emissions limits. Offering a technology that promises both energy and emissions reductions is an attractive prospect for the baking industry for financial, environmental, and social reasons.

End users that will benefit include wholesale bakeries using direct-fired ovens and other users, such as for flame treatment, gas-fired drying, process heating, and other industries using ribbon burners and zonal control systems for process heat.

Wholesale bakeries are very energy-intense operations. Energy efficiency is typically low, but upgrades to improve the energy efficiency of bakery systems are often unlikely to occur if they require costly downtime and significant capital investment. The technology being investigated in this project can be implemented without significant change or modification to the oven, the products, or the exhaust hardware. The burner fits in standard oven sleeves and burner plates.

The optimized combustion process demonstration in this project is expected to reduce natural gas consumption by 10%. Additionally, the innovative burners are expected to

Combi-burners, zone 5 replacement and interior re-firing

Photograph of the burner test-stand (clockwise from left: overall view of the test rig, test stand, fuel and air metering equipment, sampling equipment)

reduce combustion system NO_x emissions by at least 25%, helping bakeries continue to meet and exceed stringent emissions requirements.

For a bakery that uses 18 MMCF of natural gas each year (such as the host site for this project), this represents almost $7,500 savings in energy costs and 157 pounds of NO_x reductions for the facility.

Technical Concept & Approach

Specific project tasks include:

- Host site performance historical assessment and baseline testing data analysis
- Engineering, fabrication, and purchasing of the demonstration system components
- System assembly and installation
- Startup and shakedown
- Data collection and performance monitoring
- Data processing and analysis, and
- Project management, administration, and scheduled reporting.

Deliverables include a presentation of demonstration results and comparative techno-economic analysis for wholesale baking.

Results

Baseline performance testing of the existing baking oven combustion system at the host site was conducted to establish a benchmark for the follow-on performance comparison and techno-economic analysis. Combustion emissions (including NOx and volatile organic compounds) were evaluated by the project team and verified by an independent contractor.

Engineering of the new demonstration combustion system was completed. Components of the demonstration combustion system were then fabricated, delivered, and installed at the host site location, followed by system startup and shakedown. Based on technical issues identified during the system shakedown period, the OEM modified aspects of the burner and then performed laboratory testing. Two replacement burners were shipped to site for functional testing in the oven, installed in April 2023, and lit and tuned. Based on positive results, the remaining burners were modified and prepared for shipment for final testing.

Unfortunately, further testing was restricted due to multiple unrelated factors, largely the impact on production, with subsequent project delays. Because of this, it was agreed to move testing from the production bakery host site to a laboratory setting, which will permit thorough testing under a wider range of conditions without negatively affecting production.

Status

The team is working to complete the final tests in an industrial laboratory. The project is expected to be completed in the first quarter of 2025.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Energy Source Options for Industrial and Large Commercial Gas Users

Information is being developed to help end users identify the best opportunities for decarbonization by changing energy sources, using renewable natural gas blends, and/or making efficiency improvements in industrial and large commercial market sectors.

Project Description

This project supports industrial and large commercial end users as they seek to reduce greenhouse gas (GHG) emissions by providing them with comprehensive new analytical resources. Researchers are developing and validating a tool to analyze the economic and environmental impact of fuel-substitution options with related strategies. The tool is comprised of a number of interactive inputs that allow an end user to examine several potential scenarios for carbon-emissions mitigation on both an economic and environmental basis – including changing energy sources, using renewable natural gas blends, and making efficiency upgrades. The initial version of the tool focuses on boilers used for process and/or space heating – one of the largest end-use applications in multiple industries.

The tool will assist industrial and large commercial end users in understanding the tradeoffs for different carbon-mitigation scenarios, accounting for annual energy costs, equipment costs, infrastructure costs, full-fuel-cycle GHG emissions, and the total life-cycle costs associated with GHG-emissions reduction. The tool incorporates baseline natural gas consumption as provided by the end user. The tool can perform qualitative and quantitative evaluations of the carbon-mitigation alternatives and help end users prioritize options that provide the best economics and the most cost-effective reduction in GHG emissions.

The tool will allow users to calculate impacts on an individual customer level and could be used to aggregate customer data based on industry SIC code. The carbon-mitigation options evaluated include: displacing a percentage of the baseline natural gas technology with a commercially-available electric version (e.g., replacing a certain percentage of existing natural gas boilers with electric boilers); incorporating a percentage of renewable natural gas in the gas supply; and replacing a percentage of baseline gas equipment with higher-efficiency gas-fired equipment.

Example of an industrial boiler installation. Image Credit: Hurst Boiler and Welding Inc.

The effect of a carbon tax is also included in the analysis, as well as an option to purchase carbon offsets as part of total mitigation measures and scenario options analysis.

Benefits / Market Implications

According to the U.S. Energy Information Administration, the energy use of the industrial sector is projected to grow nearly twice as fast as that of other end-use sectors through 2050. Industrial applications consumed 26.1 quads of energy in the U.S. in 2023, accounting for the second-largest share (35%) of direct end use energy consumption (i.e. excluding electrical power generation) in the U.S. Thirteen percent of that (3.4 quads) is from electricity while 42 percent (11.0 quads) is from natural gas. Natural gas provides well over 50% of the energy consumption in specific industries.

This project provides end users and local utilities with insights regarding their decarbonization options such as for industrial and commercial process-heating boilers, water heaters for hospitals, nursing homes, and other life safety-critical institutions, food processing facilities (vegetables, grains, etc.), and process facilities with steam demands.

Options for reducing emissions in the industrial sector include improved energy efficiency, deploying new manufacturing techniques, using lower-emitting fuels, and integrating combined heat and power or carbon capture and storage.

Technical Concept & Approach

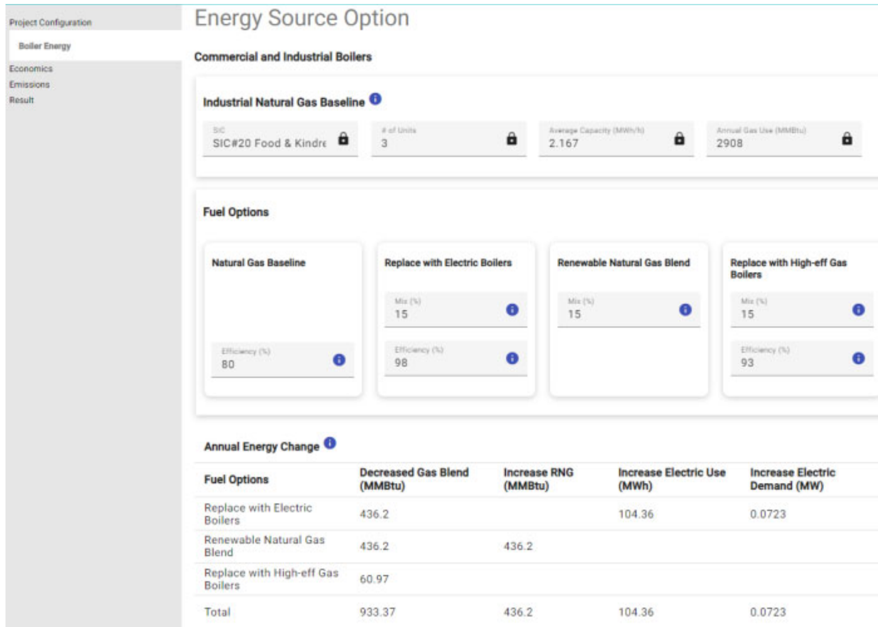
Current Phase 3 efforts are refining and expanding the tool, and then testing the tool by analyzing examples of industrial applications which are being considered for emissions reduction strategies, coupled with the techno-economic analysis, to support decision-making. Tasks for Phase 3 include:

Identify end-user sectors of furnaces and ovens

The team will identify and summarize furnace and oven applications currently being considered for decarbonization and sustainability improvements. The data available for end-use sector, suppliers and geographic distribution will be analyzed and presented.

In-depth application study examples

The team will analyze hydrogen blended to 30% vol as a potential boiler fuel. While not yet commonly available, hydrogen blends show potential for emissions reduction and cost containment when compared to electric boilers. The tool will offer users a comparison of energy changes, cost impact and emissions changes for firing boilers with hydrogen blends.



Test Enviroment Shown at the Boiler Energy Page

Software tool development

The study findings will be incorporated in an online tool, with software development efforts focusing on clarity, ease-of-use, and accuracy of supporting information. A current prototype version of the tool will be tested by UTD utility members.

Results

In 2020, a Microsoft Excel spreadsheet tool was developed and initial analysis was performed for specific UTD members who provided industrial boiler data. This allowed for an investigation of the tradeoffs between equipment costs, customer electric electricity infrastructure costs, CO_2 emissions avoided (or added), and the costs associated with CO_2 emissions reduction their service territories.

In 2021, a database of industrial energy consumption data was analyzed for key end-use applications, and was used to prioritize the industrial technologies based on geographical locations that were linked to individual funders' service territories. The total industry consumption was analyzed for nine different census regions. A database of 77,000 data points was used to categorize the energy use for each of the nine census regions based on five selected subsectors (i.e., food processing, process heating, space heating, etc.). Each of the five selected subsectors was then divided into 18 key technologies to better understand the overall spectrum of end uses and to identify the technology consuming the highest amount of energy under each of the key subsectors, with a geographical indicator.

Researchers performed a market assessment and techno-economic analysis of possible energy source options and electrification scenarios for a spectrum of industrial and large commercial subsectors and end-use applications.

In 2022, the spreadsheet-based tool was transitioned to an online platform. Several GHG reduction pathways for process-heating segments were identified and evaluated on a preliminary basis, including net-zero carbon alternative fuels, renewable energy options, energy efficiency improvements (waste-heat recovery), electrification, hybrid energy sources, and system optimization and control. For Phase 2, the team focused on expanding this tool to include boilers.

In 2023-2024 the team worked to identify furnaces and ovens using EPA emissions reporting databases, but it was concluded that the databases are not sufficiently detailed for accurate unit-level data. Some related work being done by NREL is being evaluated to see if it will provide application and geographic location of installed furnaces and ovens. Efforts to evaluate hydrogen-fueled boilers were expanded. The team converted the current program for boilers to be in a more user-friendly format. The boiler calculations have been tested for accuracy.

Status

Phases 1 and 2 have been completed. The team has started developing the calculations for hydrogen boilers and Phase 3 work is ongoing. The current prototype version of the tool will be tested by UTD utility members. The program will be finalized after user testing is completed, or additional desired improvements are incorporated.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

High-Hydrogen Burner for Commercial and Industrial Applications

Researchers are designing, fabricating, and testing an advanced fuel-flexible, high-hydrogen/renewable natural gas burner for commercial- and industrial-scale furnaces. Input from two national laboratories and from representative end users will help ensure that the final prototype burner meets performance requirements.

Project Description

In earlier UTD-funded efforts, researchers successfully developed and bench-scale-tested a new 3D-printed burner design capable of operating efficiently and robustly. This project will demonstrate a scaled-up burner in a laboratory with high hydrogen (up to 60%) to evaluate the technology with Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), and two leading large gas users.

The innovative 3D-printed burner design is anticipated to provide greater fuel flexibility with high turndown and ultra-low emissions. This design has the potential to enable the use of fuel gas containing high hydrogen without extensive modifications. Example potential applications include process reheaters, heat-treating furnaces, and mini-mills that currently use large amounts of natural gas.

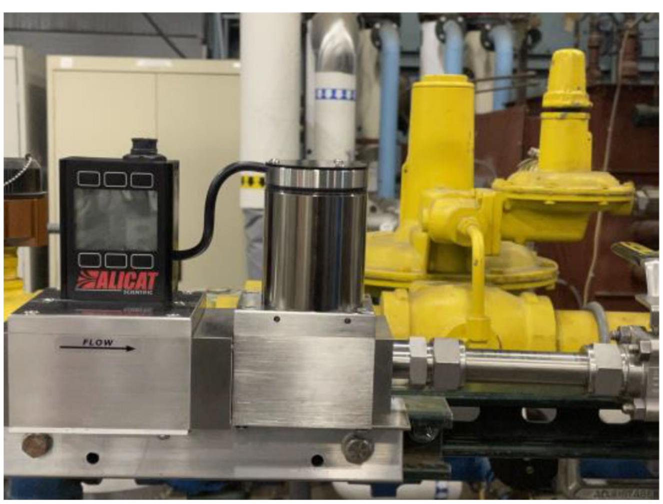
In this project, a research team will design, develop, and test the advanced fuel-flexible burner in a laboratory environment furnace to evaluate and compare the burner performance with corresponding state-of-the art natural gas burners.

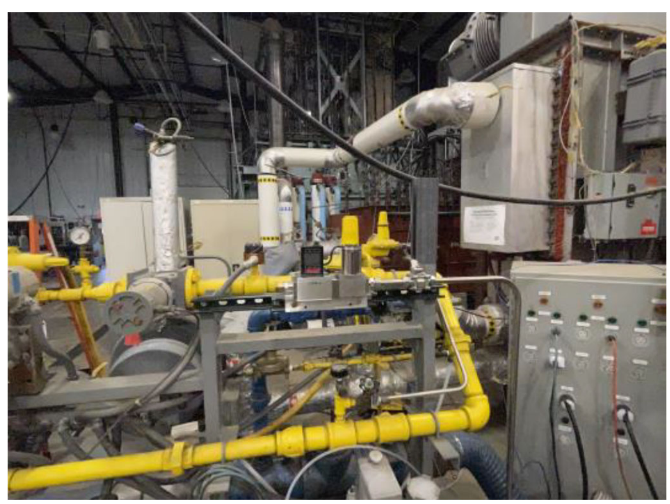
Phase 2 will build upon the results from Phase 1 to achieve sub 5 ppm NO_x (corr. to 3% O_2) in certain firing ranges. Phase 2 will also evaluate how the performance of the 3D-printed burner approach compares with the FlexGen-H burner being developed in UTD project 2.24.C, in order to provide end users with more product options for high hydrogen service while simultaneously providing efficiency benefits when the burner is used in conventional natural gas service especially for high temperature service.

Benefits / Market Implications

Hydrogen gas (H_2) is being pursued as a sustainable energy carrier and the blending of H_2 into the existing natural gas pipelines as a means of increasing the output of renewable energy systems by converting photovoltaic energy to H_2. Demonstrations of relatively low concentrations of H_2 (less than 5%-15% by volume) are under way across the world. Natural gas blended with renewable hydrogen can provide a stable, low-emissions, energy-efficient long-term solution. But to achieve larger GHG reductions, burners that are capable of operating with high concentrations of hydrogen are needed.

Blending of hydrogen into natural gas can present some challenges to various end-use applications in terms of efficiency, process control, or pollutant emissions. A burner capable of handling variable and high H_2 gas concentrations can provide a long-term and sustainable solution and will be particularly beneficial for difficult-to-decarbonize sectors such as industrial and large commercial applications.





Installed H2 flow meter for testing with higher H2 and all parts ordered for assembly

Technical Concept & Approach

For Phase 2, the project will design, develop and test stable and robust operation with up to 100% H_2 with room temperature air, with recuperative design up to 400°F/204°C air and regenerative design of up to 1000°F/540°C inlet air operation up to 2 MMBtu/h firing. The following tasks will be performed in Phase 2:

Design and Develop Burner

The team will design and develop a high hydrogen burner by modifying and adapting the NG-H_2 design for higher temperatures and higher H_2. The design will be adapted and modified to optimize mixing within the nozzles, flashback potential, and flame characteristics with the burner design with heated air and H_2.

Test Rig Setup

The team will set up a test rig to operate with natural gas along with the required flow controllers and instrumentation. Shakedown of the burner and test cell will be conducted.

Fabricate Hydrogen Burner

The team will generate burner and assembly design drawings to install the burner assembly into the furnace. Installation will include the burner assembly as well as the required flow controllers and instrumentation for hydrogen testing.

Evaluate Performance

The team will perform ignition testing to ensure the burner ignites reliably, repeatably and smoothly. The will ensure all parameters are covered by testing a different process conditions. Testing will characterize the natural gas burner's performance for various key parameters as a baseline for comparison with H_2. The key parameters will be emissions, turndown, blower power requirements and heat transfer characteristics. This will determine the operability and turndown characteristics of the natural gas burner. The tests will occur over a range of firing rates and different air-fuel ratios to evaluate the emissions and efficiency characteristics.

Results

In 2021, the project team evaluated the testing apparatus and instrumentation required to perform hydrogen testing. A flow meter, controls and other equipment for high-hydrogen testing were ordered.

In 2022, the flow meter was installed in the air/fuel train setup. Flow meter shakedown testing was performed to ensure safe and reliable operation. Design changes to the burner were reviewed using CFD analyses.

Air-fuel skid assembly for H2 operation

In 2023, assembly of the air-fuel skid for H_2 operation was completed. Job Safety Analysis (JSA) and Standard Operating Procedure (SOP) were updated to perform H_2 testing and to ensure smooth and safe operation with hydrogen. The tea m performed shakedown testing and completed testing with hydrogen.

Based on Phase 1 results, it can be concluded that the 3D printed multi-venturi burner approach tested meets many of the key performance indicators set for the project. The technology offers potential for significant improvements in natural gas fired air heating, positioning it well against current competitors. The lab prototype burner allowed operation at up to 6:1 turndown to heat process air directly or through a heat exchanger, provided very low CO emissions of ≤6 parts per million (ppm) over the entire range of firing rates and excess air levels tested, provided robust ignition and stable flames, and a NO_x performance below 30 ppm was easily achieved at all 3 firing rates on all fuel blends at specific excess oxygen (O_2) levels (market advantage for these type of burners) and NOx emissions of < 9 ppm were achieved at higher excess oxygen (O_2)

Results were publicly provided in a technical paper entitled "Advanced Hydrogen Burner for Commercial and Industrial Applications" which was presented and published at the Industrial Combustion Symposium of the American Flame Research Committee (AFRC) in October 2024.

Status

Phase 1 has completed and a final report was issued to utilities participating in UTD. The team continues work on Phase 2.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

Field Demonstration of Energy Recovery from Brewing/Distilling Operation

This project is validating an innovative waste-heat-recovery technology at two micro-breweries, and identifying potential applications in other industries. The technology will economically recover heat from brew kettles and re-use it for water heating in order to save energy, lower operating costs, and reduce GHG emissions by up to 25%.

Project Description

This project is developing and demonstrating a Waste Heat Effective Transfer (WHET) energy recovery technology at two working brewing/distilling operations in California in order to validate the technology as a robust and reliable operation where waste heat is available and water heating is needed. Benefits of the WHET technology to recover waste heat and improve energy efficiency for other markets such as commercial laundry operations or agriculture and food processing are also being identified.

The innovative WHET technology combines commercially-available technologies into a simple, reliable, compact, and inexpensive system to economically recover and reuse low-level waste heat. Previous waste-heat-recovery systems have often been large, complex, and often too expensive to be deployed because payback times from natural gas savings were too long. WHET systems can operate efficiently and economically at virtually any scale in any industrial setting where waste heat is available and there is a need for hot water or heated water entering a boiler.

The WHET process is designed to be inexpensive, easy to install, and nearly invisible to the plant operator. Simple payback periods are expected to be under five years.

The process consists of two key components:

1. A heat-exchange module made with fluted, flared, or spiraled copper tubing (to yield enhanced heat transfer rates) installed in the flue containing low-temperature (under 400°F) exhaust gas.

2. The flow rate of water through the tubing is controlled based on temperature of the exhaust gas and water before and after the heat exchanger. A flow control loop with valves is used to mix the heated WHET product water with plant water in a water heater or a working process requiring heated water.

Researchers are validating the WHET technology at two micro-breweries with the goal to recover 15-25% heat from the brew kettles, or 60% of the available waste heat in exhaust gases, and reduce CO_2 emissions by up to 25%.

UTD is partnering with the California Energy Commission (CEC) in this project, with UTD providing co-funding to a prime contract funded by CEC.

The brew kettle and one tank at Alaro Brewing

Benefits / Market Implications

Phase 1 of the project focuses on physically demonstrating the technology in breweries and distilleries, a growing market need. In California alone there are now nearly 1,000 brewery license holders and nearly 100 distillery license holders. The need to heat water, brew, and distill results in a large energy footprint for brewing and distilling, and energy costs and potential savings are high. The WHET technology holds the promise of achieving superior environmental performance for brewing/distilling operations, including a 25% reduction in GHG and NOx emissions.

In Phase 2 researchers are evaluating other industries that can benefit from this technology in order to reduce energy use, energy costs and GHG emissions. One promising application is commercial and multi-unit laundries, such as the 30,000 laundromats located in the U.S. (with more units in Canada) as well as many multi-use residential laundries and institutional and commercial laundries. Agricultural and industrial drying operations also generate large amounts of low-level waste heat that can be used to directly generate hot water for facility and process use. Markets such as these are being quantified in order to support commercialization efforts and in support of some of the analysis and activities in the prime contract funded by CEC.

Technical Concept & Approach

Phase 1 will include the following tasks:

WHET System Design and Fabrication

The team will custom design WHET systems for the two brewery demonstration sites in order to match their batch operating practices. Heat exchangers will be fabricated from extended-surface copper components. The team will assemble the WHET systems in California and install them at the demonstration sites.

WHET Baseline Testing

The team will collect baseline data to determine waste heat available from the brew kettles and the quantity and conditions of hot water used during the brewing cycle. The data will provide a baseline to determine energy savings achieved with the WHET system.

WHET Demonstration Long-Term Testing

The team will perform at least 12 months of WHET demonstration testing at both breweries. Parametric tests will be conducted to optimize energy savings, data on flue gas volume, water temperatures, and water flow rates will be collected, and the team will monitor energy requirements for hot-water heating to determine system energy savings.

Phase 2 will include the following tasks:

Market Identification

The team will identify processes where low-level waste heat is generated and hot water is needed for facility purposes and determine their suitability for WHET application and quantify market size.

Process Optimization and Costs

Potential applications are expected to vary significantly in scale and to operate in batch, semi-batch, and continuous modes. The team will determine the preferred implementation of WHET technology to the different applications and optimize the WHET system layout. They will also determine capital and operating costs and calculate energy savings and payback periods.

Process Analysis for Promising Applications

The team will conduct process analysis for the most promising applications for energy savings and short payback periods. They will include analysis of basic process layouts, methods of interconnection, operating modes, and more detailed energy and mass balances. Results from this task are aimed at providing the information needed to approach partners and sponsors for the demonstration and deployment of the WHET technology in additional markets.

Results

In 2021, the project team focused on obtaining equipment and components, selecting and then working with the installer, and planning for the first installation. One of the originally-planned brewery sites announced that they were closing. The project team then secured a new, second demonstration location while moving forward with setting up the first demonstration in Sacramento, CA.

In 2022, the project team organized the first installation of the WHET system. This included securing delivery of the water storage tanks, controls components, and other parts. The first system was put in place and underwent shakedown testing while brewery baseline data was collected. Preparations began to install the second system.

In 2023, the second demonstration site was forced to close. The team found a replacement demonstration site. The team worked with local contractors and completed the installation process for the second installation during the third quarter of 2023. Baseline testing has been completed at the second site and both sites are now in demonstration mode.

In 2024 testing continued at the second brewery location. In late 2024 the team is modifying the system at the second brewery to extend the hours that the system operates at the brewery.

The most promising applications to benefit from the WHET technology in addition to brewing/distilling installations appear to be commercial laundry facilities, commercial cooking, and industrial drying operations.

Status

The team is installing modifications to the system at the second site to make more extensive use of the recovered hot water. The project team will continue monitoring the performance of the demonstration systems for a minimum of 12 months. The team will concurrently continue to evaluate commercial and industrial processes to find the best applications for the WHET technology to recover the maximum possible waste heat economically. The project is nearing completion. Results will of course be provided publicly in a final report to be published by CEC. Efforts to commercialize the technology are ongoing.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Zero-Emission Processes with Carbon Recovery

Researchers are advancing the development of a new synthetic air-combustion process that simultaneously improves industrial boiler or furnace efficiency when using natural gas – while also lowering GHG emissions and providing a means to capture or convert CO_2 to valuable products.

Project Description

Synthetic air combustion (SAC) is a form of oxygen-fired combustion that offers the benefits of lower fuel demand and decreased emissions. Oxygen firing, however, produces a much higher flame temperature than air firing and requires complete rebuilds of equipment and using a new refractory – all of which is costly.

The goal of this specific project is to advance the development of a new SAC process that simultaneously improves industrial boiler or furnace efficiency when using natural gas, while also lowering CO2 emissions and providing a means to capture or convert CO2 to valuable products. Laboratory tests conducted at industrial conditions and completed in the first phase of this project helped compare calculated and experimental results when using SAC to typical air-fired combustion, and built upon an earlier-stage R&D project to analytically explore the potential benefits of SAC.

Current Phase 2 efforts focus on developing more advanced process layouts, scientific data, mass and energy balances, CO2 capture integration configurations, and cost estimates for SAC processes - - with the goal to prepare for submitting one or more proposals to governmental agencies requesting to receive large-scale funding for much larger next-stage, scale-up technology development and demonstration efforts.

Benefits / Market Implications

This project will help utilities and their customers address GHG reduction goals. SAC can be applied to a very wide range of industrial processes. While some processes will benefit more than others from adoption of SAC, the technology can reach all industrial sectors across the country.

SAC is compatible with a wide range of fuels, making the use of renewable natural gas (RNG), biomethane, and hydrogen-enriched natural gas. Important benefits of SAC are the ability to maintain the existing industrial furnace and boiler infrastructure and to achieve real cost savings that make SAC a practical way to operate in a reduced carbon world.

Targeted benefits to end users and the environment include a reduction of natural gas consumption and CO_2 emissions by >8%. When add-on technologies such as reforming or bi-reforming are included, SAC provides the enabling technology to provide 100% elimination of CO_2 emissions. NOx emissions will also be nearly eliminated. The CO_2 can also be more easily be converted into a number of valuable chemicals, or recovered and sequestered.

This project will also improve product throughput and quality through greater combustion control with a target of a 10% increase in furnace throughput and higher product quality.

Technical Concept & Approach

Phase 2 of this project will advance the SAC technology approach to improve industrial process energy efficiency with integrated carbon management by completing the analyses needed to prepare submission of development and demonstration proposals to governmental agency sponsors such as the U.S. Department of Energy (DOE) or California Energy Commission (CEC). Specific tasks for Phase 2 include:

SAC Process Layouts

Process layouts will be prepared for at least two major industrial processes using SAC technology with integrated CO_2 capture and compression. The layouts will consider options for air separation including cryogenic, pressure swing absorption, and perovskite adsorption. CO_2 capture techniques will consider sorbents, ionic liquids, membranes, and exhaust gas drying integrated with compression.

Options for CO_2 Processing

The project team will review the possible process configurations and determine the most promising approaches. Consideration will be given to CAPEX and OPEX costs, simplicity and footprint of operations, risk of development, and maturity of the needed technologies. The most promising configurations may vary for different industrial processes. The potential layouts will be narrowed down and the most promising will be selected for further consideration.

SAC at Low Fire and Low Oxygen (example of Phase 1 results)

Mass and Energy Balances

Mass and energy balances will be completed for the optimum SAC industrial furnaces for the cases which were selected as the most technically and economically promising.

Cost Estimation

Cost estimates including capital and operating costs for at least two major industrial processes using the SAC technology with integrated carbon capture will be completed. Potential industrial processes include cement clinker production, glass melting, steel production, aluminum melting, and industrial cooking. Options will consider the most promising paths to CO_2 management. Costs will be compared with the costs of current operations of the industrial processes.

Results

The team first conducted synthetic air combustion tests using synthetic air containing oxygen and carbon dioxide at ambient temperature. Results confirmed that burners run well on synthetic air. With CO_2 alone, NO_x is low, but CO is high under certain firing conditions.

In an effort to reduce CO, the team tested a preheated synthetic air containing steam and CO_2 at elevated temperatures. Testing found that the burner was stable when firing with synthetic air and heat release was similar to firing with air and natural gas. NO_x emissions dropped to near zero. CO levels were significantly lower than when firing with synthetic air containing only CO_2, but CO levels were still well above the levels obtained with air firing. The CO level could be lowered to the same levels as obtained with air firing by increasing the oxygen to natural gas ratio.

The team calculated conditions for the parametric synthetic air combustion tests with synthetic air containing oxygen, steam, and CO_2. The results indicate a small amount of CO_2 dissociation is occurring in flames, and the CO is elevated because a large fraction of the inlet gas to the burner is CO_2 when firing with synthetic air. To avoid the need to use high levels of excess oxygen, burners may need to be designed to change mixing patterns so CO_2 dissociation is avoided.

Several possible paths were identified to incorporate CO_2 capture. The team is focused on evaluating:

Conversion of flue gas CO_2 to syngas, merchant gases, methanol, or ethylene

This approach avoids the cost of CO_2 compression, transport, and sequestration. In some configuration, the separation of CO_2 from flue gas can also be avoided.

CO_2 purification

Flue gas from SAC (or oxy-gas combustion) can be cleaned to remove particulates, NO_x, and SO_2 using commercially-available methods. Removing residual O_2 making up 1-4% of the flue gas is challenging but can be carried out using thermal oxidation over known commercial catalysts. This leaves a gas containing CO_2 and steam. A sequence of compression steps with recirculation loops can be used to simultaneously compress ever-more pure CO_2 and remove the water.

CO2 purification with membranes

Membranes are more effective, smaller, and less expensive with higher concentrations of CO_2 in the flue gas. That makes them well-suited for SAC and oxy-firing exhaust gases. A promising modification of this approach is to use two membranes. The first 'coarse' membrane would be a hydrophobic membrane such as PTFE to remove a large fraction of the steam from the flue gas. This would significantly decrease the volume of flue gas and increase the CO_2 concentration. The first membrane would allow system designers to use an even smaller second 'fine' membrane for CO_2 recovery. Since the CO_2 recovery membrane is much more expensive, the overall process, even using two membranes instead of one, could be less expensive than using a single CO_2 purification membrane.

Temperature swing absorption

Some industrial processes have either high temperature exhaust gas or a large volume of medium temperature exhaust gas. This can often be true when operating with SAC or oxygen firing because the exhaust volume is reduced significantly. For these processes, a temperature swing absorption processes using a physical sorbent such as modified carbons, zeolites, or metal organic frameworks (MOFs) could prove straight forward and inexpensive

Status

Phase 1 is complete and a final report was issued in November of 2023 to the utilities participating in UTD. Phase 2 efforts are nearly complete and a final report is being prepared which includes the preparation of layouts, mass and energy balances, economics to be used to compare CO_2 capture approaches, and detailed analyses for the selected CO_2 capture approaches.

The results of this research directly supported a proposal that was submitted to DOE in October 2024 in response to DOE's solicitation #DE-FOA-0002614, requesting that DOE provide a prime funding award for next-stage efforts to develop and demonstrate this exciting technology development at larger scale. The project team is hopeful that DOE will provide this funding.

For more information:

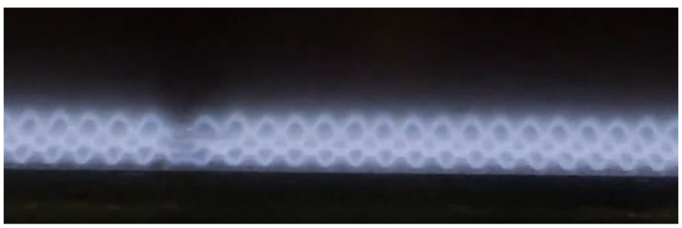
Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Ribbon Burner Performance With Hydrogen-Blended Gases

Researchers are evaluating the performance of traditional ribbon burners when operating with hydrogen and hydrogen-natural gas blends, with hydrogen content in the gaseous fuel from 0% to 100%. This research supports decarbonization efforts by end users in the baking, heat treating, and similar industries.

Project Description

The goal of this project is to evaluate the performance of traditional ribbon burners when operating with hydrogen and hydrogen-natural gas blends in the range of hydrogen content in the gaseous fuel from 0% (natural gas only) to 100% (hydrogen only), in order to prove technical feasibility and identify the optimal performance along with possible design gaps. The data and correlations obtained will serve the project team as a basis for developing innovative decarbonization concepts and hardware that will integrate green hydrogen production (zero carbon).



Natural Gas – Air baseline tests with a new burner from an OEM

Benefits / Market Implications

Deep-decarbonization policies are being expanding across the continent. That's why low-carbon, carbon neutral or zero-carbon solutions are of industry's great interest.

The primary target market is industrial wholesale baking. The baking industry is a huge business. It is projected that the revenue of bread and bakery product manufacturing in California will be approximately $5.82B by 2024. Government regulations continue to challenge the industry. The U.S. Environmental Protection Agency, the U.S. Food and Drug Administration, SCAQMD, and other entities oversee the operations of bakeries and issue new rules and regulations.

In addition, if many customers demand "climate-smart bread," then bakeries would have to prove that their bread production uses less energy than the average loaf and emit less harmful emissions. The current carbon footprint of the average wholesale bakery results in a range of 977-1,244 g CO2 eq. per loaf of bread.

Some baking applications, such as pita bread production for example, are very hard to be electrified because it requires a

Pita bread baking oven interior

flame presence, so fuel substitution is a likely viable option for pita bread baking.

Potential secondary target markets for further consideration include surface treatment and material thermoforming

Ribbon burners are widely employed across wholesale baking industry and estimated to produce over 39,000 tons a year of NOx annually in the United States. Specific burner type and firing rate depend on the product baked (bread, crackers, tortilla, bagels, etc.). Implementation of the appropriate fuel-switching technology may significantly reduce carbon footprint as well as improve energy efficiency of the operations.

Technical Concept & Approach

Ribbon burner performance will be evaluated based on a test matrix including fuel consumption, combustion emissions, temperature profile, and flame characteristics. Operation of the burners (flame shape and color, combustion and ignition stability) will be observed in the range of the hydrogen natural gas blends of 0-100%.

The project is broken down into 3 major tasks:

Lab-Scale Test Rig and Fuel Supply Setup

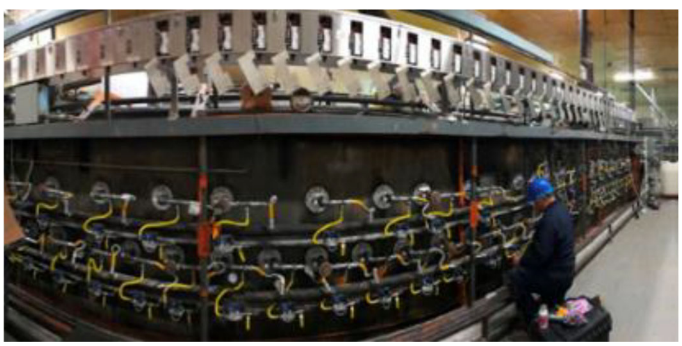
The team will construct a test facility to analyze the selected ribbon burners' performance in a controlled environment. This will include selecting the type and size of the ribbon burners to be evaluated; assembly of the components of the ribbon burner combustion system along with the control, measurement, appropriate ignition, and flame safety; setup of a gas blending system or purchase the required hydrogen-natural gas mixture; development of safe operating procedure for test firings; and startup and shakedown of the test rig.

Test Matrix Development and Performance Data Collection

The team will collect the data of the selected burners in the range of the hydrogen-natural gas blends of 0-100%. This will include development of a test matrix and selection of appropriate measurement protocols; collection of the performance data (fuel consumption, combustion emissions, temperature profile, flame characteristics); observation of the burners' operation (flame shape and color, combustion and ignition stability); and reduction of the raw data for the follow-on analysis and representation.

Data Analysis and Final Reporting

The team will analyze all project findings and report them to project funders. This will include performance data on ribbon burner heat release and emissions in a range of tested hydrogen content and recommendations for H2-retrofit in industrial bakery settings and for a follow-on demonstration.



Exterior of an industrial demonstration oven

Results

The type and size of the ribbon burners were selected to evaluate the performance of burners with a mixture of hydrogen and natural gas. A test rig was set up to analyze the selected ribbon burners' performance evaluation. Ribbon burners were tested with mixtures of 0-100% hydrogen and natural gas.

Performance data (fuel consumption, combustion emissions, temperature profile, and flame characteristics) were collected for selected ribbon burners (Task 2). The analysis of

Ribbon burner test setup in laboratory

experimental data on the tested ribbon burner in the range of the tested hydrogen content was carried out (Task 3).

Selected burners with different geometries have been successfully demonstrated to operate stable, without flashback at fuel hydrogen content up to 95% by volume. With 100% hydrogen, flashback and/or false triggering of the flame sensor is observed. The test results were discussed with an OEM of ribbon burners.

The team recommissioned the experimental test setup and performed some baseline tests with the new burner received from an OEM. They completed rebuilding the test apparatus with mass flow controllers and more precise instrumentation. They also found a solution for flame detection at high H2 concentrations using UV-based sensors.

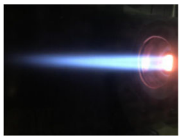
Status

The team has completed upgrades to the experimental apparatus in order to better accommodate hydrogen-natural gas blends. Experimental tests are anticipated to extend through at least Q1 of 2025.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

High Performance Adjustable Port Burner



Researchers are developing an innovative prototype adjustable port burner to provide superior ability to operate on varying mixtures of Hydrogen Enriched Natural Gas (HENG) safely and reliably with minimal emissions (O_2 , CO_2 , CO, NO_x) in order to help accelerate the use of lower-carbon fuels for end users and provide more competing product options.

Project Description

Conventional fixed port burners are constrained by being limited in the variation of fuel or oxidant flowing through the burner because of the need to stay within the required velocity limits to maintain stable combustion and performance. This project is developing and demonstrating a prototype version of an innovative adjustable port burner technology could provide superior ability to operate on variable mixtures of Hydrogen Enriched Natural Gas (HENG) safely and reliably with minimal emissions (O2, CO2 , CO, NOx) compared to current conventional fixed port burners.

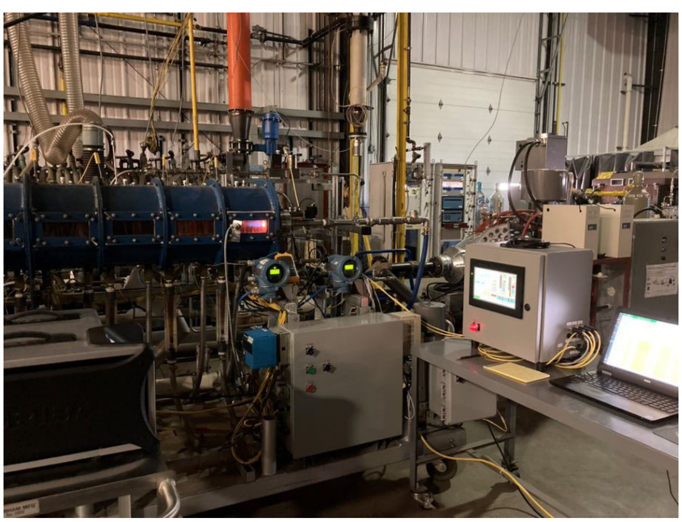
Current Phase 2 efforts will advance the development and technology readiness for the commercialization and deployment of the fuel flexible high performance adjustable port premixed burner with actively controlled element, which when integrated with advanced controls can adjust burner operation for varying capacity, fuel type or fuel mixture composition. The project will scale up the bench scale design from Phase 1 to a larger capacity (2” port; 51.8 mm size) version for demonstration and generation of performance data.

Benefits / Market Implications

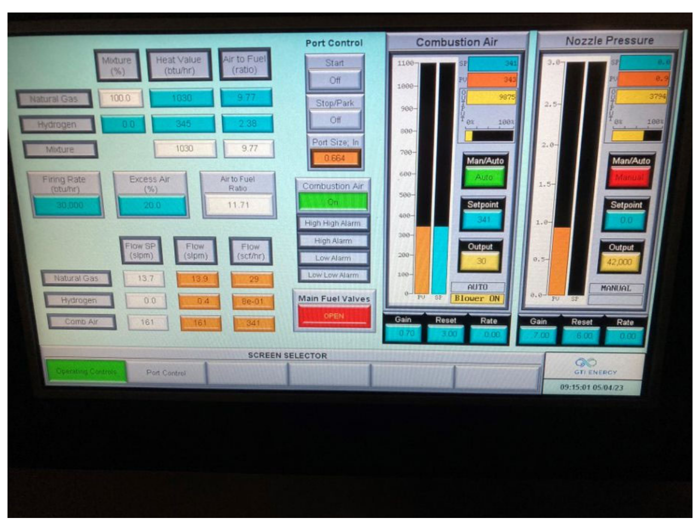
Operating fixed-port burners on HENG or other low carbon fuels can present some challenges in real world use applications in terms of combustion stability, resiliency, efficiency, and process control. There is a need for new technical solutions and there are significant differences in operational requirements for the present designs of fixed-port burners to operate effectively with HENG natural gas mixtures or alternative low carbon fuels. The combustion characteristics of HENG will change significantly as more hydrogen is added to the supply fuel; for example, increased amounts of hydrogen can increase the flame propagation speed by about 5 times. An innovative new adjustable port technology can benefit consumers and ratepayers by: expanding competitive choices when operating on future low carbon fuel alternatives; preventing product obsolescence by being adaptable to changes in gas supply compositions including HENG mixtures; and allowing flexible operation on multiple fuels and lower carbon mixtures while retaining superior performance and operational reliability. This is expected to accelerate the reduction in greenhouse gas (GHG) emissions when low carbon fuel sources are used.

The primary target markets impacted will be commercial/industrial gas-fired equipment in capacity ranges of >0.5 MBH and <15 MBH such as water and firetube boilers, furnaces and kilns, and ovens. Secondary target markets include mCHP, DG and other end use products that can benefit from a fuel flexible high-performance burner.

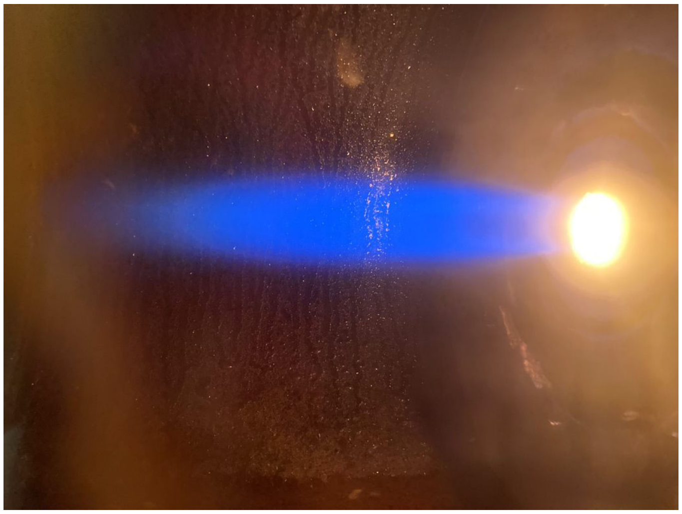
In the U.S., the American Boiler Manufacturers Association (ABMA) reported sales of 4,000-5,000 boilers per year since



Laboratory Burner Testing



Burner Test controls



40% Hydrogen by volume at 90 kBtu/hr

1992 in the <10 MMBtu/hr market segment with an average unit size of 3.5 MMBtu/hr. Boilers in this segment of the boiler inventory are mostly found in the food, chemical and other industries and at education and health care facilities. A 2005 analysis by Energy and Environmental Analysis, Inc. (EEA) for the U.S. Department of Energy estimated that the commercial boiler inventory includes 120,000 units with an aggregate capacity of 1.1 million MMBtu/hr and consume approximately 1,630 TBtu/year, which is 28 percent of all energy inputs in the sector. Commercial boilers at U.S. office buildings, health care facilities and educational establishments account for more than half of commercial boiler units and capacity.

Technical Concept & Approach

During Phase 2 of this project, the design of the adjustable port burner will be increased to accommodate a 2-inch (51.8 mm) adjustable port. The increased capacity burner will be designed, fabricated, assembled, and bench verified for proper operational control. The burner will undergo evaluation for characterization of the design performance. The following tasks are part of Phase 2 :

Burner Design

The team will complete the design and fabrication drawings of the burner with a 2-inch (50.8 mm) adjustable exit port. This task will include designing and optimizing key components of the HP Adjustable Port Burner, including the actuation hardware, ignition and flame detection elements, and necessary support hardware for testing.

Burner Fabrication and Assembly

The team will fabricate and assemble the adjustable port burner based upon the designs generated in the previous task. The fabricated components and nozzle assemblies will be evaluated for proper mechanical function prior to testing and modified if necessary.

Validation and Performance Testing

The team will validate the burner fabricated and assembled in the previous task, evaluating the performance of the burner design using a testing matrix and parameter measurements consistent with typical laboratory burner evaluations.

Results

The testing conducted during Phase 1 confirmed that the adjustable port burner technology provides superior capability for a premixed burner to operate on Hydrogen Enriched Natural Gas (HENG) with higher hydrogen content more safely and reliably than conventionally-designed fixed port burners. The burner provided stable ignition and fuel combustion while operating with changing HENG composition (0 to 80% hydrogen blending), firing rate (30 to 90 kBtu/hr), excess air flow rate adjustments (20 to 35%), and exit port size adjustments made during burner operation. The burner was able to maintain low NOx emission levels throughout the testing matrix. Automated burner operating controls were developed, and they demonstrated how a burner with adjustable port technology can easily be incorporated using a standard industrial programmable logic controller (PLC) and Human Machine Interface (HMI). These controls were used throughout the Phase 1 testing to control the burner firing rate, fuel blend composition, excess air, and port size or exit port pressure control. A Final Report for Phase 1 which describes the work performed, results, conclusions, and recommendations was issued in August 2023.

Status

Phase 2 of the project started in July 2024. The work to date has focused on scale up of the Phase 1 design to the larger 2-inch (50.8 mm) adjustable port. The adjustable port mechanical components have been designed or selected from standard parts and currently work is proceeding on design of the remaining burner assembly components. Phase 2 efforts will also continue to explore opportunities for next-step funding to advance the development of this innovative technology to a larger scale, including seeking governmental or other research and demonstration grants and exploratory discussions with potential commercialization partners.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Tecogen Hybrid Gas/Electric Chiller Laboratory Evaluation

Researchers will validate and help advance an exciting new high-efficiency hybrid natural gas/electric-driven chiller that will increase operational resiliency for end users, expand the integration of gas with renewable electricity, and provide facility owner/operators with increased demand side management of their gas and electricity costs.

Project Description

This project is validating and helping to advance the technical performance an emerging high-efficiency hybrid (natural gas/electric) chiller technology being developed by Tecogen, in order to support its market entry and successful commercialization. The new product will provide 100 tons of chilling, so when its used in multiple units represents a new option for end users that need for example 100-500 tons of cooling. Benefits to end users are expected to include: increased operational resiliency; greater integration of electricity produced from renewable energy with gaseous fuel; superior demand side management control of both electricity and gas consumption; increased opportunities to align with microgrid developments; and excellent reliability which builds on Tecogen's proprietary power electronics / inverter / generator / engine system proven in their InVerde e+ combined heat and power (CHP) product.

The approach incorporates the proven integrated InVerde high voltage DC (600V) power electronics. Packaging will be a single-skid mounted unit that is significantly smaller than Tecogen's existing Tecochill® product line. The packaging approach aligns with current market trends and supports resilience, sustainability, and ease of retrofit. The entire chiller is within the power scope and can power ancillary devices during a blackout. A utility electrical interconnection barrier is not required.

Goals of this project include:

- Demonstrating capacity and measure efficiency from low load to 100 ton rating

Factory test unit showing major components (source Tecogen)

- Demonstrating ability to power ancillary devices during blackout (pumps, etc.)
- Confirming heat recovery operation and capacity
- Supporting optimization of the control system to consider pre-programmed grid carbon intensity (gCO2/kWh), incorporate real-time utilization of heat recovery, and ability to dynamically shift percentage of one power input verses the other to provide the lowest greenhouse gas (GHG) profile.

Benefits / Market Implications

Rapidly-escalating electricity prices and a focus on grid resilience has caused some facility owners to investigate alternative cooling systems such as gas-fired absorption chillers, gas-fueled engine driven chillers, and hybrid systems. Hybrid chillers can be optimized to provide the most economical or lowest carbon intensity cooling, often depending on the time of day used (e.g. during on-peak or off-peak electric periods) or when loads are light.

The primary target markets to benefit from this technology will probably be large commercial, industrial and other applications that need 100-500 tons or more of cooling with a high degree of resiliency and energy source flexibility in gas-grid supply-constrained markets or electric-grid supply-constrained markets with high electrical energy and demand charges. This may include hospitals, nursing homes, and other life-safety-critical institutions; food processing facilities and high-value manufacturing operations for which reliable temperature control is needed to avoid spoilage/lost production during electrical outage; mid-size colleges and universities, high schools; large multi-family residences, governmental or other mission-critical facilities; and corporate or other small/mid-sized data centers.

Tecogen's planned new product offers a hybrid gas/electric chiller to serve the very large market of end-users that need 100-500+ tons with key advantages:

- This product is a compact, integrated unit with built-in controls to allow easy fuel-switching, resiliency, and time-of-day controls, which can optimize operation for maximum GHG reductions, minimum costs, or other factors selected by end user.

Relevant existing Tecogen InVerde e+ CHP product (source Tecogen)

- It incorporates heat recovery for high efficiency CHP when in the operational mode fueled by gas and it's two power sources offer extra resiliency, such as during grid outages.
- It meets the strictest ultra-low emissions standards, including being SCAQMD compliant.
- It allows consumers to avoid electric demand and other peak "time-of-day" charges.
- It can provide power to some ancillary devices during a blackout or even operate without a utility electrical interconnection.

Technical Concept & Approach

The project will validate and help advance the performance of Tecogen's hybrid gas/electric chiller.

The project is broken into the following tasks:

Evaluation agreement

The specifications of the hybrid chiller to be tested, evaluation approach, ownership of data etc. will be developed in an evaluation agreement.

Test planning

The project team will develop a detailed plan for evaluating the performance of the gas/electric hybrid chiller over a range of turndown ratios and operating scenarios. The plan will describe the conceptual retrofit scheme, evaluation test matrix, schedule, duration, measurements to be made and intended outcomes that are consistent with laboratory evaluation.

Installation and testing

The team will prepare a site in a laboratory for the hybrid chiller, secure the unit and initiate testing per the test matrix developed in the previous task, analyze the test results, and develop recommendations to support Tecogen as it further readies the new product for initial field installations.

Results

Tecogen has worked to complete fabrication of the test unit. A Power Control Module was installed into Tecogen's electronics laboratory and successfully tested with power first applied to the engine/generator side and then to the utility side. An outdoor test loop was prepared for chiller testing with the main efforts applied to the chilled water piping.

IIn 2024, Tecogen constructed the 100-ton chiller prototype. Part of the team's focus has been on debugging software. The team also developed a draft test-plan and internal piping and instrumentation diagram (P&ID) to facilitate onsite evaluation at Tecogen's facility.

Tecogen has conducted tests under full and partial loading through its four operating modes in the following sequence: Grid powered through the full bypass mode (the electricity bypasses the power electronics), grid powered through the normal operating mode whereby the electricity passes through the power electronics, engine/generator power only, and blended power to various proportions from the grid and engine/generator. Additional testing focused on operational issues associated with firmware (start/stop sequencing, PID control, etc.)

Status

Tecogen is upgrading some secondary electrical and plumbing components that initial testing identified as being beneficial, as well as making other design improvements such as to enhance noise isolation. The project team is finalizing the draft test plan which will be completed prior to the joint evaluation. Characterization testing is expected to begin soon after some test facility upgrades are completed.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Decarbonizing Large Commercial and Industrial Equipment with Hydrogen

Researchers will determine upper limits for H_2 blending for 3 to 6 commercial and industrial products or equipment categories. Using test data, they will develop H_2 penetration projections and emissions reduction potential. Evaluating equipment limitations is a critical step in integrating renewable hydrogen resources while ensuring the safe reliable, resilient operation of end user's equipment.

Project Description

This project is identifying and resolving research and technology gaps to facilitate the use of hydrogen (H2) in various combustion equipment in commercial buildings and in large commercial and industrial (C&I) processes. The team will identify upper limits for H2 blending for 3 to 6 different pieces of equipment or equipment categories and testing up to 100% H2.

Prime funding for this research effort is being provided by the California Energy Commission (CEC), and this UTD project is partnering with CEC by providing co-funding to CEC's prime funding. The project team consists of University of California Irvine (UCI), the Air-conditioning, Heating and Refrigeration Institute (AHRI), GTI Energy and Electric Power Research Institute (EPRI). Their comprehensive capabilities and contacts will help ensure that the research effort is based on comprehensive existing knowledge, is done in coordination with other global research efforts, and has significant manufacturer involvement.

The project team will identify technology and research gaps to identify equipment or equipment categories to test and analyze. For the identified equipment, they will establish technical upper limits for H2 for 3 to 6 different equipment or equipment categories through experimental tests with up to 100% H2 blends, and demonstrate the emissions, safety, operational and performance variation of these equipment.

Benefits / Market Implications

The project directly addresses UTD's Goals to reduce GHG emissions, achieve superior environmental performance, and integrate renewable energy while enabling the safe reliable, resilient operation of end user's equipment and energy delivery systems.

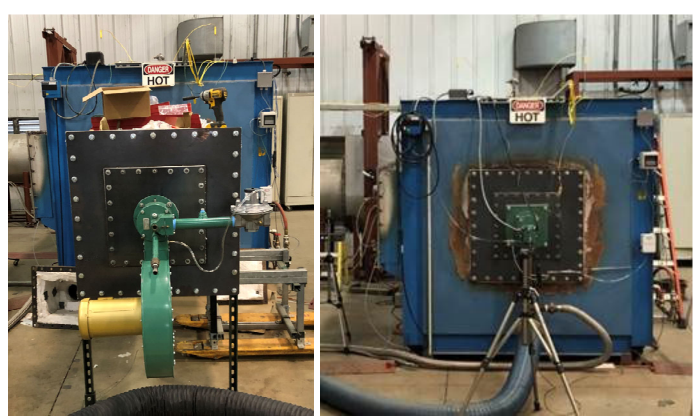
The primary target markets impacted will be commercial/industrial boilers >200 kBtu/h and < 3 MMBtu/h as well as different commercial and industrial applications such as food and beverage, paper and pulp and aluminum.

Decarbonization efforts in commercial buildings and industrial facilities are a significant challenge and NG-H_2 blending is a strong path forward for these applications that is being addressed in this effort. Complications stem from wide-ranging equipment sizes, operating requirements (e.g., high-grade process heat), diversity of application, and broad diffusion across end-use subsectors.

Numerous studies have quantified the decarbonization potential of H_2 in stationary combustion equipment, including those serving C&I sectors. Generally, these are top-down assessments, where the broad classes of equipment and end use applications are grouped into single categories. Prominent examples of these assessments include the California-specific roadmap developed by UCI for the CEC, the U.S. roadmap developed by the Fuel Cell and Hydrogen Energy Association, and the global H_2 study developed by the Hydrogen Council, all of which point to the critical role of H_2 in decarbonizing these sectors. From these studies, the high-end use estimate by 2050 for the buildings and industry is 13 million metric tons (MMT) of H_2/yr in the U.S. This is based on 10% of the 2030 NG demand for these sectors and at an estimated cost of \$5/kg H_2. This translates to a CO_2 emission reduction potential of up to 6.5 $MMTCO_2e$/year - roughly equivalent to more than half of emissions from NG use in commercial buildings (11.7 $MMTCO_2e$/yr).

With more aggressive H_2 cost targets (\$1/kg by 2035 per the Department of Energy goal) and for H_2 injection in the state (up to 20%), this estimate is quite conservative. A significantly higher emissions reduction potential is expected from this project, where the potential for higher H_2 blends will be explored.

This study will implement a bottom-up approach to develop



Honeywell Industrial Furnace Burner 1.5 MMBtu/h and Honeywell Air Heating Burner 1.5 MMBtu/h

"This research will help inform the state and the private sector about the potential for hydrogen to help decarbonize commercial buildings and industrial processes. Some processes and equipment can be difficult to electrify directly, so hydrogen and other innovative solutions will be needed to reach state goals for climate and clean air."

- Patty Monahan
Commissioner
California Energy Commission

more granular datasets than previous studies and the resulting test data will be used to guide the H_2 penetration projections and emissions reduction potential.

Technical Concept & Approach

The work will focus on H_2 implementation and testing for the various identified equipment. Given the unique properties of H_2 as a fuel, we will not focus on a single H_2 blend percentage below which the equipment can operate safely and efficiently, but rather equipment-specific tiers of H_2 blending. These volume-based blending tiers, which will likely vary for each equipment category and/or application. Our study will classify them as:

- "Low" range where little/no modifications are needed for existing equipment
- "Mid" range where moderate operational and/or equipment modifications are needed to accommodate blended H2, and
- "High" range where significant modifications are needed, often prompting replacement with 100% H_2-compatible equipment.

Tasks for this project include:

Test Planning and Preparation

The team will develop a safety plan that will include the design, installation, and operation of the hydrogen blending system. In support of that effort, the team will: conduct dispersion and blast analysis, Hazard and Operability Analysis (HAZOP), Hazard Area Classification (HAC), and Job safety analysis (JSA); evaluate NFPA codes for storage and supply of H_2; and consult other experts such as fire department personnel and NFPA code experts.

Equipment Installation and Shakedown Testing

The team will select and install three to six products from different sectors. The firing rate of the equipment will range from 200 kBtu/h up to 2 MMBtu/h with variable NG-H_2 blends. The operating range, testing methods, and evaluation of the equipment will be determined before ultimately conducting testing and data collection, including shakedown testing of the different equipment to ensure safe and smooth operation.

Assessment of H2 Impacts on equipment

The team will evaluate the following subsystem and process variables:

1) Burner - operational characteristics, impact of modulation, design and performance, pressure drop, 2) Controls review and operation and 3) Other components such as valves, sensors and controllers.

The team will start by conducting baseline monitoring of the existing equipment with natural gas in order to better estimate design loads and inform further testing. That will then be compared the baseline to performance with H_2 blends, including dynamic variation of H2 concentrations. At each condition, excess O_2 and CO, CO_2, NOx emissions, exhaust temperature, and other critical parameters will be measured. Stability and reliability of combustion system, ignition and general operation will be verified during cycling tests, both quantitatively and visually.

Emissions, Performance, Safety Characterization and Analysis

The team will conduct analysis on the performance of the complete packaged equipment and the impact of NG-H_2 blends on emissions, safety, reliability and performance. Using this analysis and feedback from discussions with OEM's, the team will make improvements to the complete system. The team will also identify market barriers, challenges, and drivers for manufacturing and installing equipment that can use H_2-NG blends and develop recommended solutions or areas of research needed to facilitate ratepayer adoption.

Results

The team has developed draft test plans for the different equipment and submitted them to the California Energy Commission (CEC). They have started designing test rigs and have nearly completed testing on two burners in the industrial sector.

The team has been conducting HAZOP analysis, job safety analysis and reviewing safety procedures for installation and testing.

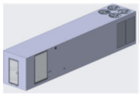
Status

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Mobile Modular Resilient Gas-fired Power Generation



In partnership with a major OEM, researchers are developing prototypes of a 1.4MW containerized mobile power generation unit which can be transported by road, rail, large heavy-lift helicopter, or cargo transport plane in order to provide resilient, reliable power supply for critical operations including in emergency situations.

Project Description

In partnership with a major manufacturer, researchers will design, engineer, and demonstrate the performance of two or more state-of-the-art 1.4 MW agile mobile power generation (MPG) units. These MPG units will use a state-of-the-art reciprocating engine and be containerized so that they can be transported by road, rail, large heavy-lift helicopter, or cargo transport plane.

Goals for this project are to demonstrate the modules can deliver 1.4 MW of uninterrupted back up power (not including parasitic loads) when tied into the building's electric infrastructure while meeting the following targets:

- Power generation efficiency ≥36% at full load based on lower heating value and in accordance with data sheet conditions
- NOx emissions in the range of 1.0 g/hp-hr
- Noise at 23 ft ≤85 db

Benefits / Market Implications

The project directly addresses UTD's goal to enable safe, reliable and resilient operation of end user's equipment and energy delivery systems. The lean-burn gas fueled generator sets from Cummins offer a key benefit over diesel counterparts – lower emissions that make them a cleaner standby alternative. Operating on a lean mixture of fuel and air, they produce up to 5 times less nitrogen oxides output than comparable diesel generator sets and near-zero particulate matter. The unit exceeds US EPA emissions standards without the use of selective catalyst reduction after-treatment systems which are often required in diesel models.

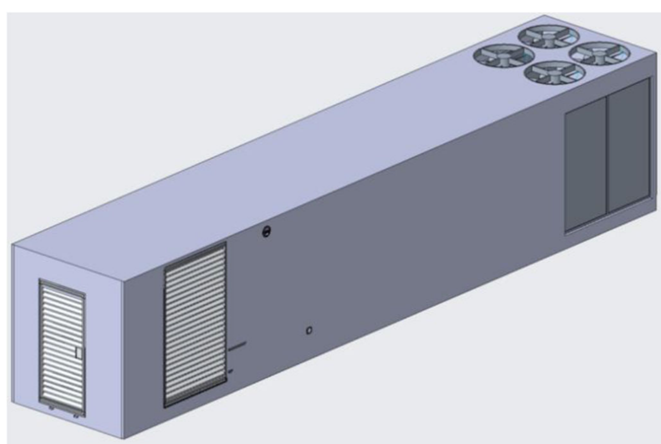
The primary markets for the MPG technology are government, institutional, commercial and industrial buildings and facilities that require capability for uninterruptible and rapidly deployable backup power. Based on industry feedback, end users are increasingly demanding resilient power. The MPG units would also be effective in areas and operations where the ability to derive power from multiple supply sources is critical.

Many facilities and operations require continuous supply of power and any interruptions in this power supply can adversely impact their effective functioning. Loss of power or insufficient power availability is a common outcome in disaster situations.

To increase power supply resilience to operations and installations, the team will develop an agile MPG system to be deployed rapidly and flexibly within a given installation as well as externally to different locations. The MPG unit is planned to include: 1) a containerized 1.4 MW module that can be transported by road, rail, large heavy-lift helicopter, and cargo or military transport plane, 2) a natural gas fired reciprocating engine driven power generator that can be modified to operate on other gaseous fuels, 3) supplementary power generator, and 4) hardware with control systems to facilitate hook-up and electrification of an indoor facility or outdoor power needs. The project will develop and deploy multiple MPG modules.

The US Department of Defense (DOD) is providing the prime funding for the overall effort, and UTD's funding will expand key technical efforts with the intent that the MPG modules developed in this project will be suitable for application to a wide range of institutional, commercial and industrial facilities.

These mobile units could be valuable to these facilities as well as the DOD and other federal agencies such as the US Federal Emergency Management Agency, US National



Rendering of an MPG Module design

Guard, Canada's National Emergency Response System, and others that provide emergency power after disasters. The MPG can be transported by road, rail, large heavy-lift helicopter, and cargo or military transport plane. Supplement backup power capability with enabled seamless connection to existing infrastructure to deliver uninterrupted power is the long-term goal. Ultimately providing critical power in emergencies or anytime auxiliary power is needed, thus speeding up response and adding resiliency to end-user facilities.

If the prototype MPG units are successful, then further advancements of the technology that could be demonstrated under subsequently-funded efforts could include: 1) a renewable component, 2) ability to tie in to energy storage package such as grid-compatible batteries for uninterruptible power supply and start-up, and 3) longer-term microgrid for cluster of buildings with control systems to facilitate hook-up and electrification of an indoor facility or outdoor power needs.

Technical Concept & Approach

The project will assess existing Cummins technologies and host site power profiles, select suitable state of the art engine and controls technologies, build and install the MPG modules with associated UPS and conduct short term performance testing and longer-term performance monitoring of the units. All design and testing activities will take place using natural gas as fuel. The following tasks will be performed in the project:

Technology Assessment and Selection

The project team will assess Cummins current offerings for power to thermal efficiency, turndown capability, controls, switch gear, ease of integration, footprint, noise, maintenance requirements and expected life.

Design, Fabrication, Installation and Testing

The team will then develop design outlines for the MPG system and its installation and integration with the host site's existing power supply system. Two or more MPG modules will be fabricated, installed and commissioned. Both short-term on-site performance testing and longer-term remote performance testing will be performed.

A standard Cummins generator (image credit: Cummins Inc.)

Data Analysis and Performance Assessment

Performance data from testing the MPG modules will be compared against design specifications, including efficiency, turndown, switching time, maintenance events, etc.

Results

The team explored present offering and assessed power to thermal efficiency, turndown capability, controls, switch gear, ease of integration, footprint, noise, maintenance requirements and expected life. The team also investigated data measurement points.

Status

The MPG units have been designed and released for fabrication. The team is focused data measurement and collection parameters that assess power to thermal efficiency, turndown capability, controls, and noise.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD
Utilization Technology Development

Controlled Mixing Burner for Process Heating

Researchers are developing an innovative 0.5-1 million Btu/hr burner for natural gas and low carbon fuels (LCFs) with an ability to accommodate widely varying amounts of LCFs in a fuel stream, in order to accelerate the use of LCFs in industrial process heating applications and thus reduce GHG emissions and integrate more renewable energy.

Project Description

Researchers are designing, building and testing a laboratory protype version of an innovative 0.5-1 million Btu/hr process heating burner for natural gas and alternate low carbon fuels (LCFs), which will allow process heating applications to accomodate widely varying amounts of LCFs in their fuel streams, including up to 100% carbon-free fuels (CFFs) such as H_2 and NH_3.

The team seeks to demonstrate through laboratory testing that the flame size and shape, heat release profile, emissions and turndown capability will remain nearly unchanged irrespective of a fuel's carbon content. The prototype will be tested under different furnace temperatures, % carbon in fuel, and other simulated operating conditions to assess the applicability of technology to key end users as they seek to decarbonize operations.

Goals for this project include:

- Achieve <25% change in flame length, NO_x emissions and peak heat release distance for 0 to 100% H_2 or NH_3 blended in natural gas
- Demonstrate that the burner maintains 4:1 turndown and <50 ppm CO with no stability, ignition and flame sensing issues
- Demonstrate that the estimated cost of burner and complexity of controls are comparable to conventional burners

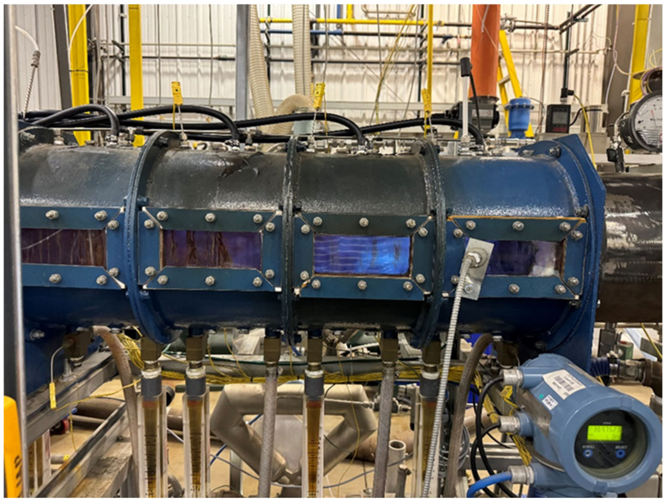
Benefits / Market Implications

This project directly aligns with UTD's goal to reduce greenhouse gas (GHG) emissions. The controlled mixing burner technology can offer many benefits to industrial and large commercial customers that are not possible with currently-available technologies. The goal is to allow end users to burn various LCFs - including those with no carbon - without the need to replace burners or process controls or major intervention by operators, and while maintaining low emissions. Many efforts are underway globally to produce LCFs such as H_2 or NH_3 in large quantities from renewable energy (such as by electrolysis or chemical reformation) and this burner will be an enabling combustion component.

The primary markets for the controlled mixing burner are industrial customers with high temperature processes such as steel, cement, and glass industries. These are attractive first targets to use LCFs since they: have been identified as large fuel consumers with high GHG emissions; often have high temperature/high thermal loads that are difficult to electrify; can more readily justify a large LCF production stream given their concentrated operations with high uptime and duty factor; are sometimes clustered in geographic areas (e.g. industrial zones or parks) that could be candidates for early LCF piping distribution networks. These industries also typically have knowledgeable in-house staff with expertise in combustion systems, instrumentation, and experience burning alternate fuels and oxidants which make them well-suited to employ a controlled mixing combustion approach that uses a wide range of carbon content in fuel.

Burners that allow efficient combustion of fuels containing widely-varying proportions of carbon content in the same burner are not currently available. Having such capability is important considering the wide variety of burner types employed in large commercial and industrial applications. Designing and offering burners that specifically target a specific LCF or LCF content would require several burners of each type at different capacities increasing equipment costs and creating challenges for inventory and delivery times. A combustion system that can effectively burn a wide range of fuels without significantly changes in heat release pattern,

Example of a commercial natural gas baffle burner – (image credit: Hauck)



Control mix burner under test

flame lengths and excess air requirements, or requiring modifications to controls, will significantly benefit end use customers. It can dramatically reduce GHG emissions from industrial and commercial facilities by being able to fire increasing and widely varying amounts of LCFs, which is likely to occur in situations such as when LCF production varies widely because of diurnal, seasonal or other variations in renewable energy output.

Technical Concept & Approach

The project will design, fabricate and test a 0.5-1 million Btu/hr burner in a laboratory under simulated industrial process heating environment. The burner will be designed to generate high-momentum, precisely-shaped jets of combustion air that promote desired mixing patterns and flame size and shape. The fuel system will be designed to strategically inject and blend very low momentum fuel into the combustion air, allowing the air to control air-fuel mixing and combustion reactions.

The following tasks will be performed in the project:

Burner Design and Fabrication

The team will design and fabricate a 0.5-1 million Btu/hr burner and supply and blending station to enable testing of combustion characteristics when fired with natural gas and CFF combinations in different proportions.

Installation and Testing

The team will install the burner on an existing 0.5 million Btu/hr or larger industrial refractory lined and water-cooled furnace and test its performance. Testing will be performed at different firing rates, NG and then NG-CFF blends (employing H_2) and air-fuel ratios. The key parameters will be NO_x and CO emissions, turndown, ignition, blower power requirements, flame size and shape, heat release and safety (overheating of burner components, flame sensor response etc.).

Data Analysis and Performance Assessment

The team will analyze the test data from NG, CFF and NG-CFF mixture firing and compare ease of ignition, NO_x and CO emissions, operating range of flame stability, flame length and shape, noise and blower power requirements for NG, CFF and NG-CFF firing. Working with a manufacturing partner, the team will estimate commercial burner costs and potential market size.

Results

The team designed initial laboratory protype versions of a 0.5-1 million Btu/hr process heating burner, including the preparation of detailed design drawing packages. Fabrication was completed of two test versions of the burner, fuel nozzle reduction inserts, and the mounting hardware required for installation. The first version of the burner with a two-inch insert was installed and initial cold flow and fired operations were conducted to verify the station equipment operation and limits. Through this evaluation, the team determined that the current air blower operating capacity was below the maximum test operating targets. The team completed testing on the first prototype version up at 100 and 250 kBtu/hr with a two-inch insert, and fabricated a higher capacity combustion air blower supply skid with the necessary capacity to provide the maximum test operating targets.

Initial testing with the higher capacity combustion air blower operating on natural gas showed non-uniform combustion, with a portion of the burner not lit. Further analysis suggested that the burner windbox may be too small in volume. A test was devised to evaluate the windbox volume using a static mixer. This premix test approach showed good emissions results, revealing that the volume of the windbox was the issue. Modifications to the windbox were performed and the overall volume increased.

Testing was performed at several firing rates using the new windbox. The flame appeared longer and the flame distribution at the air injection port was more even. The larger wind box has improved the flame distribution around the air injection.

Status

The team is continuing to test the prototypes using the revised windbox design, and is working to further optimize the design of the next prototype.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Flex Fuel Gas Nozzle and Burner for Boilers

Researchers are designing and building a 500,000 Btu/h laboratory prototype version of a novel flex fuel nozzle to fit into existing commercial boiler burners, in order to economically allow various low or no carbon fuels to be more readily used and thus reduce GHG emissions and integrate more renewable energy.

Project Description

The goal of this project is to design and build a laboratory prototype version of a 500,000 Btu/h flex fuel nozzle that can be retrofitted into existing commercial burners, and test its flame flexibility characteristics under simulated boiler conditions when fired with natural gas, hydrogen-enriched natural gas, or other alternate low carbon fuels (LCFs). The team aims to demonstrate that wide variations in flame size and shape can be made through on-the-fly positioning of the nozzle components. The nozzle will be tested to assess the applicability of technology to different boilers and process heating burners in order to optimize performance with both natural gas as well as alternate LCFs. The team will also develop preliminary designs for a 3-5 million Btu/h nozzle and burner.

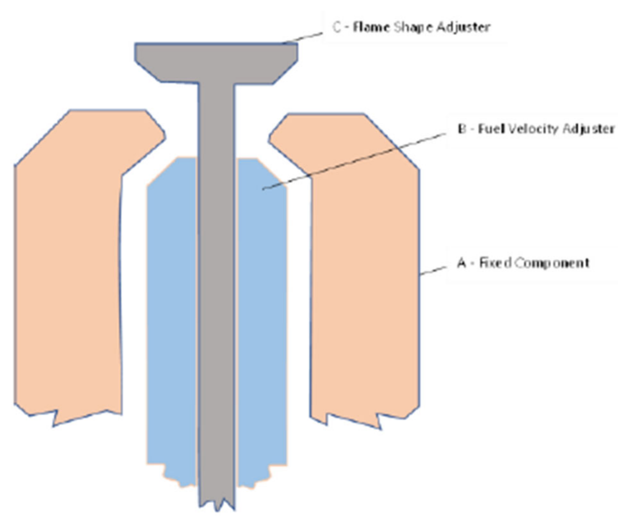
Goals for this project include:

- Modeling confirms that flame length and girth can be changed by at least 2:1 by fuel nozzle adjustments
- Testing validates the modeling results and maintains flame length and girth with 300-1,000 Btu/SCF fuel and with no significant change in air pressure drop
- The burner maintains a 4:1 turndown and <50 ppm CO with no stability, ignition and flame sensing issues
- Incorporating the flex nozzle does not significantly increase design and operation complexity of the burner
- The cost of burner and controls increase by <20% when the nozzle and associated adjustment control hardware are incorporated

Benefits / Market Implications

The primary markets for the flex fuel nozzle are commercial and industrial boilers, which are prime candidates for early adoption of LCFs. These boilers, of which there are more than 150,000 in the US per the US Department of Energy, are used for space heating in commercial and institutional buildings and for process steam in industrial facilities. Compared to process heating which uses a variety for furnace designs, operating temperatures, air temperatures and excess air levels, there is much less variation in steam producing boilers in both design and operation. Most of these boilers fall into two configurations – firetube and watertube. Consequently, there are fewer variations in burner designs and fewer burner models offered by manufacturers for boiler applications compared to process heating. This simplifies the application of the flex fuel nozzle to be compatible with a wider base of boiler burner population and should help accelerate its adoption. Commonly-employed boiler combustion and process control strategies and instrumentation are expected to be well suited to the flex fuel nozzle.

The flex fuel nozzle technology presents several significant benefits for boiler operators and burner manufacturers. One of the primary advantages is its ability to offer wide fuel flexibility, allowing operators to switch seamlessly between various LCFs, including those with zero carbon content, without the need to replace existing burners or make substantial changes to process controls. This adaptability supports the use of a broader range of renewable fuels that can be substantially derived from renewable energy (such as hydrogen made by electrolysis), which is essential for meeting aggressive decarbonization goals.



Simplified conceptual schematic

The nozzle's design also enhances combustion control, allowing operators to fine-tune flame size, shape, and heat flux profile. This precision should enable optimized combustion to reduce emissions, minimize flame impingement, and improve heat delivery - - ultimately enhancing overall boiler performance and energy efficiency.

In addition to its versatility, the flex fuel nozzle is anticipated to be a cost-effective solution in part by enabling retrofitting of some existing burners and minimizing the need for expensive equipment replacements.

Technical Concept & Approach

The project will first fine tune the design of the flex fuel nozzle design using CFD modeling, followed by fabricating and testing an ~500,000 Btu/h flex fuel nozzle on an existing burner under simulated boiler conditions. The nozzle will be designed to provide at least 2:1 variation in flame length and width with natural gas and a selected alternate LCF.

The following tasks will be performed in the project:

CFD Analysis

The project team will conduct Computational Fluid Dynamic (CFD) analysis on the nozzle integrated into a conventional boiler burner to prove the concept analytically and make any needed design refinements.

Nozzle Fabrication and Testing

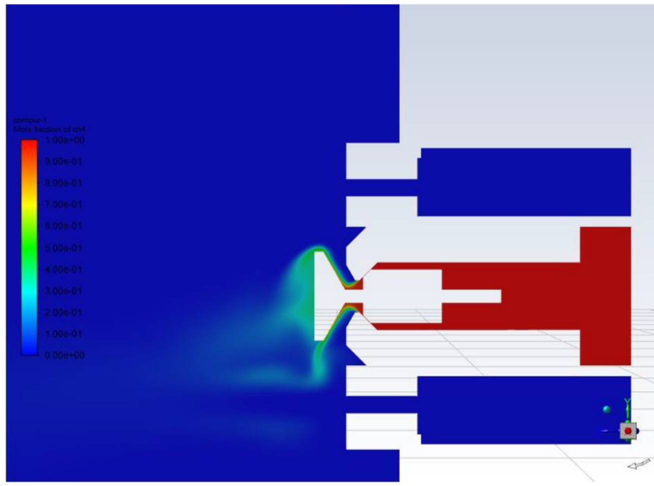
A nozzle will be built, fitted to an ~500,000 Btu/h conventional burner, and then tested in order to prove performance. Tests on natural gas and selected low carbon fuel such as hydrogen will be performed to measure flame size, shape and appearance, and emissions.

Data Analysis and Performance Assessment

Test data will be analyzed to assess nozzle performance. A preliminary design for a 3-5 million Btu/h nozzle and burner will be developed. The project team will partner with manufacturers to assess the market potential and refine the design.

Results

The team completed a preliminary burner design. Computational Fluid Dynamic modelling was started by building a mesh-grid and cold flow analysis. Once methane was introduced at the gas inlet mixing was observed. Further analysis revealed back pressure/back flow in the simulation, leading to unstable combustion. The first structure was designed for one end of the burner design. The next step was to rebuild the structure and re-simulate with the same flow settings and combustion settings. This should resolve the back pressure issues developed from the nozzle design approach. The team generated a revised burner approach and sought input from fabricators on manufacturability. The feedback was critical of assembly with tight tolerances and moving parts. Suggestions from the fabricator were incorporated into a design modification. The revised drawings are under review.



Cold flow mole fraction of Methane (Computational Fluid Dynamic analysis)

Status

The team continues to refine the CFD analysis, and is focused on finalizing the burner design and then starting fabrication.

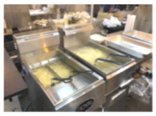
For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

FOOD PREPARATION AND SERVICE

UTD Utilization Technology Development

Commercial Foodservice Equipment Demonstrations



Through restaurant and commercial-cooking field demonstrations in real-world situations, researchers gathered valuable data and refined a performance comparison tool to quantify the operating savings and energy efficiency benefits of gas-fired commercial foodservice equipment for end users.

Project Description

Researchers and gas-industry representatives conducted demonstrations of gas-fired commercial foodservice (CFS) equipment to quantify the benefits of the equipment in real-world situations. Demonstrations were designed to address the reluctance of some CFS operators to replace existing equipment with newer high-efficiency models because of concerns about higher costs or uncertainty that the new equipment will be able to prepare the food as expected. Chain restaurants – which represent about 50% of the CFS industry – more commonly recognize the long-term cost benefits of newer equipment; however, this information is not generally available to the rest of the industry.

In UTD-supported CFS demonstrations, technicians tested selected equipment in the laboratory and/or at commercial demonstration sites and document performance. Testing was conducted with some of the industry's most recent market introductions, including a steam kettle, range, conveyor oven, convection oven, boiler-less steamer, low-oil-volume fryer, and griddle. Other appliances of interest were targeted for laboratory performance testing or field demonstrations.

Demonstration activities focused in two areas: 1) long-term demonstrations in restaurants; and 2) single-day demonstrations at test kitchens and trade shows showing how well new high-efficiency equipment performs when compared to traditional equipment, including the development of software and associated data collection to visually demonstrate equipment performance results.

Griddle testing at Piedmont Tech Center.

Benefits / Market Implications

Verifying the performance of a CFS technology in the laboratory or the field demonstrates the advantages of specific technologies and provide valuable performance information for: end users such as restaurants, culinary schools, and cafeteria; utilities (to aid the development and refinement of their energy efficiency incentive programs); and manufacturers and others with the ability to quickly evaluate appliances (whether gas-fired or electric-driven) and understand the true efficiency and cooking performance of the appliance.

Technical Concept & Approach

The appliance performance and feedback from the test sites were incorporated into reports detailing the benefits and performance of the systems. In addition, a system to provide comparative real-time energy consumption and product performance of various CFS equipment was developed.

Opportunities for demonstrations were identified at other utilities and end-user host sites as additional project funding was provided. The time and cost varied based on the appliance and scope of the tests.

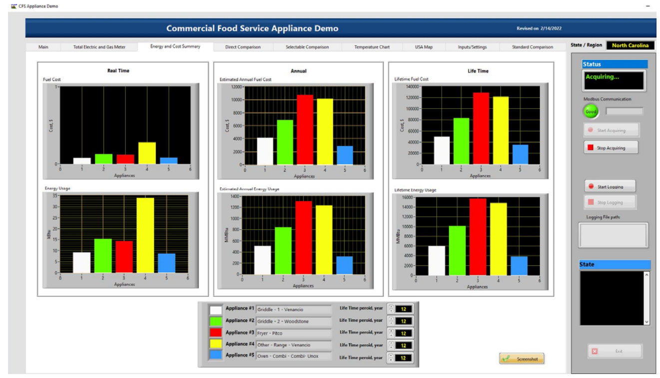
Results

Whole-kitchen assessments (WKA) were conducted at:

- A 120-seat restaurant that serves a wide variety of dishes and is especially known for its extensive dessert menu of pies. **Findings:** Replacing the existing fryers, convection ovens, and griddle with energy-efficient models would save 2,597 therms ($1,346) per year of energy usage. Assuming an operational life of 12 years, the total savings is 31,164 therms and $16,152.
- A full-service caterer. **Findings:** Replacing the existing convection oven, combination oven, and griddle with energy-efficient models would save 668 therms ($349) per year of energy. Assuming an operational life of 12 years, the total savings is 8,016 therms and $4,188.
- Two counter restaurants with menus that focus on hot

"UTD developed and provided software capability that allows our customers to make an informed decision on energy consumption before purchasing. It is user friendly and allows a clear demonstration of energy use with live data. Our new Technology & Design Center is all about innovation, flexibility, and versatility. The implementation of this program adds to the overall capability of the Center, delivering added value and helping our customers make the best purchasing decisions."

- Carl Peterson
Manager, Gas Regional Sales
Piedmont Natural Gas



One tab of the FEMS Tool

dogs, burgers, sausages, and French fries. **Findings:** Replacing the existing fryers and griddle with energy-efficient models would save 2,721 therms ($2,535 per year) of energy. Assuming an operational life of 12 years for both appliance types, the total savings is 32,652 therms and $30,420.

Overall, the WKAs showed the potential savings of 109,000 therms and $85,716 over a 12-year appliance lifespan if the standard equipment used in just these four locations were replaced with existing energy efficient options.

A fryer comparison demonstration was initiated at a casino. The demonstration compared three different models from different manufacturers. Three baseline fryers were monitored. After about a month of monitoring, the baseline fryers were replaced with ENERGY STAR equivalents from three different manufacturers.

In 2018, a cooking demonstration was conducted in Tulsa, OK, where the energy usage for four fryers were compared with each other and with standard gas and electric units. Annual energy cost savings for the highest-efficiency fryer tested was $540 per year when compared with a standard gas fryer and $785 per year when compared with an electric fryer. Data collected during the demonstration showed that a CFS facility could achieve significant operational savings by using energy-efficient natural gas-fired equipment compared with standard gas-fired and electric equipment. Based on these results, UTD members directed the project team to further design and develop a Foodservice Energy Monitoring System (FEMS) under subsequent phases of this project that could be used at trade shows, test kitchens, and similar venues.

In 2019, a new demonstration site was identified and evaluated for replacing an electric fryer with an energy-efficient gas unit. The entire menu is prepared in the kitchen equipped with an electric fryer, oven, and rangetop. Advancements were also made to the FEMS system.

The most recent phase of the project was conducted in 2020-2024, researchers began working on a unique opportunity on a larger rack-oven monitoring project. Data from rack ovens in California and the Midwest was analyzed to determine potential energy savings of efficient models. Efficient gas ovens should have a much lower source-energy use and significant cost savings that can be proven through this project.

The rack oven field data showed that efficient rack ovens can have large energy and cost savings over standard rack ovens. For double rack ovens the ENERGY STAR average oven saved over $1,000 per year over conventional ovens, and the best-in-class oven saved $1,600 over the conventional ovens. The main difference between the ENERGY STAR and the best-in-class oven was the cooking energy consumption and efficiency due to the modulating burner, as well as a more efficient fan motor. Both efficient classes of oven outperformed the conventional oven by having much more efficient idle and setback modes, saving nearly 4 therms per day.

In the second focus of the most recent phase of research, the project team worked closely with Duke Energy to install an improved Foodservice Energy Monitoring System (FEMS) in the test kitchens built into Piedmont Natural Gas's new Technology & Design Center in Charlotte, NC. The system allows for live monitoring of energy use as well as temperatures on multiple appliances being cooked on at the same time. This data is then used by the program to provide estimated annual energy and costs for operating each appliance so that end users can see the large benefit of high efficiency equipment over standard models, while simultaneously seeing how well it cooks. The software was installed in both test kitchens, and a demonstration of the FEMS system was conducted in both test kitchens to prove the system and test various commercial foodservice appliances.

Status

This project is complete. A final report was issued in September 2024.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Demonstration of High-Production Fryers

Commercially available, high-production, high-efficiency fryers were evaluated in restaurants to compare their performance to alternative gas and electric models. The field work demonstrated very large energy savings, which will help end users make more informed product choices as they evaluate energy efficient options.

Project Description

High-energy-density electric-powered fryer models are capable of delivering more heat in a given amount of frying space than gas-fired fryers on the market. However, today's advanced gas heat-exchanger designs can transfer more heat from a burner in a given frying space than electric models, allowing gas models to better serve end users who need high-production capacity.

To demonstrate current technology, in this project a research team tested and evaluated two high-production fryers at field sites.

Sites within the sponsors' territories were chosen to demonstrate the efficiency, cost, and production benefits of commercially available gas fryers.

Benefits / Market Implications

High-performance gas-fired fryers are often used in commercial kitchens. Generally, gas-fired models will save end users money and reduce emissions (on a source-energy basis) versus their electric counterparts. Producing high-production models that cook well and deliver even greater cost savings will further serve end users in the fryer market.

Detroit baseline fryer.

Technical Concept & Approach

Leading high-production gas fryers were compared to standard electric and gas fryers. The team documented the energy efficiency and performance advantages of high-production fryers, including baseline monitoring of previous fryers to demonstrate the potential cost and energy savings. Sites with both legacy electric and gas fryers were found in order to assess the benefits over older-generation models.

Results

In 2018, the research team conducted a field demonstration of a high-production fryer in Oklahoma, with a one-day test demonstration comparing four different fryers. The fryer was installed at a field test site and data and results are being collected.

A high-production fryer was demonstrated in collaboration with UTD CFS demonstration project 1.14.B. This high production and high efficiency gas fryer was compared in a test kitchen one-day evaluation with a low-cost ENERGY STAR gas fryer, a baseline gas fryer, and an additional standard gas fryer the site had on hand (as well as a comparison to an estimated electric fryer). Energy use was monitored in real time with gas and electric meters, while also measuring recovery time with thermocouples in the oil. Results showed that the unit saved 56% energy use while also recovering quicker and cooking the food faster than the baseline gas model. The unit also saved 32% over a low-cost ENERGY STAR gas model.

The project team purchased one of these same fryers for installation at a barbeque restaurant in Tulsa where the performance of existing older equipment had already been baselined. In 2019, the new fryer was delivered and installed in Tulsa.

A second site was found in Detroit and baseline monitoring completed on their electric fryer. At the test sites, detailed energy usage, cost analysis, and usage profile reports were

	Average Daily Energy use (CF)	Annual Therms	Annual Electric Usage (kWh)	Annual Cost	Annual Savings	Percent Savings
Baseline Unit	307.4	1145	-	$840	-	-
Efficient Unit 2020	129.2	481	501.1	$406	$434	52%
Efficient Unit 2021	137.5	512	916.5	$473	$368	44%
*EIA 2020 National Annual Cost of Natural Gas (Commercial) ($/1000CF) (2020): $7.49 **EIA 2020 National Average Cost Electricity (cents/kWh): 10.59						

Rib Crib Royal Range RHEF-45 Results

produced to demonstrate the benefits of high-production gas fryers. The high-production gas fryers were compared to standard electric and gas fryers.

The project team specified and ordered a high-production, high-efficiency fryer to finish out this testing. The new fryer was delivered, but due to complications with the field test sites savings had to be estimated based on rated efficiencies of the baseline and new energy star gas fryer.

In 2020-2022, researchers monitored the high-production fryer in Tulsa. The fryer monitoring had issues with a temperature sensor and control that was leading to the oil being too hot, and this led to the installation of a new controller. Identifying this issue as part of this UTD demonstration project will lead to permanent changes for the model design, and make this high-production fryer operate more efficiently in all future applications.

The research team completed analysis of the site in Tulsa, finding around a 50% reduction of gas use with their new high-production fryer.

Image Credit: Royal Range of California, Inc.

The second fryer demonstration at a restaurant in Detroit was delayed for a long time due to the impacts of Covid-19. The project team specified and ordered a high production and efficiency fryer to finish out this testing and the fryer was delivered during the last quarter, but the restaurant was waiting on other equipment to arrive and completing some facility renovation work before installing the fryer. This site became unresponsive and the team had to use baseline data and rated efficiencies to calculate the energy and cost savings of the new Energy Star gas fryer rather than detailed monitoring of this site.

Results from the Royal Range fryer demonstrated in Tulsa, OK are provided in the table above. The fryer was monitored across two years, and the high efficiency and production range performed well producing a 44-52% cost savings and reducing natural gas use by 55-58% compared to their standard efficiency gas fryer. This produced annual savings of around $400 per year for the site. For the second demonstration in Detroit, the demonstration was not completed due to issues with the site associated with COVID, but based on rated efficiencies and the baseline data the Vulcan fryer to be demonstrated would produce a 55% reduction in their energy cost to operate the fryer. The data clearly showed high efficiency and production gas fryers are a good choice for restaurants for both the energy and cost savings whether that is in comparison to standard gas or electric fryers, or even high efficiency electric fryers.

Status

The project is complete and a final report was issued in September 2024. Large energy and cost savings were shown for the high production high efficiency gas fired fryers over the standard gas and electric fryer models, as illustrated in the table shown above.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

Residential Cooking Pollutants and Indoor Air Quality

Researchers are conducting an analytical and laboratory investigation on the impact of residential cooking on indoor air quality. Rigorous scientific methods are being used to determine emissions. Novel new burner and hood designs are also being investigated.

Project Description

A research team is conducting an analytical and laboratory investigation on issues and concerns for indoor air quality (IAQ) with residential cooking based on information from a review of existing literature and data from other research projects. The project uses rigorous scientific techniques to experimentally determine the impact of residential cooking on IAQ and to identify opportunities to advance technologies. The Propane Education and Research Council (PERC) is partnering with UTD in some phases of this research, with PERC providing co-funding to UTD.

Phase 1 of the project studied capture hoods and showed that the capture effectiveness of residential hoods was less than 50% for cooking on the front burners and would be ineffective at capturing cooking and combustion emissions. Phase 1 also conducted a review of the relevant scientific literature, and the characterization of some studies in some popular press articles. This review also analyzed the methodology of measuring emissions and conclusions drawn based on that data.

Information from Phase 1 was used to guide Phase 2 laboratory tests, including determining which emissions should be measured and what technology improvements may be needed to improve IAQ. A comparison of particulate emissions from natural gas, propane and electric range tops was completed and published.

Residential Kitchen Ventilation Test Setup

The objective of Phase 3 was to develop and test new burner designs for residential ranges. These included drop-in designs for existing ranges and power burners for new models. The goal was to design a drop-in solution for residential range burners with at least a 50% improvement in efficiency and 60% improvement in NOx emissions compared to existing burners.

In Phase 4 the team developed an 80% capture efficient hood and demonstrated a prototype in laboratory setting.

In Phases 5 and 6, the team will expand cooking emissions tests (NOx, PM) of Phase 2 to include induction cooking. This will include measuring combustion emissions, comparing source emissions using UTD funded CFS calculator, testing different food types and styles of cooking, and measuring detailed pan surface temperatures. Phase 6 will also include a comparative analysis of gas, resistance electric, and induction cooktops including cooking performance, total cost of ownership, and emissions (including particulate size).

Benefits / Market Implications

With increased concerns about tight homes and Net Zero Energy homes, data is needed to fully understand the impact that residential cooking has on indoor air quality and what changes may be needed to residential cooking ranges, burners, and capture hoods to meet consumer's needs.

Technical Concept & Approach

Researchers are using an existing residential cooking setup to perform an analytical and laboratory investigation into the pollutants contributed by gas and electric residential cooking for a standard residential range that includes range top and oven cooking. These emission types were identified in literature as the ones most negatively associated with cooking with natural gas. Established testing protocols and procedures for cook testing emissions capture are used to quantify the emissions. A comparison was completed for gas and propane vs. electric ovens and an evaluation completed to establish emission capture impact on IAQ and implications for range-hood design.

Research is being conducted to determine how improvements in emissions and efficiency can be achieved by modifying the existing residential burner design, using a new burner concept, or through the development of a new ventilation hood. The impact on IAQ issues will be calculated based on the improvements in emissions and efficiency, including percent reductions in NOx and other combustion products.

Tasks for Phases 5 and 6 include:

Residential Cooking Emissions Testing

Expanding on the work in Phase 2, the team will use its existing residential cooking setup to perform an analytical and laboratory investigation on the pollutants (NOx, PM) contributed by natural gas, propane and electric resistance, and induction residential cooking for a standard residential range top.

Using the methods for PM emissions developed in Phase 2, the team will expand testing in cooking performance evaluation, total cost of ownership evaluation, and the site vs source evaluation with a gas, propane, electric resistive, and induction stove tops. Cooking performance will include an evaluation of the temperature uniformity, food quality and food type. Total cost of ownership will evaluate the cost of stoves, energy use, and cost of additional tools as necessary. Site vs source emissions analysis will take a deeper investigation into the emissions generated because of the different stoves. A comparison and evaluation will also be conducted on indoor air quality will be completed to establish emission capture impact with the implications for range hood design. The results of these analysis will be published as a peer reviewed technical paper or presentation.

Review Issues and Concerns With Residential Cooking

The team will continue to maintain a list of resources addressing the issues and concerns associated with residential cooking. New publications will be reviewed for relevant scientific and technical information. The team will attend conferences and workshops to gather information which will inform their testing and reports.

Results

A review of existing articles and presentations on the effects of cooking with natural gas on residential IAQ found many examples of conclusions or statements based on inconclusive or inadequate data. These results create more questions than answers for what conclusions can be determined for the effects of residential cooking on IAQ for both gas and electric as the primary energy source.

Results from this project were presented in a technical paper delivered at the 2024 ASHRAE Winter Conference on the cooking emissions tests comparing cooking with natural gas to electric range tops, and additional reporting occurred at the Indoor Air 2024 conference. For this study, cooking emissions are defined as only the emissions from the food during the cooking process and not the combustion emissions from the heat source. Based on the range top cook test and the tests conducted with natural gas, propane and electric range tops; a conclusion that one energy source generates more cooking emissions than the others cannot be made. Results showed cooking emissions were more a function of the cooking vessel and food product cooked than energy source. The results varied with different boxes of the same food product and with the age of the food. The temperature control and temperature distribution of the pan's cooking surface was also shown to affect the cooking emissions generated. The temperature varied more for the electric range and was more difficult to control than natural gas or propane.

For Phase 3, a number of burner modifications were completed in order to improve the overall functionality of the cooking process for residential ranges. In particular, technologies utilizing radiant surfaces were considered due to a reduction in plume size as well as a more even heating surface resulting in improved emissions. The reduction in plume size can be attributed to the radiant combustion mechanism providing heat directly to the cooking surface, rather than through primarily convective heat transfer which entrains large volumes of secondary air. This phase resulted in a prototype which demonstrated efficiency rating increases from around 30% to 38-58%. Additionally, NOx emissions were demonstrated to be reduced from over 100ppm to sub-10ppm air-free.

For Phase 4, work has focused on developing an air curtain to improve capture efficiency of the hood. A number of tests were completed with different air curtain layouts and varying degrees of success were achieved, with both nozzle type and nozzle angle of attack being the primary variables. This phase resulted in a successful demonstration of an air curtain method adapted from commercial foodservice that improved capture efficiency of the front burners of a typical residential range by 20%. The data shows that generally residential hoods are under powered and need higher flowrates to significantly improve capture efficiency.

Status

The final report for Phase 3 was issued to UTD members in August 2024 and the final report for Phase 4 was issued to UTD members in September 2024. Work continues on the testing comparing the cooking emissions for natural gas, propane, electric resistance and induction cooking under Phases 5 and 6.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

High-Efficiency Smart Convection Oven

A prototype high efficiency convection oven has been developed. Laboratory testing has demonstrated a 12.8% increase in anticipated energy efficiency rating, and a 15.3% reduction in standby energy use, versus a conventional convection oven. CFS equipment manufacturers are considering opportunities to commercialize this promising technology.

Project Description

Convection ovens used by Commercial Food Service (CFS) end users utilize a high-temperature cooking process, which means that the flue products need to leave the system at no less than the oven setpoint temperature of 350-500ºF. Convection ovens by design also constantly flow heat out of the oven as they operate (with the fan flowing air across the oven and then out the flue), which results in high standby energy use. There are currently 36 gas ENERGY STAR convection ovens available, but they deliver only 44%-55% cooking efficiency.

In this project, researchers incorporated a heat exchanger to recover heat from the flue and feed it back into the combustion air. The objective is to develop a prototype high-efficiency smart convection oven that increases efficiency by at least 5%, to maximize food preparation quality and consistency.

Based on initial proof-of-concept testing results, the project team anticipated that a 5%-10% cooking efficiency should be achievable once the design has been optimized. In addition, a targeted 10%-20% reduction in NOx and CO emissions were expected.

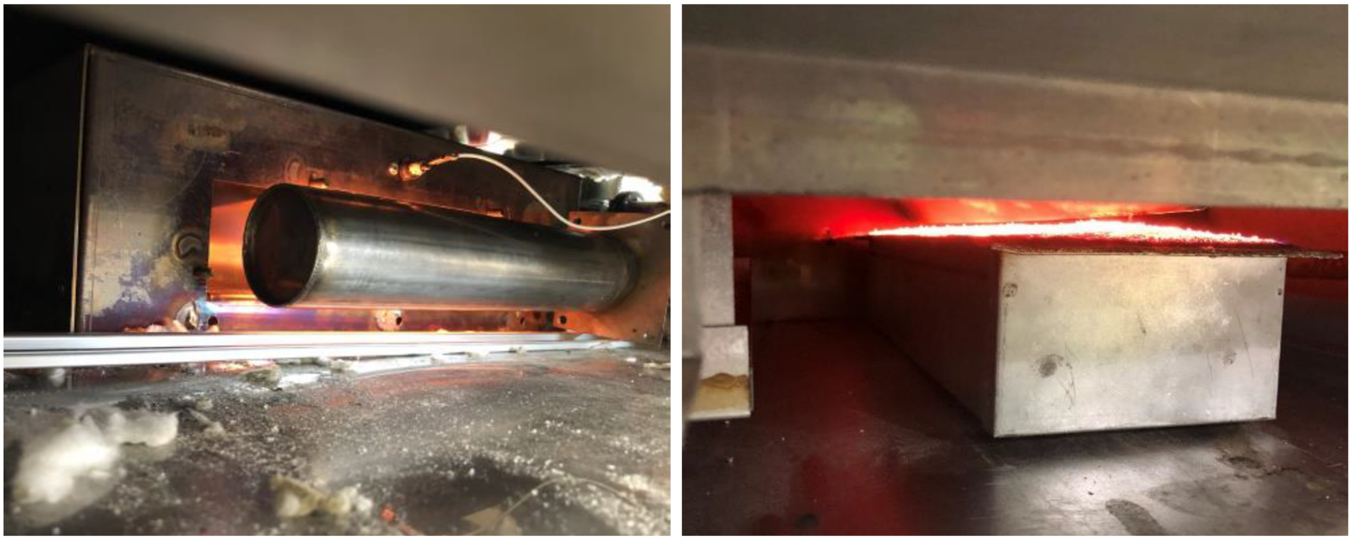
Laboratory testing of prototype units ultimately demonstrated a 6.5% increase in rated efficiency (or 12.8% increase over baseline energy efficiency) as well as a 15.3% reduction in standby energy use. Efforts to commercialize this technical innovation are in progress.

Benefits / Market Implications

The population of convection ovens in the U.S. is estimated to be around 650,000-700,000, according to a 2015 U.S. Department of Energy study. About 32% of commercial foodservice operations have at least one standard convection oven.

Convection ovens currently use 800 therms annually according to the ENERGY STAR calculator tool. A 2013 California Energy Commission analysis found that replacing existing

Laboratory analysis of a commercial oven



Left: Burner firing in the combustion chamber. Right: Premix burner installed on the bottom of an oven.

convection ovens with even 44% minimum ENERGY STAR level ovens resulted in an average energy use reduction of 40% across three field test sites.

The proposed design was targeted to be 10% more efficient than current ENERGY STAR designs. When compared to installed ovens, it could save more than 50% of the energy use (i.e., over 400 therms per year). A 50% savings translates to $300 in savings annually for the customer (assuming $0.75 per therm) compared to baseline existing ovens. It would be expected to pay back in one to two years, since the cost premium may only be around $300-$400.

Technical Concept & Approach

This project focused on developing and demonstrating a prototype next-generation, high-efficiency, convection oven in coordination with a leading manufacturer. An innovative heat-recovery heat exchanger and burner design will be incorporated into an existing oven, with the goal of reaching 5%-10% improvement to the cooking efficiency and standby energy use of the oven.

Results

In 2020, baseline testing of a current ENERGY STAR convection oven was completed. A computational fluid dynamics model was made to model several different heat-exchanger designs that could be applied to this oven design. Several heat-exchanger designs and variations were created and researchers began modeling their performance.

Technicians then fabricated a prototype heat-exchanger design and installed it on the convection oven for testing in the laboratory along with a blower and controls. The initial testing showed that the standby energy use was reduced by 15%. A few additional design modifications were implemented in coordination with a leading manufacturer, and modeling designs were completed. A final heat-exchanger design was selected based on all of the modeling results.

A potato cook test was completed using the refined prototype oven. The optimized heat recovery oven design demonstrated a 6.5% higher rated efficiency or a 12.8% rise in efficiency (or reduction in gas use). In addition, the standby energy use was reduced from 11,418 to 9,674 Btu/hr with the optimized heat recovery heat exchanger (a 15.3% improvement).

A final report for Phase 1 was issued to UTD members in November 2022, and a Final Report for Phase 2 was issued to UTD members in July of 2024.

Status

A technical innovation has been developed and demonstrated which provides a 12.8% rise in efficiency (or reduction in gas use) in a representative prototype convection oven, as well as a 15.3% reduction in standby energy consumption.

Efforts currently underway by the project team in Phase 3 of this project are to identify a manufacturing partner to commercialize this innovation, so that a new higher-efficiency convection oven is available to restaurants, campus kitchens, military canteens, and other CFS end users.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

Gas-Fired Warewasher

Efforts are under way to develop prototype gas-fired door- and conveyor-type warewashers in the laboratory. When commercialized, consumers could achieve significant energy and cost savings by using a new option of gas-fired warewashers.

Project Description

Most commercial dishwashers (also called warewashers) are electric driven, and many electric warewashers use chemicals (i.e., "chemical warewashers") rather than high temperatures to disinfect, which further increases their environmental impact. This project is developing reliable gas-fired warewashers so that consumers can have more energy choices and reduce their environmental impact and operating costs.

Four types of commercial dishwashers are available to wash and sanitize plates, eating and cooking utensils, and other items: flight type; rack conveyor; stationary door; and undercounter. Flight-type and conveyor warewashers are used for high-volume applications.

This research project is developing prototypes of both door-type and conveyor-type gas-fired warewashers. These are two very popular warewasher types, representing a combined 43% segment of the warewasher market.

Benefits / Market Implications

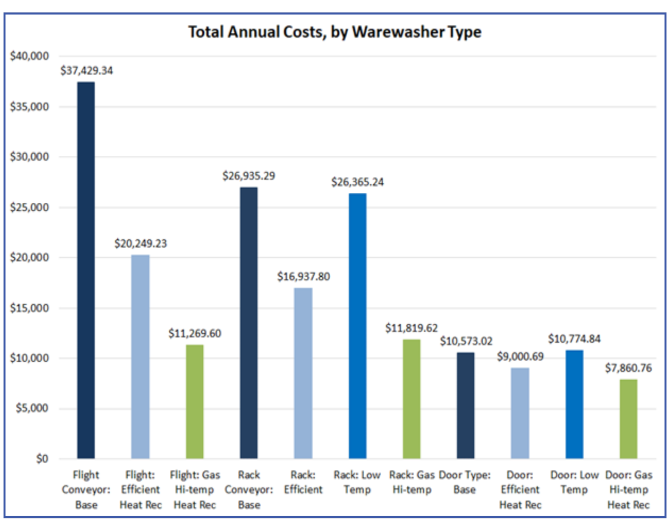
Warewashing equipment is a significant part of the commercial foodservice business, with global equipment capital costs estimated to be approximately $4 billion per year. There are more than 100,000 conveyor-type warewashers in the U.S. alone. A reliable gas warewasher would provide large operating savings for commercial foodservice facility owners and operators while also reducing source-energy and chemical use.

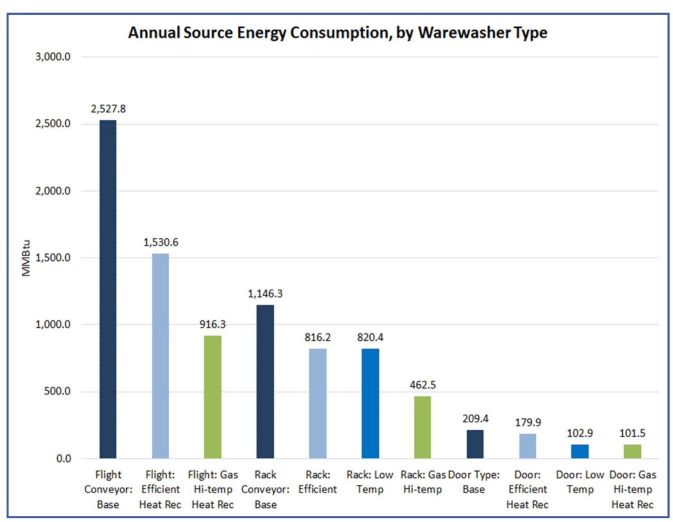
Initial estimates indicate a site will only use one-third of the source energy with a gas warewasher compared to alternative technologies. Even a representative low-usage restaurant, with only 1,100 therms of annual usage, would reduce the carbon footprint of the restaurant from 49,610 pounds of CO_2 per year with electric units to 16,088 pounds of CO_2 per year. In addition, it would cost the restaurant three times more (using national average gas and electric prices) to run that warewasher on electricity instead of gas. The restaurant would save more than $1,900 a year on operating costs with switching to a gas warewasher.

Data from earlier UTD project 1.18.B showed that a gas-fired conveyor warewasher would save a restaurant $15,115 per year over a standard electric warewasher and $5,118 per year over a more efficient electric warewasher with heat recovery.

Technical Concept & Approach

In this project, researchers and a manufacturing partner are modifying current electric-driven warewashers as they develop prototype gas-fired warewashers.



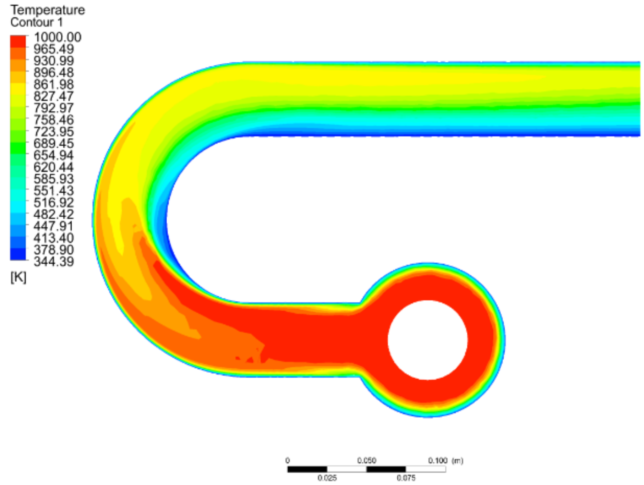


Different heat exchanger designs are being modeled to determine the best-performing designs that fit into the needed footprint of an existing electric warewasher. Prototype heat exchanger(s) will then be fabricated and put into prototype warewashers along with a burner and blower. The design will be tested and refined to continue to improve performance and address any issues that occur with initial testing.

Functional prototypes will be tested for combustion efficiency, safety, and emission standards. The results from testing will also assess improvements over electric units.

One prototype will be tested by a manufacturer partner in its facilities and one in a laboratory to prove the performance of the machine. The results will be used to finalize the design or any potential issues that may need to be resolved.

A field demonstration will be conducted at test sites. Test sites will be baseline-monitored for six months, followed by at least six months of monitoring the prototype gas-fired warewashers.



Example CFD model.

Results

Door Gas-Fired Warewasher

In 2020 and 2021, the project team continued to work closely with a manufacturing partner. Researchers modeled 13 variations of different heat-exchanger designs and tested the combustion system in the laboratory with the prototype warewasher tank and heat exchanger.

The project team developed some basic heat-exchanger designs that would fit into a given warewasher tank space. The main constraints were the small dimensions of the tank as well as avoiding contact with and allowing for access to the strainer.

Researchers investigated a variety of burner types to fit in the heat exchanger and provide the needed surface area for heat exchange. Two burners were provided, both of which performed well on emissions.

Technicians assembled the burner, blower, and gas valve assembly, along with a new control for the combustion system. Initial testing of the combustion system in the prototype heat exchanger was completed.

Conveyor Gas-Fired Warewasher

Modeling was conducted to determine the heat-exchanger designs that could have the best performance in a conveyor warewasher. The team was able to test the real-world performance of the warewasher at an installation in the Chicago area to get actual performance data of the heat exchanger and burner. After some modifications, the test results did align with the expectations of the model.

The team worked with the manufacturing partner to incorporate a new heat recovery design used in electric models into an existing gas-powered model of warewasher. The team was able to prove that the gas conveyor unit they have modified with heat recovery is effective, both through modeling and by leveraging some related field demonstration tests. Four units have been installed at Naval Station Great Lakes (with funding other than by UTD), and they produced very large energy and cost savings and have been extremely reliable. These units should be eligible for energy efficiency programs of gas utilities, as their efficiency far exceeds the basic Energy Star dishwasher energy efficiency requirements.

Status

The team is working to find demonstration sites that currently have standard electric-driven conveyor warewashers in order to monitor their baseline performance and then install the new gas-fired heat recovery conveyer warewashers and gas fired booster heaters in order to measure the energy and water savings of the new system. These steps are expected further prove-out the energy savings and performance of the gas-fired conveyor warewashers and provide additional technical documentation which can support including this high-efficiency equipment in gas utility energy efficiency programs.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Field Evaluation of Indoor Air Quality in Residential Kitchens

This research is gathering data to determine the effect of cooking emissions on residential indoor air quality in a scientific manner in real-world situations through field evaluations. This project presents a unique opportunity to collect field data to differentiate emissions from cooking processes versus emissions from appliances.

Project Description

Some publications reporting on residential indoor air quality (IAQ) have suggested that emissions from cooking can negatively affect a home's air quality. Specific emphasis is sometimes put on combustion emissions instead of emissions produced from the food, whether cooked using electric or gas. This project will help address the need for scientific data to quantify the effects on IAQ from natural gas cooking, and collect real-world scientific data.

A field evaluation study of overall building performance on two geometrically twin multifamily buildings is being conducted in Chicago. The uniqueness of the location is that it represents one of the only buildings in North America that not only meets rigorous energy-design standards, but includes natural gas for cooking purposes.

This UTD project is using the unique ready-made field test project site to help quantify the effects on IAQ from natural gas cooking and collect scientific data.

Phase 1 gathered and publicly reported the results of baseline emission testing, while Phase 2 is comparing best-in-class commercially-available range hood to the baseline hoods.

Benefits / Market Implications

This project presents the opportunity to collect field data to differentiate emissions from the cooking processes versus emissions from the appliance (gas and electric) in order to aid consumer understanding.

Technical Concept & Approach

The goal of this project is to determine the performance comparison between a demand-controlled hood over, a best-in-class residential range hood, and a baseline hood on the effects on kitchen IAQ.

Results

The IAQ sensor packages and range cooking-location sensors gathered gas and particulate measurements from six kitchens in ENERGY STAR units and six Phius-occupied units. (Phius is non-profit organization committed to decarbonization.) The gas and particulate data are being analyzed during cook events and non-cooking periods. Researchers are comparing ventilation strategies based on gas and particulate measurements between the direct-vent range hood in the ENERGY STAR units and the recirculating hood and heat-recovery ventilator in the other units.

A variety of food products – including bacon, eggs, pasta, and chicken nuggets – were cooked in an apartment to evaluate the hood performance and IAQ effects. The apartment was

Frying Bacon and Eggs on a Gas Range Top in the ENERGY STAR Residential Unit with a Direct Vent Range Hood

IAQ sensor installed in kitchen with an energy-recovery ventilator.

constructed to Phius energy standards. The cooking processes included pan frying, boiling, and baking. Foods were cooked on both the gas range and induction hob. A recirculating range hood and an energy-recovery ventilation system was operating in the apartment used for the IAQ cooking evaluation.

The team has completed analysis of:

- One-second gas and particulate measurement data during the natural gas and induction cooking events and non-cooking periods in the ENERGY STAR and PHIUS buildings
- IAQ sensor data for NO2, CO2, CO, RH, TVOC, PM2.5 and Formaldehyde during ambient and background conditions
- IAQ sensor data during cooking tests conducted in apartments and comparing ambient, background conditions.
- Time weighted averages
- Ventilation strategies between the direct vent range hood in the Energy Star units and the recirculating hood and heat recovery ventilator in the PHIUS units

The results of Phase 1 were summarized in a Final Report issued in December 2023, and in a poster presentation at the Indoor Air 2024 conference held July 7-11, 2024 sponsored by the International Society of Indoor Air Quality and Climate. Additional opportunities to publish Phase 1 results are being sought.

For Phase 2, the team sourced and purchased typical residential range hoods, both direct vent and recirculating, reviewed current residential hood performance standards and performance test methods, and characterized typical hood airflow measurements. The team is in the process of measuring performance characteristics of the baseline hood such as airflow rates and capture and containment effectiveness.

The team evaluated hood recommendations from the Association of Home Appliance Manufacturers (AHAM) and determined the best-in-class hood. The hood was installed into the Energy Star and PHIUS residential apartment units. The team also installed IAQ gas and particulate sensors at ceiling of lab and at breathing zone.

The project team completed performance evaluations of the baseline hood, including airflow rates, capture and containment effectiveness, and resultant IAQ during cooking in the lab. The team is also monitoring IAQ in the Energy Star and PHIUS residential apartment units. Hood IAQ performance is being evaluated by measuring gas and particulate concentrations at ceiling of lab and at the breathing zone.

Status

The team is working to analyze data from the field and the lab, and is completing the Phase 2 final report.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD Utilization Technology Development

Technical Support to Address Gas Foodservice Technologies

This project provides technical support and assistance to commercial foodservice industry groups and manufacturers to make advancements so that end users can increase energy efficiency, decarbonize, reduce emissions, and enhance cooking performance.

Project Description

The majority of appliances used in the $1.1 trillion North American commercial foodservice (CFS) industry use natural gas as the main fuel source. Compared to other commercial products, CFS has traditionally had fewer regulations in terms of efficiency, emissions, and other operational requirements. However, with the push for more efficient technology, improved emissions (especially in California) and decarbonization, newer regulations are being developed and implemented.

Energy-efficient options for most categories of cooking equipment are currently available; however, the industry has been reluctant to adopt new technologies. CFS owners and operators have traditionally been hesitant to replace functioning equipment or buy new efficient equipment because of initial costs and concerns about cook quality. End users do not have information readily available detailing the long-term savings vs. the initial costs of more energy-efficient equipment and have not had a chance to observe and compare the cooking performance. Post COVID recovery of the industry has also resulted in the sales of cheaper and less efficient equipment to increase because of the initial cost savings.

This project provides technical support, assistance, and education to CFS groups and manufacturers to make advancements related to energy efficiency, environmental impact, decarbonization, and cooking performance.

Cooking demonstration at Louisiana Restaurant Expo of energy-efficient

Project representatives represent gas ratepayer interests by assisting in consensus-development efforts within technical advisory committees, including ASTM F26 for commercial foodservice, the North American Association of Food Equipment Manufacturers (NAFEM) Technical Advisory Committee, ASHRAE CFS Ventilation, and the Blue Flame Alliance Technical Advisory Committee. Technical information that helps CFS manufacturers meet California's low-NOx requirements will be provided.

For previous projects similar in scope to this one, the project team attended meetings or served on committees that addressed over 50 issues associated with CFS equipment, including NOx emissions in California, gas vs. electric cost for a CFS fryer for two chain accounts, data protocols for CFS, and meetings with various trade organizations and industry groups.

More than a dozen cooking demonstrations were conducted at conferences and other industry events. At the events, information on the energy and cost savings of efficient gas equipment was conveyed to consumers using the CFS tools and calculators developed with funding from the UTD.

Benefits / Market Implications

CFS is a large market with sales of about $1.1 trillion in North America. The National Restaurant Association also projects total employment grow to over 16.9 million by 2029.

Of the approximate nine million commercial cooking appliances installed and operating in North America, roughly 70% are powered by natural gas (in categories where there are gas and electric options), with an estimated five billion therms of natural gas consumed annually. This large customer base needs accurate information about equipment performance, impacts, rules, regulations, and other topics related to energy selection.

Technical Concept & Approach

The following tasks are being performed in Phase 4:

Addressing Code and Standard Issues in FS Industry

The team will identify issues and concerns associated with existing or potential new codes and standards relevant to CFS and RFS. The team will attend and provide industry expertise for the gas industry at codes and standards meetings such as ASTM F26 for commercial foodservice, NAFEM Technical Advisory committee, ASHRAE Technical Committee 5.10 Kitchen Ventilation, and BFA Technical Advisory committee. The team will also assist manufacturers with information about potential changes in the FS industry related to decarbonization and indoor air quality.

Technical Assistance, Education and Outreach to CFS Industry

The team will assist manufacturers with addressing technical issues related to gas burner design and operation. This will include complying with potential NOx standards, specifically informing them of testing procedures and required testing equipment. The team will also assist with developing and testing new energy-efficient designs and other combustion-related issues like hydrogen blending, decarbonization and indoor air quality.

To support this effort, the team will use CFS tools and calculators developed in previous projects to demonstrate to the CFS industry the value of efficient, clean burning gas-fired cooking equipment and promote advanced CFS equipment. The team will also make updates to the CFS Tools and Calculators website available at http://cfscalc.gastechnology.org/.

Results

In 2023, the project team provided technical support and/or expertise to organizations including NAFEM, Blue Flame Alliance, and a major gas utility. The team also met with a residential range manufacturer to discuss technology issues with current designs for burners in residential ranges.

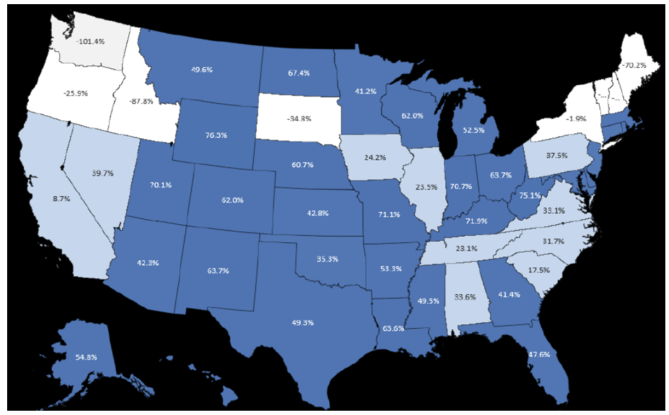
A project representative led the Fuels Group in NAFEM's Technical Liaison Committee. The group presents and discusses energy usage and supply issues with CFS manufacturers and other energy-related organizations.

The project team has provided information to the gas industry about the use of hydrogen in CFS and how CFS industry is changing post pandemic. One of the biggest changes in the industry has been increased consolidation of CFS equipment manufacturers due to acquisitions of competing OEMs. The project team conducted several webinars on indoor air-quality issues with residential cooking.

An existing tools and calculators website was updated with a new user interface which highlights decarbonization calculations (http://cfscalc.gastechnology.org/).

The team worked with various manufacturers on concerns ranging from resolving issues with a stove burning a mix of gas and hydrogen, providing information on past projects and discuss involvement in upcoming projects, evaluating and providing recommendations on issues with a gas fryer.

In 2024 team members continued to chair of the Fuels committee for NAFEM, supplying information and data for devel-



Percent Difference in Annual CO2e Emissions (efficient gas compared to

oping energy efficiency measures for range tops in California, and providing information and expertise on potential NOx emissions rules at the state level.

The team has supported efforts to set standards. The team attended the ASTM F26 meeting in Washington DC for commercial foodservice codes and standards. Update to standards that were discussed included combi ovens, ventilation, speed ovens, griddles and range tops. The team also attended the NAFEM Technical Liaison Committee Meeting in DC and participated in a CSA TC Z21/83 Mobile Food Facility working group for the development of test standards and codes for mobile food applications including food trucks.

The team also monitored regulations at the state and federal level. Several states have enacted legislation or are considering legislation requiring restaurants to use only Energy Star listed appliances.

Phase 3 has been completed and the final report was issued to UTD members in July of 2024.

Status

Phase 4 efforts are underway, focusing on the Tasks outlined earlier and continuing many of the efforts described above such as supporting NAFEM's Technical Liaison Committee and CSA TC Z21/83.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

CFS Burner Technology Carbon Reduction Including Hydrogen Blending

Efforts are under way to determine the potential decarbonization of typical CFS appliances using improved burner technologies, enhanced control systems, and blending natural gas with hydrogen on existing CFS appliances in a laboratory setting.

Project Description

The objective of this project is to determine the potential decarbonization of typical CFS appliances using natural gas blended with hydrogen and using improved burner technologies and enhanced control systems. Specific topics being addressed include energy-reduction technologies and controls, including burner modulation.

While controls, construction materials, and insulation have improved in the Commercial Food service (CFS) industry, most burner designs have varied little over the past decades and are atmospheric stamped metal or cast iron with drilled ports. Previous efforts by manufacturers to improve the cooking characteristics of these burners typically focused on modifying the existing designs by changing the configuration of the burner ports or the air-to-fuel ratio and not by investing in advanced combustion technology. This lack of advanced technology makes CFS appliance less tolerant to changes in the fuel content. There is also concern that changing fuel content will change the cooking performance of the appliance. This includes inconsistent crust color on breads, over or under cooking of fried foods, and inconsistent cook times on other products. Most food in quick-service restaurants is cooked using timers and is not being watched by employees.

Efficiency gains and improved emissions have been limited in CFS due to issues with the willingness of owners and operators to pay a premium for units with advanced combustion systems. The result is that most gas-fired CFS appliances use relatively simple, old, and inexpensive technology. These older technologies are less likely to operate correctly if the content of energy source is changed. Hydrogen represents another issue because the increase in flame speed is likely to cause flashback on many of the older CFS burner technologies. Also, changes in flame appearance will cause concern among restaurant operators, even if the flame is still safe.

Phases 1 and 2 of this project focused on performance testing with blending of up to 30% hydrogen in natural gas, as well as potential energy efficiency improvements. In Phase 3 the team will expand upon testing in the first two phases to include a griddle run on 100% hydrogen as well as up to 5 CFS appliances with hydrogen and hydrogen/natural gas blends. Testing will again include efficiency, emissions measurements (O_2, CO_2, CO, NO_x), cooking performance, and flame appearance.

Benefits / Market Implications

CFS is a large market with sales of about $900 billion before COVID. Post COVID projections show the industry is expected to recover and grow at a rate greater than 5% for next several years. This growth is significantly ahead of most other commercial industries. The National Restaurant Association also projects total employment growth to over 16.9 million by 2029.

Of the approximately nine million commercial cooking appliances installed and operating in North America, roughly 70% are powered by gas (in categories where there are gas and electric options), with an estimated five billion therms of natural gas consumed annually. Increasing the amount of hydrogen blended into natural gas will retain end-users options for gaseous fuels and customer choice while increasing decarbonization.

This project will help the industry determine the potential for improved burner technologies, control systems, and blending with hydrogen in CFS appliances.

Technical Concept & Approach

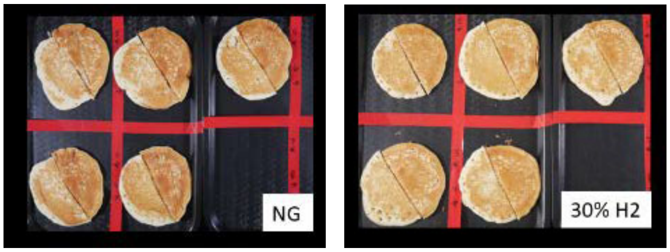
A research team will test CFS burners using a range of natural gas mixtures blended with hydrogen (0%-30%). The burners will be tested for combustion emissions and flame appearance. A determination will be made on the compatibility of each burner to the different blends of up to 30% hydrogen. Researchers will capture any cooking performance changes which would not be acceptable to end users and any safety issues such as carbon monoxide emissions and flashback.

The goal is to determine the level of decarbonization that can be achieved for a standard-efficiency CFS appliance by using advanced burner technology and improved burner controls. A standard appliance will be baseline tested for efficiency and combustion emissions and then updated with new technology and retested for comparison to the baseline.

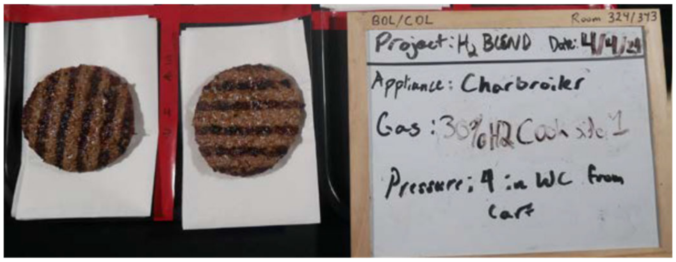
Specific task for Phase 3 include:

CFS Appliance Testing with 100% Hydrogen

The team will test CFS appliances made to operate with



Pancake Comparison



Charbroiler Burger Overview 30% Hydrogen / 70% Methane

100% hydrogen. These will include the Falcon fryer from England and the Heatlie grill from Australia. The appliances will be tested for combustion emissions (O_2, CO_2, CO, NO_x) and flame appearance and the results compared similar natural gas appliances. Testing will show if the cooking performance changes such that it would not be acceptable to end users in terms of quality and quantity of food cooked.

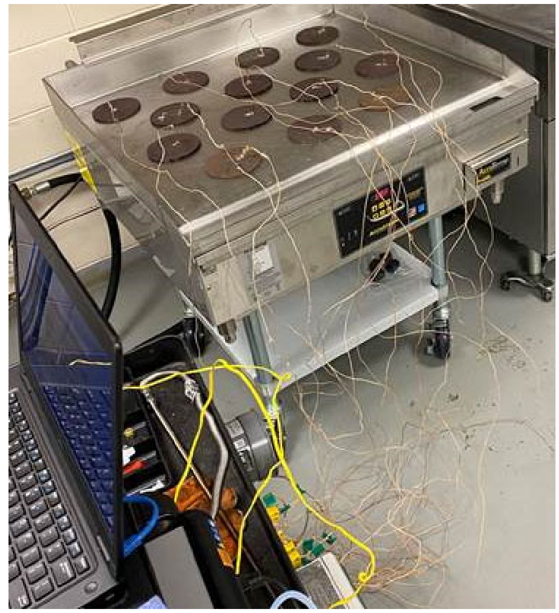
CFS Appliance Testing with 0-30% Hydrogen in Natural Gas

The team will test CFS appliances with a range of natural gas blended with hydrogen (0-30%) using similar test methods from Phase 2. Appliances for testing will include fryers, griddles, ovens and ranges. The appliances will be tested for combustion emissions (O_2, CO_2, CO, NO_x) and flame appearance and the results compared for the different fuel blends. A determination will be made on the compatibility and safety of each appliance with the different fuel blends using existing ASTM test standards. Testing will also show if the cooking performance changes such that it would not be acceptable to end users in terms of quality and quantity of food cooked.

Results

In Phases 1 and 2, flash back and flame appearance do not appear to be an issue for blends of natural gas and hydrogen of up to 30% for the 13 CFS burner types tested. Flashback did not occur during testing for any of the test conditions except for the stock pot burner; this incident was the function of how the burner was shut off and not of the addition of hydrogen to the fuel mix. The appearance of the flame did not significantly change with the addition of up to 30% hydrogen to the fuel mix.

Burner emissions of CO and NOx were shown to be more affected by changes in firing rate than the percentage of hydrogen in the fuel. Typically, the values were within the same



Griddle Temperature Distribution Setup

ranges for each percent of hydrogen. The only exceptions were CO for the fryer and NOx for the Infrared burner where both slightly, but consistently decreased as the percentage of hydrogen increased.

The team conducted 0-30% hydrogen blend appliance testing on a charbroiler. The charbroiler results focus on combustion emissions, temperature distribution, and cook performance differences with burgers. Emissions data including NOx, CO and O2 were measured and analyzed.

Images were taken of the hamburgers and pancakes cooked with 100% natural gas with a progression to 30% hydrogen. Reviews of the post cook images identified no noticeable difference in cooking appearance, although further analysis may be done during Phase 3, if the team develops a method to compare the color of the cooked foods to compare doneness.

Results were publicly presented in 2024 at a meeting of the American Society of Gas Engineers. Project Final Reports were provided to UTD members for Phase 1 and 2 in April 2023 and September 2024, respectively.

Status

Phase 3 activities are underway. The team is completing griddle testing with blends of natural gas and begun testing a griddle from Australia which is designed to use 100% Hydrogen fuel.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

CFS Decarbonization Tool Development and Demonstration

Researchers are expanding a tool to compare carbon footprint, source efficiency, source emissions, lifecycle costs savings, and payback periods of high-efficiency Commercial Foodservice equipment. This will allow CFS end users to identify opportunities to save on energy and operating costs, while addressing their emission reduction goals.

Project Description

This project will expand the capabilities of a Foodservice Energy Monitoring System (FEMS) software to show carbon footprint, source efficiency, source emissions, lifecycle costs savings, and payback period for electric, natural gas, and NG/hydrogen blended CFS appliances. This information will allow Commercial Foodservice (CFS) customers, restauranteurs, and kitchen operators in campus, commercial or other settings to make more data-based decisions regarding the impact of equipment selections on emissions, energy, and cost savings, and help them identify opportunities to save energy and operating costs while retaining superior cooking performance. Efforts will include quantifying the large benefits of NG and NG/Hydrogen blends in High Efficiency Gas fired CFS appliances. The team will install FEMS capability at one utility test kitchen and conduct a live cooking demo with updated FEMS and NG/H2 to show the large carbon reduction capability of high efficiency gas burning CFS equipment.

Benefits / Market Implications

Commercial foodservice operators have not had access to many tools which allow them to compare lifecycle costs and emissions of new equipment. Expanding the FEMS software will increase the ability for CFS equipment purchasers to understand the overall impact of the equipment choices they make.

Many restaurants (especially chains) are making efforts to lower their carbon footprint and make greener choices. The results of this project will provide them the ability to make more data-driven choice on their equipment selections by seeing equipment comparisons live as the equipment is cooked on, how each piece of equipment compares on cost of operation, what the carbon footprint impact is, and how quickly one piece of equipment would pay back over other cheaper choices. The updated tool will also show the potential large carbon footprint reduction that can occur as gas supplies shift to hydrogen or hydrogen-enriched natural gas, and how well CFS equipment can cook and perform when using these low carbon fuels.

Screen shot of Fryer comparison test using existing FEMS software.

Live cooking data in the existing FEMS software can easily show the operating savings if a customer is located in specific geographic areas with various gas and electric rates

The tool will at the same time show them how quickly specific CFS products recover from transient loads, and how well each product cooks, which is usually the primary metric used when restaurants or chefs choose equipment.

Over $40 billion of energy is consumed yearly in CFS in the U.S. According to survey data gathered by the U.S. Energy Information Administration (EIA), foodservice customers have 2.2 times the energy intensity (Btu/ft2) of the average commercial customer. Providing CFS operators with a clear understanding of the impacts of upgrading to higher-efficiency equipment is expected to provide significant cost, energy, and emissions savings.

Technical Concept & Approach

This project will give consumers energy usage and cooking performance data to assist with equipment purchasing decisions.

Tasks for this project include:

FEMS Update

The project team will update FEMS Software to show the carbon footprint, source efficiency, and source emissions for electric, natural gas, and NG/hydrogen blended CFS appliances. An ability to print pdf reports with results of live testing for participants will be added, along with a calculation of expected lifecycle cost savings and the payback period of the equipment.

Installation of FEMS

The FEMS software system will be installed at one utility test kitchen and a live cooking demo with NG/H2 will be conducted to show the large carbon reduction capability of high-efficiency gas burning CFS equipment and the potential of lower-carbon fuels. Utility members and other users of the FEMS software system will be trained on how to use the new version of the software.

Results

The team began to modify the FEMS software show carbon footprint, source efficiency, and source emissions for electric, natural gas, and NG/hydrogen blended CFS appliances

Status

The project team continues work to modify and update the FEMS software.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Technical Assistance to Advance Gas Foodservice Equipment

Researchers provided technical assistance to Commercial Foodservice (CFS) equipment manufacturers to help them address issues, challenges and opportunities with developing new energy-efficient CFS technologies, and demonstrate qualitative and quantitative comparisons of energy-efficient gas-fired equipment.

Project Description

This project identified issues and concerns associated with developing new food service technology and assisted commercial foodservice (CFS) original equipment manufacturers (OEMs) to address these issues. The team provided technical expertise on topics such as compliance with potential NOx standards, testing procedures, combustion optimization, and required testing equipment.

The team also conducted cooking demonstrations of energy efficient gas-fired equipment to show cooking quality and cost, and emissions data including at CFS conferences, expos, shows and webinars, and provide information and assistance to CFS manufacturers from these events. Enhancements were made to existing tools as needed to demonstrate the value of these technologies. This project was performed in coordination with the Propane Education and Research Council (PERC), with PERC providing co-funding to UTD.

Benefits / Market Implications

Commercial and Residential Foodservice is a large and stable market. Sales in CFS and the Restaurant Industry have continually grown over the past decades before COVID. Post COVID, industry is projected to be over $900 billion in 2024. This growth is significantly ahead of most other commercial industries. The National Restaurant Association (NRA) also projects total employment to reach 16 million in 2024.

Of the approximate 9,000,000 commercial cooking appliances installed and operating in North America, roughly 70% are powered by natural gas (in categories where there are gas and electric options), with an estimated 5 billion therms of natural gas consumed annually. With the push for lower emissions and decarbonization, newer regulations are being developed and implemented by organizations such as ASHRAE, ASTM and air quality management districts in different areas of North America.

CFS customers are often not aware of or been able to quantify the specific advantages of higher-efficiency gas-fired equipment, which has limited the development of new products in some cases. Energy efficient options for most categories of cooking equipment are currently available, but the restaurant industry has often been reluctant to adopt new technologies. Commercial foodservice owners and operators have often been hesitant to replace functioning equipment on the grounds of cost and concerns about cooking quality.

Technical Concept & Approach

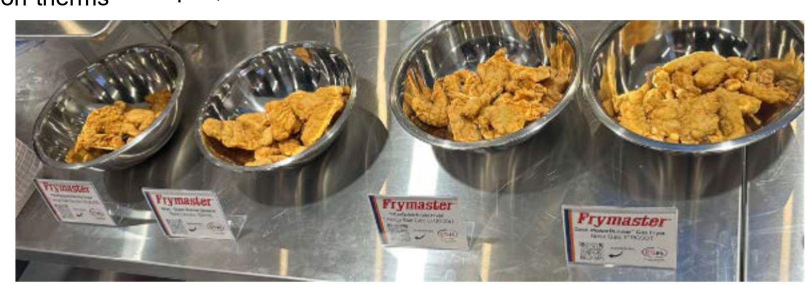
Tasks for this project included:

Technical Assistance to CFS Industry

The project team identified issues and concerns associated with developing new food service technology with input from contacts in the gas and CFS industries, and assisted manufacturers with addressing technical issues related to gas burner design and operation, including compliance with potential NOx standards, testing procedures, and required testing equipment. They also assisted with the development and testing of new energy efficient designs and other combustion-related issues like hydrogen blending and renewable propane/LPG.

CFS Consumer Education and Outreach

The project team demonstrated to CFS end users the value of efficient, clean burning gas-fired cooking equipment and promote advanced CFS equipment, in part by providing data using the CFS tools and calculators developed in previous projects and developing new calculators. The team also conducted cooking demonstrations of energy efficient gas-fired equipment to show cooking quality and quantity. Work in this task also included participation in CFS conferences, expos, shows and webinars.



Food Quality Comparison during Demonstration

International Pizza Expo and Conference in Las Vegas, NV

Results

FEMS

The team added decarbonization calculation capabilities to the Foodservice Energy Monitoring System (FEMS) software that is currently installed at a large gas distribution utility in North Carolina and in a portable FEMS unit. The FEMS system is connected to foodservice equipment to monitor the energy usage (gas and electric) and select temperature measurements. The software monitors live energy use as chefs cook the exact same food on all the considered appliances. The software then provides graphs showing the annual savings while they see how well it cooks their food. The software also shows temperatures of desired data points to show other advantages of more efficient equipment (such as fryer oil temperature dropping less, or more consistent oven temperature). Users can change the estimated or assumed future utility rates and the software will automatically update the savings graph as cooking is taking place live.

The project team also developed a new portable FEMS system to be used for short-term CFS demonstrations.

Technical Assistance to OEMs

The team gave a presentation to ESC's Blue Flame Alliance on current issues associated with indoor air quality and residential cooking.

The team provided a demonstration at a Gas Education and Training (EAT) event in coordination with a large gas distribution utility in Oklahoma. Attendees at the demonstration included foodservice equipment manufacturers/dealers and end users, including a regional chain account and energy industry representatives. During the demonstration the cost, energy usage, carbon footprint and cooking performance was measured and compared for an efficient natural gas fryer, a standard natural gas fryer and a standard electric fryer. Attendees were able to taste test several food products cooked with each fryer and decided which performed best.

The project team met with about ten pizza oven manufacturers at the International Pizza Expo and Conference in Las Vegas, NV to discuss decarbonization in the CFS pizza industry. Several manufacturers are considering how to address decarbonization initiatives. They shared that most customers request natural gas-fired ovens. Several manufacturers did request follow-up meetings and plan to contact the project team to receive future technical assistance regarding potential energy-efficient or emission-reduction technical innovations, combustion technology expertise, and decarbonization developments including potential use of hydrogen-enriched natural gas. The project team is assisted one manufacturer with the process of getting energy-efficiency rebates, for example. The team also had a conversation with a major pizza restaurant chain to discuss decarbonization opportunities in the pizza industry.

Status

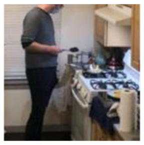
The project is complete. A final report was issued in August 2024. The team plans to conduct follow-up meetings with manufacturers and leverage these meetings and contact made during this project to continue to help manufacturers address technical issues and opportunities in commercial foodservice during future UTD projects.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

Advanced Controls for Residential Kitchen Ventilation Systems



Researchers are working to enhance indoor air environments by developing a demand-controlled residential kitchen ventilation system. This system can also save energy compared with existing ventilation hoods by reducing losses of conditioned air.

Project Description

The project seeks to develop better systems to control residential cooking ventilation in order to address concerns and issues about indoor air quality (IAQ) associated with residential cooking. The team will develop and evaluate novel advanced controls for Demand Controlled Kitchen Ventilation systems and monitor air quality and test various control strategies.

The project goal is to improve capture effectiveness by 30% compared to standard ventilation hoods while reducing conditioned air loses by 10% compared to standard ventilation hoods. The team will also model and measure energy savings.

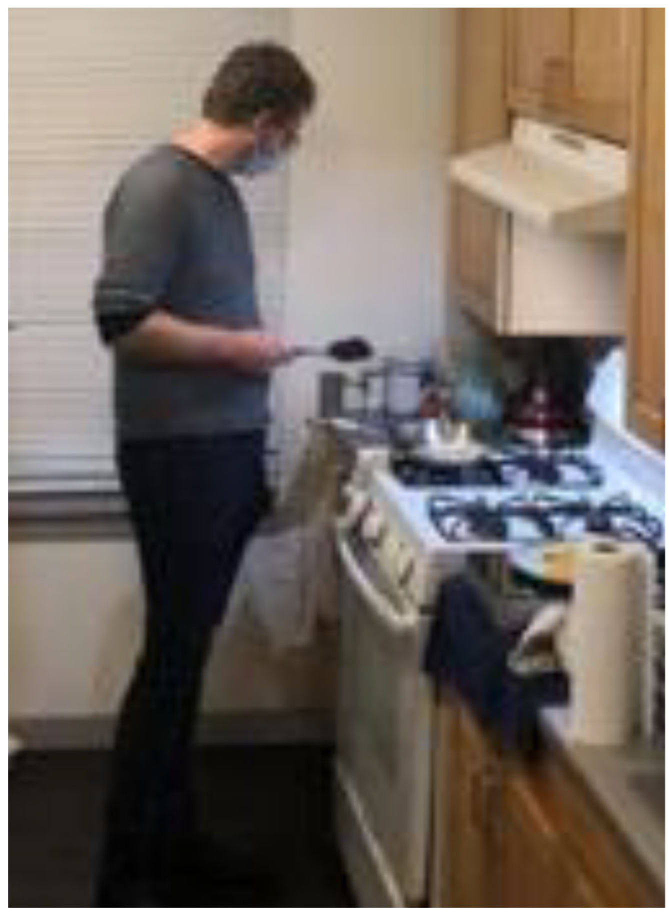
Benefits / Market Implications

Emissions from indoor cooking include carbon monoxide (CO), nitrous oxides (NOx), VOCs, water vapor and particulate matter (PM). Many publications have used different methods to measure the problem and have developed a wide range of conclusions for determining the impact cooking has on indoor air quality, but most of them point out the importance of an effective ventilation system to improve IAQ. The development and proper use of a high-performing residential range hood will benefit the IAQ of all residents no matter their choice of energy.

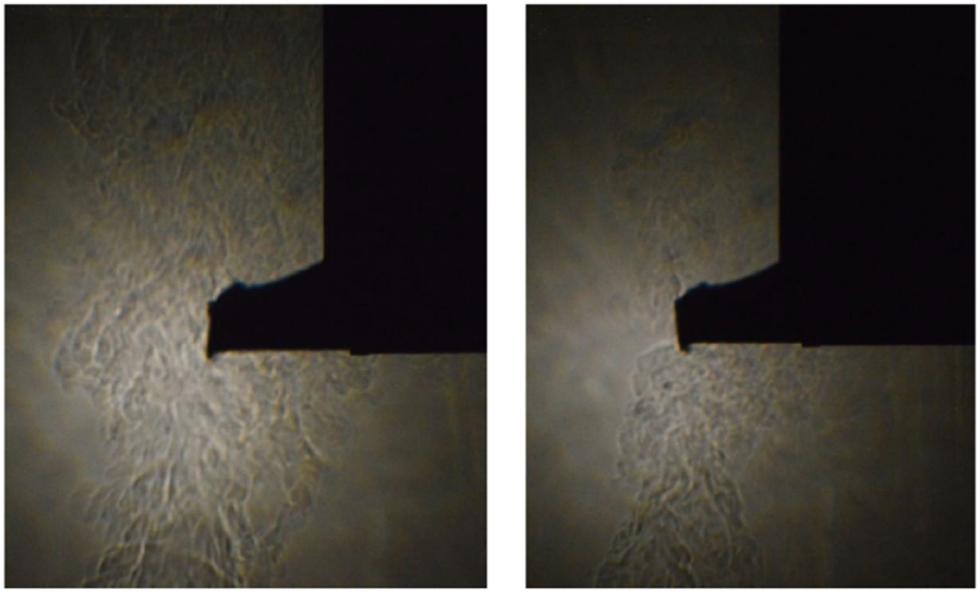
The current performance of typical residential kitchen hoods leaves plenty of room for improvement. Homeowners often forget to turn on the hood, complain about the noise, or don't think that they are necessary. This is in contrast to commercial food service applications, for which ventilation hoods are well developed and very effective.

This project will develop residential hood technologies that will address optimum ventilation design to answer IAQ concerns, and produce data to confirm that a key solution to improving residential IAQ is capturing, containing, and removing the cooking plume at the source. This project will concentrate on utilizing novel methods to trigger residential hood operation on demand, and modulate ventilation air flow rates to maintain capture and containment of the cooking plume while not over-exhausting and thereby wasting energy. The technologies developed through this project are targeted to improve indoor air quality in the kitchen space as well as in the living areas.

This project is being done in partnership with the Propane Education and Research Council (PERC), with PERC providing some co-funding to UTD.



Ventilation Testing



Laboratory test baseline results (L) and with experimental modification (R)

Technical Concept & Approach

Advanced Ventilation Controls

The team will conduct laboratory testing using residential ranges to determine what triggers during the cooking process can be used to turn on and/or modulate the ventilation rate of the hood. Current triggers include duct air temperature, IR sensors and opacity sensors, but can be too slow or too expensive to be practical. Real-time energy use is of particular interest as a potential trigger. Energy will be monitored by a compact gas flow meter that could be incorporated into the production range.

Methods for improving ventilation effectiveness by controlling the flowrate of the hood during cooking will also be investigated. This includes varying the flowrate to ramp up at the start of cooking and to run for an extended time after cooking.

Indoor Air Quality Monitoring

The team will install an IAQ monitoring system in the ceiling of the test bay to measure emissions such as NOx, PM and CO. These measurements will be used to evaluate the effectiveness of the ventilation control methods.

Results

The team has finalized and installed instrumentation to measure IAQ at both the cooking surface and at room level through using existing standards as a guideline for measurement and placement. Demonstrations of up 65% capture improvement have been achieved when analyzed using imaging analysis, with further work needed to repeat these successes. Inclusion of a novel approach has proven to show demonstrable improvements for the baseline testing, with tests using a minimally-sized hood design.

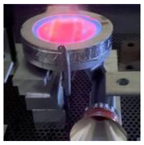
Status

Installation of an electric induction system using the existing hood is underway. This will allow for a comparison of capture efficiency without combustion gases included and the effectiveness of a baseline standard hood and an air curtain system. Once completed, an improved hood design will be installed and retested with comparison to existing data sets.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Next Generation Commercial and Residential Range Top Burner



Researchers are developing prototype burners for commercial and residential ranges to achieve a targeted 20% improvement in energy efficiency and 75% reduction in NOx emissions. Commercializing these products will improve indoor air quality, reduce greenhouse gas emissions, and save consumers money.

Project Description

Recent publications on the topic of residential indoor air quality have suggested that emissions from cooking can negatively affect a home's indoor air quality. Specific emphasis has been put on the volume of pollutants generated by combustion from natural gas and propane and the cooking process in general. The typical residential range has relatively low efficiency (~35%) and higher NOx emissions (>100 ppm corrected to air free) compared to other residential burners including water heaters and furnaces.

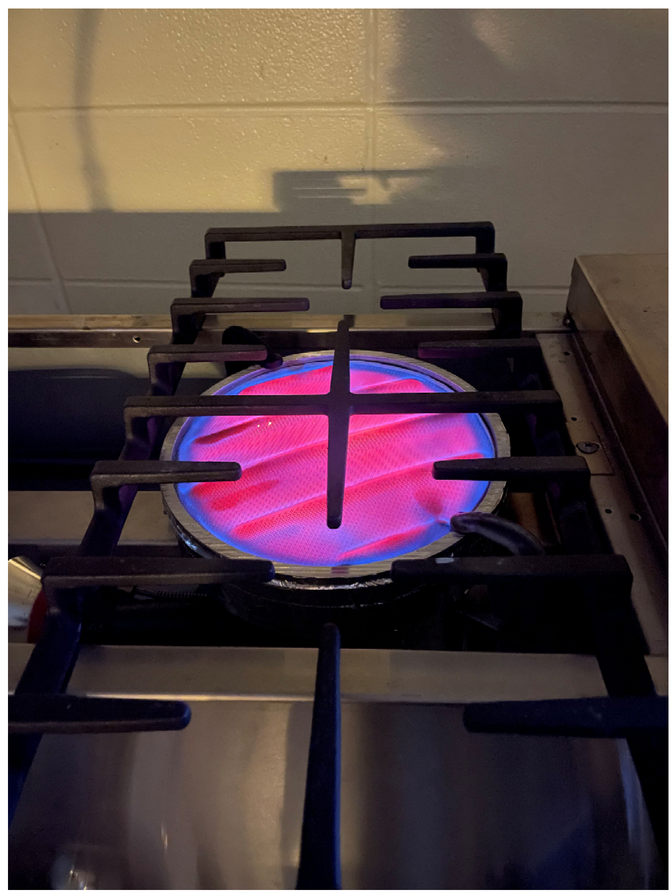
This project will take steps to commercialize advanced range burner designs developed during UTD project (1.17.H Residential Cooking Indoor Air Quality) as well as other leading burner designs for cooking with natural gas and propane. These designs have shown promise to improve efficiency and lower emissions.

The goal for this project is to incorporate a new burner design into prototype commercial and residential ranges that demonstrate 20% improvement for energy efficiency and 75% reduction for NOx emissions. This project is being performed in coordination with the Propane Education and Research Council (PERC), with PERC providing co-funding to UTD.

Typical Residential Range Burners

Benefits / Market Implications

This project addresses concerns about the effects of burning natural gas and propane on indoor air quality. While a definitive relationship between burner NOx emissions and asthma has not been established, it merits more scientific study. This project seeks to develop a residential stove burner that has significantly lower NOx emissions. In addition to end user health benefits, manufacturers may want to adopt these designs in anticipation of compliance requirements for future standards. Though there are not currently NOx emissions standards for residential ranges, there could be some in the future.



Prototype Residential Range Burner

Testing Commercial Ranges

Technical Concept & Approach

Tasks for this project include:

Develop Range Burner Designs

The team will refine the advanced burner concepts developed in UTD 1.17.H project or identify burner designs being developed by burner manufacturers and work with the appliance manufacturers and burner manufacturers to install prototype burners into cooking appliances.

Range Performance Testing

The project team will work with the project's manufacturing partners to test ranges with the new burner concepts. Tests will be completed to determine energy efficiency, emissions, cooking performance (food quality and quantity), safety and user ergonomics. Based on these results, adjustments will be made to the burner design if needed before shipping the units to the manufacturers for testing at their facilities. Assist manufacturers with onsite testing as needed. Burner concepts will be developed using natural gas and then modified and retested with propane.

Results

The team has completed lab setup and is conducting baseline testing on commercial ranges. Testing has been completed on some ranges, and the project team has reported the results to the respective manufacturer. The team also acquired seven burner prototypes from a leading European-based burner manufacturer to test.

Status

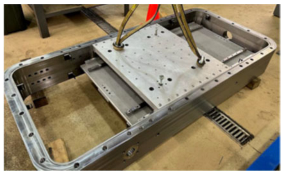
The team is currently testing burner prototypes from various leading manufacturers.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

CLEAN TRANSPORTATION

Cost-Effective CNG/GH2 Pre-Cooling Technologies



A research team is developing an innovative, cost-effective system to pre-cool compressed natural gas (CNG) or hydrogen prior to it being dispensed into a vehicle. Pre-cooling will enable full fills and extend operating range, improve user experience, and effectively reduce the volume, weight, and cost of on-board storage tanks - thus accelerating the use of lower-carbon transportation fuels.

Project Description

Compressing gas into a compressed natural gas (CNG) or gaseous hydrogen (GH2) fuel storage tank causes a significant temperature increase, resulting in the pressure limit being reached prior to transferring the total mass that defines a full fill. Pre-cooling the gas before it enters the vehicle is essential to achieve consistent full fills under most fueling and ambient conditions.

Research has been ongoing to improve full fills by developing improved dispenser algorithms, investigating vehicle-to-dispenser communication, and analyzing pre-cooling systems. These activities have concluded that some form of pre-cooling is necessary to guarantee a full fill.

The most obvious method for pre-cooling is to use a vapor-compression chiller to cool the gas being delivered to the vehicle. This method is being used for some virtual pipeline filling stations but is too expensive for most CNG vehicle filling stations. Alternatively, existing CNG compressors could be used to drive a Joule-Thomson cooling loop that is used to store cooling capacity between vehicle fills, and then use that cooling capacity to pre-cool the CNG going into the vehicles during a fill. This strategy can reduce capital cost since it uses existing CNG station equipment, but will add run time, complexity, and maintenance cost to the CNG compressor; operating costs will also increase.

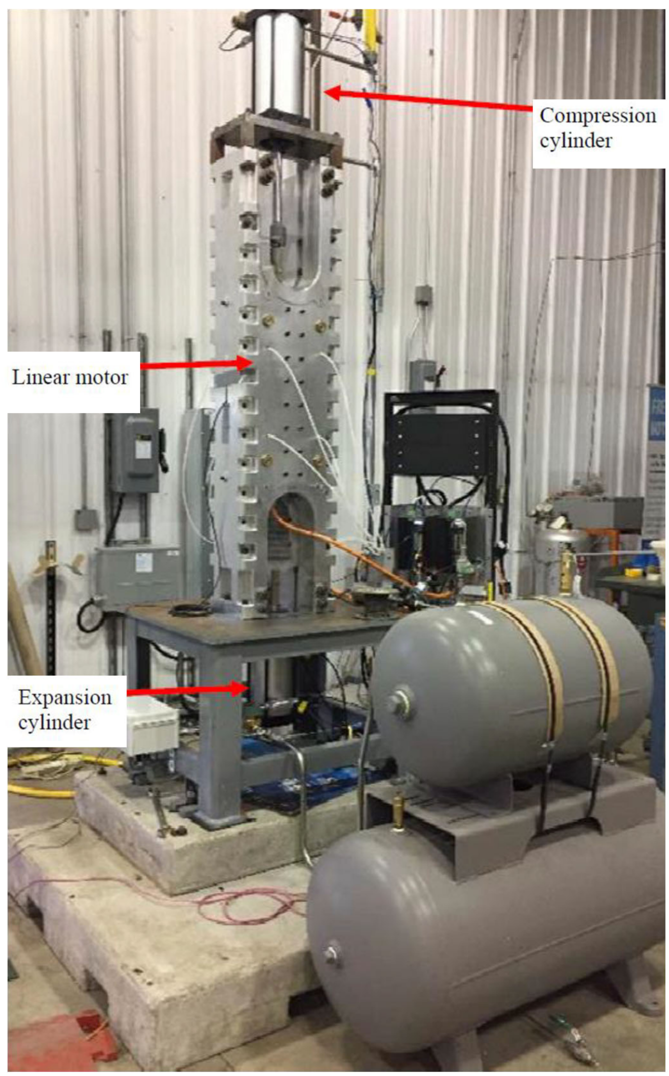
It is also possible to use a turbo-expander or similar device to pull energy out of the gas as it flows into the vehicle. An expander causes the gas to get colder than it would with Joule-Thomson cooling, allowing more gas to enter the vehicle before the pressure limit is reached. Expanders show the most promise since they do not require additional input energy to achieve the desired pre-cooling, but conventional radial expanders would need to be custom-designed for the high pressures required for CNG or compressed GH2 storage and would likely be difficult to operate over the necessarily-wide range of pressure ratios.

The objective for this project was to design, build, and demonstrate in a laboratory a prototype of a novel linear piston expander to pre-cool CNG or compressed hydrogen, in order to achieve full fills of gaseous fueled vehicles and thus increase effective storage capacity by 20%-25%.

This UTD project provided co-funding to a significant prime contract funding award from the U.S. Department of Energy.

Benefits / Market Implications

The issue of under-filling directly impacts the volume of storage required on a vehicle. By providing consistent full fills, a vehicle requires a smaller fuel system, reducing the cost and weight of the vehicle's CNG or hydrogen cylinders. This im-



Early prototype linear expander in laboratory test.

proves the vehicle's range, economics, and the user experience.

The use of pre-cooling would improve the quality of the fueling procedure since the gas temperature would be controlled by the station and would have less variability than occurs in existing fueling stations. This technology can provide significant potential benefits to economically fill zero-tailpipe-emission, gaseous-hydrogen-fueled vehicles, for which market interest is rapidly growing.

Technical Concept & Approach

The project team performed a preliminary design analysis of a novel expander for pre-cooling CNG. The design included detailed models, simulation, and schematics of the selected technology that estimate the expected cooling performance and how much it impacts CNG full fills, as well as the estimated capital and operating cost of the technology in a simulated station. Based on the optimized design, a complete working prototype was then fabricated and tested under simulated operating conditions.

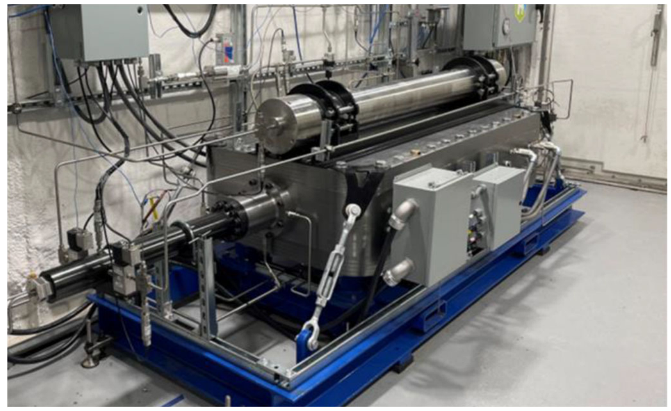
Results

The project team developed a design for the free piston expander that will remove energy from the CNG and hydrogen and reject that energy as heat. In the future that energy could be converted to power that can be used to reduce the cost of operating the fueling station.

A simulation of the free piston expander was completed to better estimate the performance of the system. The simulation optimized stroke, frequency, and other relevant design parameters. The initial goal was to simulate an "ideal" expansion cycle at nearly 100% efficiency, and then start adding system losses into the simulation to accurately represent the real-world expander performance. The simulation determined how the expander attributes such as stroke length and piston diameter impact the efficiency.

The simulation also allowed the team to finalize the expander geometry and components. The project team developed custom valves that can be actuated by the expander piston. However, commercial valves were later identified and used to test the expander operation. The custom valves are still being actively considered, but the commercial valves reduced some of the risk associated with the prototype development.

The project team completed the design, fabrication, and assembly of the prototype expander. The expander was initially tested with nitrogen up to about 12,000 psi to test the controls and operation of the design. During operation, several operational issues were identified and corrected. This included inconsistent signals from the encoder which required the expander to be partially disassembled to correct.



Fabricated expander tested in laboratory during this project.

Following the successful completion of the nitrogen testing, the team switched to hydrogen testing. In preparation for the switch to hydrogen, helium was used to verify that the seals were working properly and that no hydrogen would enter the motor housing. This was done by pressurizing the fluid ends using helium and then taking gas samples from the motor housing and looking for the presence of helium using a gas chromatograph.

Following the validation that the seals were working as intended, the expander was tested with hydrogen at pressures up to 12,000 psi. The team consistently achieved thermal efficiencies around 70% and believes this could be improved to 80-85% with some relatively simple modifications to the design. The expander is also producing power at about 50-60% efficiency which can be used to offset some of the power consumed by CNG or hydrogen compressors at fueling stations.

When testing with natural gas, the efficiency was lower than with hydrogen at around 40%, but the team is confident that this can be improved if the design was optimized for natural gas instead of a compromise between natural gas and hydrogen. The expander was connected to a dispenser and was used to fill a cylinder. The expander achieved a significantly improved fill compared to the same cylinder filled from a traditional CNG station

The team finds these results promising and believes additional improvements are possible by optimizing the valves, seal design, and operation of the unit.

Status

Phase 2 is complete and a Final Report was issued to UTD members in August of 2024. The project team is in discussions with potential commercializing entities, and assessing other next steps to advance the technical development.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

CNG Dispenser – Tank Communication

Researchers designed, built, and demonstrated a prototype compressed natural gas (CNG) station that includes a smart CNG dispenser and a smart natural gas vehicle (NGV). Pre-commercial prototype hardware and protocols enabled the vehicle and station to communicate with the vehicle's fuel system to safely deliver 10-15% fuller fills for end users, thus reducing operating costs for ratepayers and extending vehicle driving range.

Project Description

Researchers improved the ability to completely fill natural-gas-vehicle (NGV) storage tanks using an improved dispenser algorithm paired with innovative vehicle-to-dispenser communications.

State-of-the-art compressed natural gas (CNG) stations fill vehicles using a dispenser that processes payment, controls the filling sequence, and determines when the vehicle is full. Unfortunately, current CNG dispensers consistently underfill vehicles because they are unable to accurately compensate for the heat of compression onboard the vehicle since they only measure the vehicle's pressure.

Heat of compression is the term used to describe the process that causes the gas onboard the CNG vehicle to heat up as more gas flows into the cylinder, causing the existing gas to be compressed. Immediately following fueling of a typical CNG vehicle, the temperature in the vehicle's cylinders can be significantly warmer than the ambient temperature due to this heat of compression effect. This increased temperature also impacts the measured pressure onboard the vehicle, making it difficult to accurately determine when the vehicle is full.

NGV fuel systems are typically oversized because of this systematic underfilling. Achieving consistent fuller fills would allow smaller NGV tanks, which can lower fuel system costs. This project is a critical part of a multi-project effort by the project team to solve this problem and thereby improve the safety, reliability, and economics of NGV fueling.

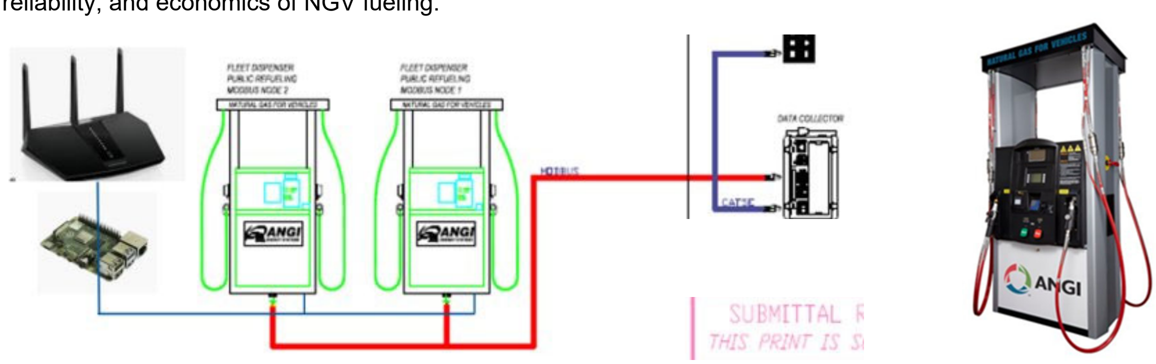
This specific project focused on establishing reliable communications links between the fuel dispenser and the vehicle so that the dispenser can leverage more information about the vehicle's status during fueling to enable the filling consistency, which will result in more affordable NGVs.

This UTD project provided co-funding to a $2.6 million research project award, with prime funding provided by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). UTD's project partners also include a major concrete supply company as the end-user host site, a CNG station supplier, and the core project team.

Benefits / Market Implications

Improving full fills using communications can lower the cost or improve the range of an NGV by up to 10%. Active communication will also improve the safety of a CNG fill. Testing of existing algorithms demonstrated that it is unlikely, but possible, to over-fill a vehicle. Using communications, researchers developed a filling algorithm that will never result in an over-filled vehicle as it is monitoring the CNG cylinders directly.

The primary target market impacted will be NGVs, with a focus on heavy-duty trucks. Secondary applications include virtual pipeline gas transport, locomotives, and some marine ferries using CNG. While the core technology being developed in this project will be demonstrated for CNG applications, it is expected to be transferrable and beneficial to vehicles fueled with gaseous hydrogen (GH2).



(Right) Single-board computer that can control multiple dispensers, time fill, and other station safety features simultaneously. (Left) An example of the ESP32 microprocess developed for installation inside a dispenser.

Smart dispenser components being tested with storage.

Technical Concept & Approach

Tasks for this project are to develop and validate the wireless connection protocol, develop a CSA standard with stakeholder input, and build and test the smart dispenser and vehicle. Project efforts are being coordinated with the work under way in UTD project 2.20.G.

Results

A smart CNG station and vehicle that can improve CNG full fills has been developed and demonstrated.

Existing CNG vehicles were fitted with improved sensors and controls that allowed the pressure and temperature onboard the vehicle to be monitored in real time. The pressure and temperature in the cylinders were measured and added to the vehicle's CAN bus for use onboard the vehicle. A transmitter was then connected to the CAN bus that enabled data to be transmitted to the fuel system and other vehicle info to the station.

A Smart Station Controller was developed that is capable of monitoring every CNG dispenser at a CNG station while also monitoring vehicles upgraded with communications hardware. The Smart Station Controller monitored when a fill started and then automatically determined which vehicle and dispenser were connected. This was verified using numerous criteria and the accuracy of the identification algorithm was verified during extensive lab testing.

Once the connected vehicle and dispenser were successfully identified by the Smart Controller, the controller overrode the standard dispenser controls and provided a more accurate and fuller fill to the vehicle. Lab testing demonstrated that the smart controller can improve fills by 10-15% compared to the standard dispenser algorithm that is programmed to be extremely conservative under most filling conditions.

The ANGI dispenser in the test chamber along with two target cylinders. The Smart Controller is connected to the ANGI Modbus to monitor data coming from the dispenser. In parallel, it also receives data from the dispensers that is transmitted over Wi-Fi using HEM data collection hardware.

Status

This project is complete. A Final Report was issued to UTD members in August 2024 and a related submission entitled NGV Consortium Smart CNG Station Final Report was submitted to the prime funders of this research in June 2024. The project team is now working to commercialize the Smart Station and Smart Vehicle hardware to enable fuller, more consistent fills of CNG- and GH2-fueled vehicles.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Next-Generation NGV Driver Information System

This research project developed and demonstrated a next-generation NGV driver information system to provide an accurate miles-to-empty estimate for the vehicle. By increasing confidence in the fuel gauge, excess fuel storage capacity can be reduced and the cost of the fuel system can be lowered by as much as 20%.

Project Description

Maximizing the fuel used in onboard storage is a well-identified impediment to greater adoption of natural gas vehicles (NGV); challenges which also apply to vehicles fueled by compressed hydrogen. The U.S. Department of Energy's (DOE) Clean Cities program performed a nationwide survey of NGV drivers and unreliable fuel gauges were a consistently mentioned deterrent to adoption due to causing range anxiety, frequent and unnecessary fueling stops, reduced driver productivity, and disrupted workflow for the fleet operator.

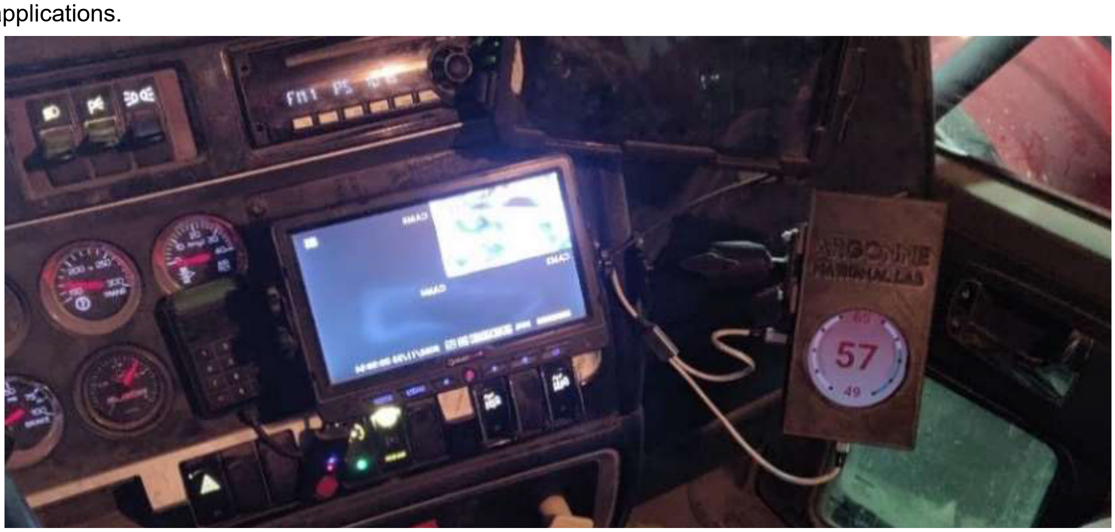
The goal of this project was to provide the NGV driver with an accurate estimate of the distance the vehicle can travel with the fuel left on board. While often simplified to a pressure measurement, large variations in gaseous fuel pressure can occur due to large swings in temperature. During fueling, the gas in the tank heats up to as high as 185°F, which can provide a premature "full" indication. As the gas cools down, the pressure drops sharply, giving the appearance that a full tank leaving the fueling station has drained very quickly. The gas in the tank also expands and cools as fuel is consumed (to temperatures as low as 80°F below ambient temperature), which further reduces tank pressure and leads the driver to mistakenly believe that the tank is almost empty. This project demonstrated how additional information such as the fuel consumption rate of the vehicle in various driving situations (traffic, weather, terrain, etc.), knowledge of the route to be followed, and storage tank performance can be used to provide an accurate miles-to-empty estimate for the driver in real-world applications.

UTD partnered with the DOE on this effort by providing co-funding to a major research contract with prime funding provided by the DOE. Other project team members include Argonne National Laboratory (ANL) and a leading concrete delivery supplier.

Benefits / Market Implications

Heavy-duty NGVs (Class 8-10 trucks) and vehicles fueled by compressed hydrogen will benefit the most from an advanced driver information system due to the larger savings in fuel-system size and cost. Medium- and light-duty NGVs can also benefit. Market entry, however, will focus on the large existing fleets of heavy-duty NGVs.

The benefits of an improved NGV driver information system will depend upon the driver's risk tolerance and driving behavior, but discussions with vehicle drivers indicate that they typically return for fueling when their vehicle tanks are 20%-40% full. Decreasing this remaining fuel reading to below 10% would result in significant savings in fuel system costs, driver productivity, and fueling efficiency. NGV fuel systems are typically oversized due to concerns about achieving a full fill and range-anxiety issues. By increasing confidence in the fuel gauge reading, the vehicle fuel capacity can be reduced, lowering the cost of the fuel system by as much as 20%. The productivity of the driver can increase as the truck would make fewer trips to refuel, and fewer refueling trips will lower emissions and save energy.



First installation of the prototype next generation NGV fuel gauge and driver information system in a ready-mix concrete delivery truck

Technical Concept & Approach

Data Collection and Application Development

The first task of this project was to instrument a fleet of vehicles to collect compressed natural gas temperature and pressure data during filling events and regular operation. The team then combined this data with data from controlled laboratory testing to enable development and validation of a thermodynamic model to estimate the usable fuel status of a vehicle's fuel system at any given time.

The team used the collected data to develop a more accurate miles-to-empty prediction method and integrate it into a phone-based display on board the vehicle. From this estimate, the driver has more accurate information to determine if a refueling stop will be necessary. The team also aimed to integrate the prediction tool into fleet dispatch software which would enable the dispatcher to determine if changes to vehicle routes could improve fleet performance, and evaluate driver performance for maximum efficiency.

Application Validation and Deployment

The models were validated using laboratory data to ensure proper operation of all data collection and transfer systems. Data from fleet vehicles was used to validate the thermodynamic model in the field.

Performance Monitoring, Improvement, and Know-ledge Transfer

The team compared NGV fuel gauge predictions to driver reports and operating data gathered from the data acquisition systems on the vehicles. Feedback was solicited from drivers to evaluate the perception of system accuracy and identify changes in driver behavior.

Results

In 2020, an analytical model was built to calculate the gas remaining in the fuel tank based on tank pressure and temperature – with accuracy >95% for a wide range of gas compositions between -60°F and 140°F.

In 2021, data-acquisition systems were installed on all 12 trucks participating in this program, including sensors to measure internal tank temperature and pressure. The collected data was used to validate and improve the calculation of remaining fuel on board the vehicle. The upload speed and time intervals of the data loggers were adjusted to ensure the loggers can successfully upload all information in the allotted time. These modifications were applied to all new logger units. Calculation of the remaining fuel on board the vehicle was finalized.

In 2022, a data visualization tool was completed and beta-tested. This tool uses cellular phones with customized cases installed by ANL that allow display of only desired information and prevent their use as phones. Researchers found that the driver information display needs to include an upper and lower bound for range in addition to the central estimated value, due to the variability observed in the vehicle duty cycle. Because the test vehicles are concrete trucks the duty cycle varies with large amounts of time spent idling, the energy used to turn the drum, and driving differences between urban and rural environments.

In 2023 and 2024, fuel gauge displays were installed on eight concrete delivery trucks. The fuel gauges use data from the sensors installed on the vehicle as well as engine data (distance traveled and fuel mass flow rate). Distance-to-empty was predicted using readings from these sensors combined with operating history data. This distance-to-empty calculation was validated to be accurate within the upper and lower bounds displayed. The prediction methodology did not require any knowledge of the fuel system size or gas composition; this information was calculated on a per-vehicle basis each day the vehicle is operated.

A custom end plug incorporating an in-cylinder temperature sensor was designed, incorporating a thermistor for in-tank temperature measurement. As thermistors are typically used in vehicle applications, this would enable the temperature data to be uploaded through the CAN system without requiring an expensive data acquisition unit as was needed for the thermocouples used in the initial phase of this project. The ability of a thermistor to withstand pressure cycles was tested during the project, and the results showed that these devices could be used for in-tank temperature measurement.

For the technology transfer task, the team worked with the concrete delivery fleet's dispatch software company to incorporate the fuel gauge into their dispatch system, enabling real-time optimization of the fleet fuel status as well as monitoring and rewarding driver fuel efficiency. The team is seeking partners to commercialize this technology advancement in coordination with the CNG Smart Station development efforts underway in UTD project 2.20.G.

Status

This project is complete. A final report was issued to UTD members in January 2024, and a final report was submitted to DOE in September 2024. Subsequent commercialization efforts are underway.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Smart CNG Station Field Demonstration

A novel CNG fueling system is being developed to increase the effective use of onboard CNG storage capacity by 10%-25%. The smart fueling system will use sensors and algorithms to provide consistent full fills - - saving end users up to 25% in CNG storage capital costs and also reducing weight. The system can likewise benefit compressed H2 fueling stations.

Project Description

A “smart” compressed natural gas (CNG) fueling system is being developed that will increase the utilization of onboard CNG storage capacity by 10%-25% compared to current practices and provide substantial savings to end users. The smart CNG fueling system will use improved sensors and algorithms to provide consistent full fills, resulting in up to 25% lower capital cost for fuel storage on natural gas vehicles (NGVs). While currently focused on CNG applications, if successful the innovations in this project could also greatly benefit compressed hydrogen fueling stations.

CNG vehicles are often under-filled because the gas heats up and expands during the filling process; 20%-25% under-filling is frequently cited by fleets and industry experts. This is further supported by the fact that commercial fuel systems are nominally designed 30% larger than the “usable” fuel capacity quoted by the manufacturer. On many heavy-duty CNG vehicles, adding 30% extra storage can easily be the difference between needing three versus four storage cylinders to achieve the vehicle’s required driving range. By eliminating the fourth cylinder, the weight and cost of the fuel-storage system can be significantly reduced.

Researchers will install sensors and communications equipment on the vehicle and station and feed the information to an improved CNG filling algorithm. The project team will demonstrate the system at one fueling location to analyze the real-world improved filling performance, and any increase in the vehicle or dispenser costs. Fuel-system and operational savings will be calculated to determine the true net benefits, and the results will be used to support a commercialization strategy.

In this project, UTD is partnering with the U.S. Department of Energy (DOE), leading manufacturers, and end users. UTD is providing co-funding to a prime contract from the DOE.

Benefits / Market Implications

The initial target markets for this technology are heavy-duty trucks, with the focus on reducing the frequency of fills to improve the productivity of CNG-fueled trucks. Higher productivity will provide greater economy for end users.

Developing and commercializing a smart CNG fueling system would reduce the capital cost differential between CNG and diesel trucks. This expands customer’s competitive choices for fuels, including potential applications for hydrogen fueling. The smart CNG fueling system could reduce the capital cost for fuel storage by about 25%.

Technical Concept & Approach

This project addresses the major technical issues by working closely with commercial partners and using real-world testing. Tasks include developing and deploying an advanced dispenser algorithm and wireless vehicle-to-station commu-

(LEFT) One of the HEM DAS with a built-in streamer. (CENTER) The router connected to the HEM DAS. (RIGHT) The micro-controller that connects the dispenser to the vehicle.

"Oklahoma Natural Gas is pleased to partner with the U.S. DOE and others through UTD to demonstrate this innovative smart station. We're excited about its potential to increase onboard CNG storage capacity by up to 25% while reducing station and fleet operating costs. With 127 CNG stations in our Oklahoma service area, this significant technology advancement can potentially provide substantial savings for our CNG customers and help reduce greenhouse gas emissions in our state."

- Dave Miller
National Accounts and CNG
ONE Gas

nication devices that will transmit real-time fueling information between the vehicle and the dispenser for the first time.

The project team will assemble and deploy data-acquisition systems on multiple demonstration sites and vehicles to collect necessary filling data. Station components for vehicles and dispensers will be developed. These smart components will be designed to securely transmit real-time data (e.g., temperatures and pressures) between the vehicle and station, enabling a safer, more accurate full fill using an advanced fueling algorithm. Components will be designed to applicable wireless data-transmission standards.

Researchers will initially test and validate the performance of the components and algorithm in a controlled laboratory setting. Testing will validate that the dispenser wirelessly connects to the correct vehicle and then accurately transmits the required data when filling a variety of CNG cylinder types, volumes, and configurations. Upon successful validation of the smart component performance, the systems will be integrated into test dispensers and vehicles, and then operated for a year at a demonstration site.

The research team will monitor data collected from a variety of CNG stations and vehicles during smart-filling events. This data will be analyzed and compared to the baseline to quantify the improved performance and accuracy of the prototype system. The project team will also begin initial commercialization steps for the technology.

Results

Researchers deployed 18 HEM data-acquisition systems (HEM DAS) onboard a local fleet of concrete mixers. This allows the project team to collect fueling and fuel-consumption data onboard each vehicle in order to better understand how baseline dispensers operate and how much they truly underfill vehicles. The system collects data about the fuel system which investigators can download to evaluate fills and driver filling practices.

The fully installed ANGI dispenser

The team has also installed a commercial dispenser in an environmental test chamber to test smart fills across a wide range of operating conditions. Two vehicle cylinders were also installed along with HEM DAS to test the vehicle communication with the station. As the vehicles are filled, they are broadcasting the vehicle information to the station's Wi-Fi network. A smart controller is monitoring the vehicle via the Wi-Fi network and comparing that information to data received from the dispenser via a Modbus connection. The smart controller then determines which vehicle is connected to which dispenser so that it can override the dispenser and assure the vehicle receives a full fill. The smart components have been fully demonstrated and validated.

The team is developing an override feature for the dispenser to continue the fill after the dispenser target is reached to ensure vehicles achieve a full fill. They have successfully bench-tested hardware that will enable the dispenser shutoff to be overridden and allow the smart station controller to achieve a fuller fill and are in the process of installing the override hardware into the dispenser.

Status

A final report for Phase 1 was issued to UTD members in March of 2024. Efforts under Phases 2 and 3 are continuing.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

UTD
Utilization Technology Development

CNG/RNG Locomotive Field Demonstration

Researchers are designing, building, and testing a pre-production compressed natural gas/electric hybrid line-haul locomotive to demonstrate the commercially available Cummins X15N near-zero-emission engine in rail service in order to substantially reduce GHG, SO_x, No_x, and particulate emissions while also reducing operating costs.

Project Description

For this project, a locomotive powered by renewable or fossil natural gas will be designed, built, and tested at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC) testing facility. The locomotive will operate on a 50-mile test loop in real-world conditions. Operation at TTC will allow researchers to perform controlled testing and gather critical data for emissions, fuel consumption, specified performance metrics, dynamic and other safety characteristics, and reliability during revenue service simulations. This locomotive demonstration will provide needed solutions and support the Class I, II, and III railroads as they seek ways to reduce the adverse environmental impacts of aging high-emission, diesel-fueled locomotives.

This project is funded primarily by the U.S. Department of Energy (DOE) and will demonstrate the first use of the on-road Cummins X15 engine in off-road markets, which may open additional markets for other end users (e.g., marine and agriculture). UTD and others are partnering with DOE by providing co-funding. The Cummins X15N engine is an evolution of Cummins ISX12N engine and other NGV engines developed with earlier support from UTD.

Engine enclosure prototype

DOE's objective to increase the adoption of alternative fuels in the railroad industry has been limited by the pace of engine technology development from traditional locomotive manufacturers. This project will expand the use of natural gas to serve a new class of off-road customers with large potential for environmental benefits by demonstrating two significant challenges that can be met: 1) achieving near-zero emission operation, and 2) multi-engine, line-haul service feasibility.

The locomotive will use U.S. Environmental Protection Agency certified rail engines and will reduce criteria emissions by more than 95% vs. current Tier 4 standards, reduce fuel costs, and reduce greenhouse gas (GHG) emissions by more than 40% when used with renewable natural gas (RNG). Reducing criteria pollutant emissions is of critical importance because railyards tend to be in environmental justice areas where underserved populations are exposed to some of the lowest air quality.

The intent of this project is to document that multiple CNG (compressed natural gas) engines in hybrid locomotives can increase overall system energy efficiency and reduce fuel consumption by 20% to 40% by including the utilization of regenerative braking and hybridization. This project also intends to show that Class I, II, and III railroads can dramatically lower GHG emissions compared to diesel by using compressed RNG. There will also be significant importance to validating success in the most challenging applications (i.e., line-haul) to remove concerns for the rail sector to adopt RNG or CNG as a viable fuel.

Benefits / Market Implications

This technology program will demonstrate how a suite of commercially available products can be integrated to create a viable CNG hybrid system to power locomotives with near-zero emissions. This solution will be safe and reliable, while at the same time, reducing fuel costs, having a nominal maintenance impact, and creating a roadmap for accelerated deployment with predictable costs and production schedules. Anticipated benefits include:

- 20% to 40% lower fuel consumption than diesel, with negative GHG emissions when consuming carbon-negative RNG

- Capital costs of the CNG hybrid (when commercialized) will be comparable (or lower) to conventional Tier 4 diesel locomotives
- Demonstrate that a 4,300 HP line-haul locomotive can be re-powered as a natural gas hybrid locomotive at near-zero emissions – to exceed Tier 4 emission standards and meet proposed Tier 5 standards, and
- Advance the potential for gas-fueled engines to serve a key role in addressing emission challenges and environmental justice concerns in dense urban areas affected by railyards or commuter operations.

Validating the performance and maintainability of the Cummins engine in very demanding line-haul locomotive service will support commercialization in all rail sectors (e.g., passenger rail and switching locomotives) and provide a springboard to expand applications in off-road transportation, construction, and other markets.

Technical Concept & Approach

Specific tasks for this project include:

Specification, Engineering, and Design

The team will create detailed system specifications for the locomotive that will drive quantitative metrics to be used during systems validation and operational testing. Based on these specifications, the team will design the locomotive with hybrid powertrain.

Procurement and Production

The team will procure the components and repower the locomotive. Feedback from manufacturing will be used to update the designs and identify process improvements.

System Testing and Validation

The team will conduct functional testing, including dynamics and static vehicle testing as well as full operation on a 50-mile test loop at FRA's TTC facility in Pueblo, CO.

Results

An innovative design for the locomotive was developed which will employ individual modules (engine pods, fuel storage, batteries) locked onto platforms and to each other, which will allow quick and easy assembly and serviceability. A variety of modules are being designed, including ten natural gas engine pods (45 inches wide x 80 inches deep x 80 inches high), each with a water-cooled 380 kW generator, associated water-cooled power electronics, and radiator-based cooling system.

The first two generators set up and ready for testing.

Baseline power will be provided by ten 510 hp Cummins X15N natural gas engines to provide 5,100 hp (continuous). The project initially planned to use Cummins ISX12N engine but switched to the X15N after its successful initial demonstrations in trucks during 2022-23, with expected wide-scale adoption in 2024. To get the goal of 5,600 hp, 380 kW of batteries will be used to be added in a hybrid configuration. The configuration of the engine modules on the locomotive is optimized to increase airflow to the radiator of each module while providing upper space for the catalyst and the radiators.

The team also switched the locomotive platform to an EMD SD90M-2, allowing more space on the locomotive deck to arrange the engine/RNG modules and move the batteries below the deck. The two RNG storage modules (with a total of 2,000 DGEs) are in the middle of the locomotive improving the balance of the locomotive (front to back) to help tractive effort be applied evenly on both trucks, as well as yielding compact plumbing to the storage modules. Work also continued on the design of power electronics, primarily built around BAE's Modular Power Control Systems (MPCS).

Components of the project have been presented at multiple public meetings and expositions. The design and engine pod were exhibited at the ASLRRA Annual Conference and Exhibition in March 2024. The team also presented the project at DOE's Annual Merit Review in Washington, DC on June 4, 2024.

Status

The design and selection of major components and suppliers is complete, and procurement has kicked off. The team continues to work on procurement of long-term components (CNG tanks, batteries, engines, alternators, power electronics).

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Distributed RNG or Biogas Production and Cleanup

Researchers are improving the productivity of small-scale distributed renewable natural gas and biogas production in order to reduce GHG emissions from biomass waste and to reduce energy used from off-site sources. A variety of technologies and methods to maximize production are being investigated and employed.

Project Description

This project focuses on small-scale anaerobic digestion to expand the applications and locations for which anaerobic digestion is feasible, allowing for the growth of renewable natural gas (RNG) production that is needed to meet decarbonization goals.

There are an increasing variety of anaerobic digestion technologies to consider. Each method has unique technical and economic barriers to overcome. Conventional anaerobic digesters are large, custom designed for each facility, and constructed on site with correspondingly high costs. Anaerobic digesters can be used to treat wastewater and have potential to be used at small- and medium-sized facilities such as breweries, distilleries, cideries, dairies, cheesemakers, seafood processors, and campuses could benefit from anaerobic digesters. However, their operations are normally too small to afford the capital expense of a traditional digester.

Significant effort is needed to: analyze applications; optimize novel, emerging technology packages and potential high-value co-products; and find ways of increasing reliability and productivity without increasing labor and management.

This project seeks to determine technical and market requirements to build and operate novel, integrated technology packages to convert various organic wastes into high-value RNG. In particular, there is a need to assess to what extent these systems can be commercially viable at much smaller scales than previously possible via enabling strategies such as: novel modular technology packages; optimized co-production, co-product development, marketing and sales of co-products given the geographic location; and alternative and innovative business models to capitalize the equipment.

Prefabricated units drive down capital costs and allow for quick delivery.

Credit for image above: Chomp

In summary, researchers are investigating anaerobic digestion and gasification technologies that are suitable for small-scale onsite service, potential feedstocks, feedstock preparation and pre-treatment options, reactor designs, biogas and producer gas cleanup, economic modeling and performance analyses, and methods of digester monitoring and control to increase the throughput of small-scale digesters.

This project serves end users, society, and the environment by advancing RNG in distributed energy applications. These technologies can lower greenhouse gas (GHG) emissions, increase energy resiliency, and decrease solid waste disposal costs paid by the onsite user.

In Phase 2, the team will work on increasing system automation and remote monitoring with the goals to further reduce costs and further improve system performance.

Benefits / Market Implications

Example target markets are smaller municipal waste management facilities, food processing plants, small farms and dairies, and campuses with foodservice for large populations. Potential secondary target markets include horticultural operations, restaurants, grocery companies, and microbreweries.

A 2019 assessment of RNG by the American Gas Foundation illustrates RNG potential as a GHG emission-reduction strategy. According to this study, "…there is a portfolio of potential feedstocks and technologies that are or will be commercialized in the near-term future that will help realize the potential of the RNG market." Most RNG continues to be produced using anaerobic digestion paired with conditioning and upgrading systems. The post-2025 outlook for RNG will increasingly rely on thermal gasification of sustainably harvested biomass, including agricultural residues, forestry and forest product residues, and energy crops."

This project focuses on broadening the quantity of organic waste accessible for RNG production and will advance technology that can be deployed for smaller dairies, farms, water-resource-recovery facilities, food processing plants and many other facilities.

Technical Concept & Approach

This project is analyzing small-scale RNG production technologies with feedstock inputs ranging from hundreds to thousands of pounds of waste feedstock per day. Two technologies are being considered: anaerobic digestion and gasification. Gas cleanup technologies such as membranes, solvents, or more novel solutions are being studied for small-scale as well as medium-scale applications such as farms with herds of 100 to 1,000 head of cows.

Tasks for Phase 2 will focus on anaerobic digestion:

Identify key technology advancements, conduct preliminary economic studies

The project team will work with our commercial partner to identify key areas of improvement, with a focus on increasing RNG production, system optimization, and enhanced process automation. To streamline efforts, 2-3 pieces of instrumentation or data collection hardware will be down selected to be installed on a single digester. The selection criteria for the items will be cost, delivery time, and potential impact on the process. The team will also begin working on the layout of the digital twin for at least one digester.

Implement, monitor, and optimize system; update economic studies

The team will install the equipment on one of their digesters, develop the remote data acquisition system, and complete the layout of the digital twin architecture. Once the data is available, data update frequency will be determined and reviewed, and the data will be fed to the digital twin. The dashboard will provide data collection, monitoring, and visual representation of the data. The team will monitor 1-2 digesters for up to a year and collect data on the process performance. This data will be used to study the economics of the digester. The team will also use the digester to study the economics of one or more other potential end users.

Results

The team conducted a literature review and collaborated with a small scale digester vendor to identify known and hypothesized limiting factors of long-term small scale anaerobic digester productivity, and assess sensing, control, and analytical strategies to increase digester productivity.

A detailed experimental plan was created with the goal of studying typical digester behavior, especially focusing on typical small scale digesters being used to process food waste. The nature of upsets and performance challenges was logged and multiple monitoring approaches for small-scale digesters were simultaneously used for optimal monitoring and control. This project has collected substantial operating logs from an operating, 480-gallon, continuously-mixed digester designed for onsite organic waste treatment service.

"Impact Bioenergy has built and deployed over 17 small-scale, onsite, modular anaerobic digester solutions since 2013. We are excited about how our distributed and modular systems empower their owners to divert organic waste from landfill, reduce the waste-transportation footprint, generate energy, and generate organic plant food that supports food production onsite or in the community or campus hosting the digester.

- Jan Allen
President
Chomp [previously called Impact Bioenergy]

Data collection for this effort includes the FOS/TAC score via the Nordmann method, biogas quality (% CH_4), biogas quantity (flowrate), digestate pH, and digestate alkalinity. Data was collected for a baseline, first, and second level of digester feed rate in an experimental test series. The first increase in feed rate (100 lb/day to 140 lb/day) was completed in early Q2 2023, and definitively verified that successful long-term performance was viable at this level of digester duty.

The second increase in feed rate was to 180 lb/day. A rise in FOS/TAC score was then noted (from about 0.14 to 0.59), which alerted the digester operators of a developing over-fed, also known as over-acidified state. Operators were then able to cease feeding of the digester. The FOS/TAC score then returned to normal levels within a couple of days, upon which in a commercial installation, normal feeding could once again be resumed. Both the normal operating state as well as the over-fed state were simultaneously evaluated using all of the digester monitoring parameters that were being trialed to evaluate their effectiveness. Experimental work was concluded early in Q3 2023.

In 2024, team members started working to develop a preliminary digital twin model for the digester system. They also held discussions around the best use of a digital twin, improved process control systems, and data aggregation expertise to create a live model of the digester system which would allow remote monitoring of the system. Team members also started to update the preliminary economic analysis.

Status

A final report summarizing Phase 1 results was released to UTD members in July of 2024. In current Phase 2 efforts, the team is working to complete a preliminary digital twin and finish work on the economic model. They are also conducting further industry outreach to look for other methods and new instrumentation options to monitor digesters.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Improved Hydrogen Fueling for Heavy-Duty Vehicles

In partnership with the National Renewable Energy Laboratory and others, a new publicly-available protocol for high-pressure, high-flow hydrogen fueling of heavy-duty vehicles was developed and issued. SAE J2601/5 is now available to help transportation end users reduce GHG emissions by using zero-carbon hydrogen fuel.

Project Description

Deployment of heavy-duty fuel-cell vehicles is limited by the availability of hydrogen fueling technologies that can affordably and reliably dispense hydrogen. High-flow fueling (approximately five times faster than current light-duty hydrogen-vehicle fueling) is necessary because heavy-duty trucks need to store 50 to 100 gasoline gallon equivalent (GGE) of hydrogen onboard, which is at least 10 times what is typically stored on current light-duty hydrogen vehicles.

While the fill rate required will vary depending upon a truck's class and vocation, the U.S. Department of Energy's (DOE) fueling rate target for Class 8 long-haul trucks is 10 kilograms (kg) per minute (one kg of hydrogen is approximately one GGE) to enable full fills within timeframes comparable to those for today's diesel trucks (e.g., approximately five to six minutes). This target is based on a desire for hydrogen fuel-cell trucks to achieve a 750-mile driving range between refueling, which will require onboard storage of approximately 60 kg of hydrogen.

The accepted fueling procedure for light-duty vehicles was developed with support of National Renewable Energy Laboratory (NREL) researchers and it allows for more flexible and lower-cost fueling stations while maintaining safety and reliability. Previously, a prescriptive protocol for high-flow heavy-duty hydrogen fueling did not exist. This project – in partnership with NREL and in coordination with Southern California Gas (SoCalGas), a major public transit agency, and others – supported the technical development of a standardized prescriptive fueling protocol which is applicable to a wide range of vehicles and storage system designs and can be used for public-access fueling stations.

Researchers conducted the modeling and testing required to validate the fueling protocol and facilitate its potential adoption in future international consensus standards, within the limits of the project resources.

Benefits / Market Implications

In order to achieve deep decarbonization goals in the transportation sector, a wide variety of alternative pathways are needed. This sector is particularly important because it is a critical growing industry for goods movement, and it is challenging to electrify because of the energy-density requirements. U.S. DOE data shows that heavy-duty trucks produce approximately 25% of the greenhouse gas emissions in the transportation sector while comprising only 5% of the total vehicles.

This project removed barriers to the installation of public high-flow hydrogen stations for heavy-duty vehicles to expand the range and operation area of these vehicles. This is especially important as California and other states adopt aggressive zero-emission vehicle targets for heavy duty vehicles (e.g., California's Advanced Clean Truck Regulation and the 15-state initiative signed in 2020 to advance the market for zero-emission medium- and heavy-duty vehicles).

Hydrogen fueling dispenser. Image credit: California Energy Commission

Technical Concept & Approach

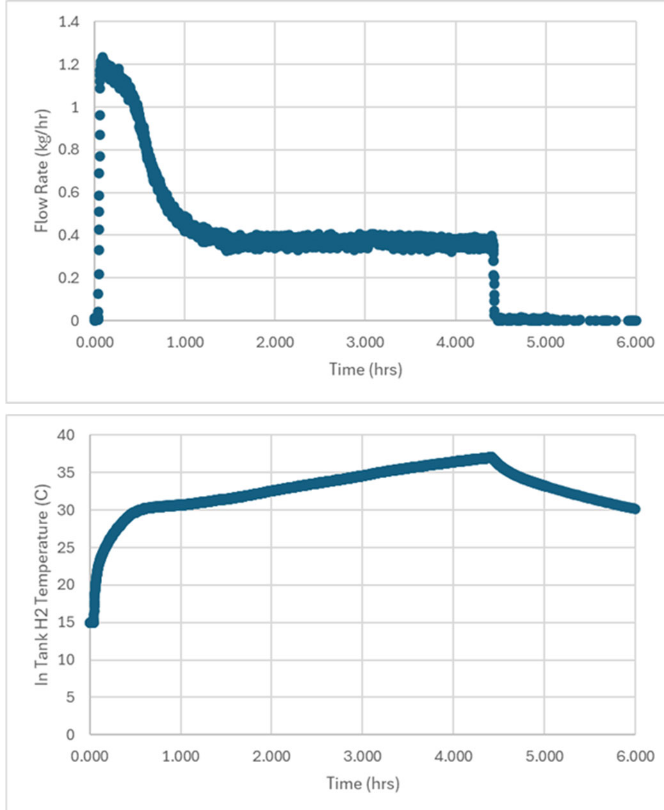
Specific activities of the UTD project team included:

- Organizing and coordinating discussions with relevant stakeholders on process and interfacing specifications.
- Supporting the data analysis of modeling and experimental results, and
- Performing validation testing, if time and budget allows, including fueling and defueling vehicle pressure vessels.

Results

The first task of the UTD project team was to support NREL with several technical tasks. These included definition of protocol specifications (e.g., expected fuel-system size and target final fill conditions), assisting in data analysis of simulation and validation data, and assisting in the development of a validation calculator to be used to verify dispensers accurately follow the protocol. NREL adapted their light-duty fueling model to heavy-duty vehicles, with collected input from manufacturers on the type, size and properties of the storage tanks on these trucks. They developed a matrix of simulations to find end-of-fill conditions for a range of cases and conducted high-flow fueling component testing. These simulations were used to create a fueling protocol, that was published by SAE International in February 2024 as SAE J2601/5 "High-Flow Prescriptive Fueling Protocols for Gaseous Hydrogen Powered Medium and Heavy-Duty Vehicles". This standard is available on the SAE International website and is based on the modeling results that were a direct result of this project.

The project team was also able to dedicate some effort to testing an extremely valuable pathway for heavy-duty fueling, which is time-fill fueling. Heavy-duty vehicles have seen huge benefits from time-fill fueling in CNG applications, and the same potential exists in hydrogen fueling. Significant challenges exist in this area to ensure the tanks remain within their temperature limits, while achieving full fills and maintaining flow rates above the minimum check valve chatter flow rates advised in the high-flow fueling protocol. Developing this protocol will also lead to a preliminary time-fill fueling station design that can be utilized for station deployments in the future.



Example data from laboratory tests of hydrogen time filling

The team designed and constructed a time-fill test unit. The unit enables filling of up to 6 target cylinders from either 900bar storage or directly fill from a compressor at 450bar. The test program looked at the temperature increase in tanks and final fill percentage for a several different fueling patterns and final pressures.

Through this testing, the project demonstrated safe and complete filling of 35MPa and 70MPa storage vessels with a lower-cost time fill protocol. This time fill protocol has the added advantage of providing an estimated 30% reduction in capital cost of the refueling station and a 25% reduction in the total cost of dispensed hydrogen.

Status

This project is complete and a final report was issued to UTD members in September of 2024.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Technical Support for Clean Transportation Testing, Performance, and Safety

This project provides technical information and input to support the consensus development or refinement of natural gas vehicle standards, as well as to investigate and learn from safety incidents, in order to enhance the safety of NGVs, financial savings to end users, and reductions in NO_x, Sox, and particulate emissions by using less diesel fuel.

Project Description

Over the past several decades, the natural gas industry has supported the development of minimum safety standards that guide natural gas vehicle (NGV) end users and other industry stakeholders. As a result, a suite of compressed natural gas (CNG) and NGV components and systems have been developed that satisfy key technical standards to help ensure the safety of end users, vehicles, fueling infrastructure, and the general public.

Ongoing innovations and changes necessitate that careful attention be placed on codes and standards. Knowledgeable technical input into the consensus-building process is critical to ensure proper coverage to protect users and the general public. This includes clarifying coverage between new vs. existing standards and, where appropriate, expanding coverage to new applications and technologies. Outdated standards should not create an obstacle to product advancements that can benefit end users. As manufacturers of vehicle and station components expand their businesses to broader markets, harmonization of standards across North America, South America, and Europe is also gaining importance.

This project provides technical support and input related to NGV standards development and refinement, for consideration and/or consensus action by the technical committees of: CSA standards such as NGV 4.3 (Temperature Compensation Guidelines), NGV 4.1 (CNG Dispensers), NGV 4.8 (NGV compressors), and NGV 6.1 (CNG Fuel Storage); Gas quality standards from the CSA Group, ASTM International, American National Standards Institute (ANSI), and others; and National Fire Protection Association 52 revisions.

This project also provides technical data and information to the Technology and Development Committee of The Transport Project (formerly NGV America, or NGVA) to support accident investigations and help establish safety, technical, and environmental priorities.

Benefits / Market Implications

Enhancing the performance and safety of NGVs, the fueling infrastructure, and maintenance facilities helps end users and facility owner/operators reduce costs and incidents while gaining the environmental benefits of CNG.

This project provides technical support to enhance consensus-developed standards and introduce new or updated minimum safety requirements affecting compression equipment, dispensers, vehicle components, and natural gas storage products in the North American marketplace.

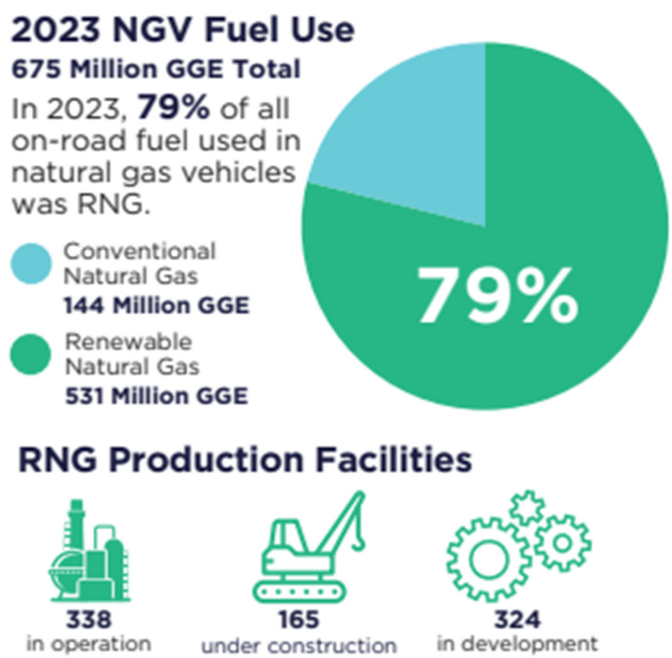
By striving for single, globally-acceptable technical standards and conformance tests, new or improved products that benefit end users can be introduced at a broader scale and with lower cost and shorter time to market.

By participating in technical advisory groups, experts share best practices learned over decades of experience and influence the standards developers and product manufacturers.

The primary markets to benefit are: NGV end-users including fleet operators, vehicle and engine manufacturers, CNG station providers; and additional stakeholders such as first responders, maintenance facilities, and utilities.

Technical Concept & Approach

Project representatives participate as members in the Tech-



The development of renewable natural gas (RNG) production is directly tied to the transportation sector and credits for RNG use in vehicles.

Source: The Transport Project Data on RNG Use in NGVs.

nical Advisory Group's standards groups and chair The Transport Project's Technology and Development Committee. Updates are provided through various tasks, including:

Technology Committee Support for Standards Development, Updates, Monitoring and Review

Project representatives participate in regular technical discussions and committee meetings scheduled by standards-setting organizations, testing organizations, and vendors to monitor and support by open meeting consensus the updates and progress of key standards and code documents.

Support The Transport Project's Technology and Development Committee

The project team's participation provides extensive NGV and fueling experiences.

Results

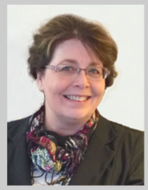
In 2022-23, the project team continued to participate in the development of CSA NGV 4.3 (Temperature compensation guideline for compressed natural gas vehicle fueling) which led to its finalization by CSA and its publication; this included serving as Vice Chair of the applicable CSA Working Group. NGV 4.3 underwent a major overhaul to include testing for new dispensers as well as updates to better reflect accurate temperature compensation. Researchers supported the base technical case for updates being evaluated by the entire Working Group.

The project team also provided technical support to ANSI and CSA committees for the technical development of temperature compensation requirements in NGV 4.1, 4.8 and 6.1.

The project team also provided technical support to advance CSA NGV 5.1 (Residential Fueling Appliances) and CSA NGV 5.2 (Vehicle Refueling Appliances), which were finalized and published by CSA.

The project team also provided technical support for The Transport Project's Technology and Development (TD) Committee, including serving as TD Committee Co-Chair. Activities of the TD Committee included assessing technical issues critical to end users and public safety, such as:

- Discussed and investigated, on a quarterly basis, the root causes of safety accidents and then communicated findings.
- Updated the Guide to Safe Vehicle Conversions with the latest requirements listed in FMVSS 304, NFPA 52, and EPA/CARB compliance regulations.
- Held a Technology Webinar in September 2022 on the use of Modal Acoustic Emission (MAE) technology and its applications for vehicular and tube trailer CNG cylinder inspection.
- Supported development of Recommended Practices for Unattended CNG Time-fill Refueling Stations document, which can be found at: https://ngvamerica.org/wp-content/uploads/2021/09/ANGI-FDS-White-Paper-8.31.21.pdf
- The CNG Fuel System Inspection working group produced a CNG Cylinder Pressure Indication Safety Bulletin -https://ngvamerica.org/wp-content/uploads/2023/02/NGVA_safetybulletin_CNGcylinderpressureindication_28FEB2023.pdf



"CSA recognizes the input and insight that our committee members provide on NGV technical subcommittees. Through participation in the standards-development process, UTD contributes to the deployment of safe and reliable components, equipment, and practices for the industry."

- Julie Cairns
Sr. Project Manager, Alternative Energy
CSA Group

"NGVAmerica's Technology & Development Committee largely relies on the voluntary efforts of member companies and their representatives to address important issues in the NGV industry related to technology, innovation, safety, and sustainability. UTD's support to provide representation on the Committee and each of the subcommittee working groups has been instrumental in the many achievements to date for the advancement of natural gas as the most proven, cost-effective, and ready-now solution for decarbonizing transportation."

- Paul Sandsted
Director of Technology and Sustainability
The Transport Project (formerly NGVAmerica)

In 2024 the team continued to provide technical support for The Transport Project's TD Committee. This includes supporting ongoing development work with the NGV 6.1 Technical Subcommittee for the next edition of the standard for CNG fuel storage and delivery systems for road vehicles, the release of the TD Committee's Technology Bulletins, and the discussion of safety incidents with investigations of the root cause.

Status

The project team will continue to monitor and participate in relevant CNG and NGV codes and standards developments, and support key technical initiatives through The Transport Project's Technology and Development Committee.

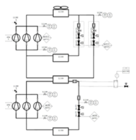
For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

PROJECT NO. 2.22.G
SUMMARY REPORT

Utilization Technology Development

Cost-Effective Pre-Cooling for High-Flow Hydrogen Vehicle Fueling



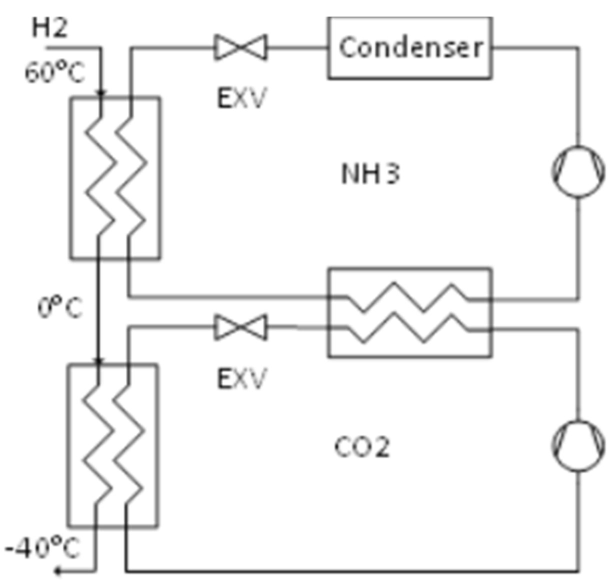
Researchers will design, fabricate, and validate design of a cost-effective, high-efficiency chilling system to pre-cool hydrogen for high-flow fueling of heavy-duty trucks at 70 MPa. This pre-cooling system will reduce the life-cycle cost of hydrogen fueling and reduce greenhouse gas emissions from heavy-duty vehicles.

Project Description

The goal of this project is to design, fabricate and validate a prototype sub-scale version of a cost-effective, high-efficiency chilling system which uses commercially-available components and natural refrigerants to pre-cool hydrogen for high-flow fueling of heavy-duty vehicles at 70 MPa.

High pressure is required to provide reasonable vehicle range. However, the high pressure gas must be pre-cooled because the gas heats up significantly when compressed and the gas must remain below the maximum allowable temperature of the vehicle's hydrogen storage system. Equipment capable of cost-effectively delivering pre-cooled hydrogen at high flows for heavy-duty trucks is not commercially available. Applying commercially-available pre-coolers which are currently used for fueling light-duty hydrogen fuel cell vehicles would require five light duty chiller units at approximately $250,000 each for a heavy-duty hydrogen fueling station. Fueling stations for light-duty vehicles deliver hydrogen at approximately 2 kg/min, while typical targets for stations for heavy-duty hydrogen vehicles are 10 kg/min.

Light-duty hydrogen pre-cooling units typically utilize a single refrigerant in a loop with a two-stage compressor and economizer to chill a large aluminum block to approximately -45°C. The hydrogen gas is then chilled from temperatures that can exceed 60°C down to -40°C in a single step.



Selected Chiller Configuration

This project will utilize a cascade refrigeration cycle design that is more complex but provides large efficiency and energy savings - more than a 100% improvement in total coefficient of performance (COP). The economic trade-offs of this option will be weighed against simpler single-refrigerant designs.

The US Department of Energy (DOE) is providing prime funding for this project, which focuses on developing near-term solutions utilizing commercial products while solving a considerable problem for end users. This low risk, high reward approach is expected to lead to rapid commercialization of a critical technology in this growing market segment. UTD is partnering with DOE by providing co-funding, along with the Southern California Gas Company (SoCalGas). Other project team partners include Argonne National Laboratory (ANL).

At the end of the project, the technology will be ready to transfer to a chiller manufacturer for detailed design of a full-scale system for subsequent installation and testing in a heavy-duty hydrogen fueling station. Key performance targets are for the pre-cooler design to fill a 60kg fuel system in 6 minutes (equivalent to diesel fueling speeds) at the temperature required by the applicable fueling protocol (currently under development), a cost of less than $500,000, and have a maximum power requirement under 200 kW. The team will build and validate a 2-3 kg/min lab-scale unit and develop a promising commercialization plan and economic analysis, with support from an industrial partner.

Benefits / Market Implications

The primary market impacted will be heavy-duty trucks that require high pressure (70 MPa) hydrogen fueling. The development of this heavy-duty pre-cooling unit will reduce the life-cycle cost of hydrogen fueling, while accelerating a transition toward use of natural refrigerants – such as CO2 and NH3. This will reduce barriers to adopting heavy-duty hydrogen vehicles by lowering the cost of fueling stations.

Transitioning to hydrogen fuel cell heavy-duty vehicles would significantly reduce greenhouse gas emissions. Heavy-duty vehicles travel only 10% of the total annual vehicle miles driven, but they contribute 23% of transportation emissions of greenhouse gases according to the Environmental Protection Agency.

Technical Concept & Approach

This project will develop a pre-cooler design which will significantly benefit from refrigeration cycles that utilize several evaporator stages such as cascade refrigeration or more complex single-refrigerant circuits. The end product will be a fully-designed, optimized, and performance-verified chiller system capable of fueling 70 MPa hydrogen vehicles at an average of 10 kg/min. The following tasks will be performed:

Preliminary Chiller Design

The team will develop a preliminary design of a full-scale chiller system capable of fueling a heavy-duty vehicle within the acceptable design parameters.

Detailed Design and Build, and Economic Analysis

The team will complete a detailed design and build of a test unit and install it in the lab for testing. An economic analysis of the full-scale unit will be performed assuming production volumes of 100 units per year and the team will assess if the targeted capital and operating costs of the system appear likely to be achieved.

Performance Validation and Final Design

The team will validate the performance of the test unit through thorough lab testing. Lessons learned will be incorporated into the design of a full-scale system suitable for commercialization by a manufacturing partner and installations at a high-flow hydrogen fueling station. This task will also include commercialization planning to ensure the design is available for purchase by future stations.

Results

Modeling the worst-case scenario of a heavy-duty hydrogen vehicle fuel system showed that a pre-cooling temperature of -30°C is required to ensure a full fill at high ambient temperature, and this finding is consistent with other research analyses. For the preliminary chiller design, the team only considered refrigerants which have a zero Ozone Depletion Potential and low Global Warming Potential (less than 10), which left only three refrigerant options: CO_2, ammonia, and propane. A total of nine refrigerant systems were considered for the design, all of which were various combinations of these three refrigerants. Of these, three systems in particular were investigated: NH_3/CO_2, NH_3/Propane, CO_2/CO_2 (two-stages of compression and cooling).

After careful consideration, the team selected the NH_3/CO_2 system for the preliminary design of the pre-cooling unit. One of the main considerations was whether to use propane or CO_2 for the low stage of the chiller. The advantage of propane is the low operating pressure, making components cheaper and easier to procure. The downside is the high flammability that presents an additional hazard to the site. The team ultimately chose to move forward with CO_2 due to its high efficiency and lower flammability. Modeling of the Coefficient of Performance and maximum power requirement was completed. The modeled maximum power for the NH_3/CO_2 system was found to be 110 kW. This is before any over-design margin is allowed and some ancillary components (like cooling fans) are specified.

A heat exchanger to cool the high-pressure hydrogen to -30° C was sourced from two vendors. This heat exchanger is designed to withstand 1,000 bar of hydrogen on one side and a heat transfer fluid on the other side. Modeling of heat exchanger location was conducted. Typical light duty stations require precooling at the dispenser, but the flow rates for heavy duty are so much higher that this configuration needed to be reconsidered. Modeling showed a delay of 100 seconds before the delivered hydrogen temperature fell below 25°C if the precooling unit was 30 meters from the dispenser, which would cause an extended time delay for the fueling process. Therefore, locating at least the final stage of precooling at the dispenser will likely be needed in most station configurations to ensure fueling efficiency. The first stage of cooling with ammonia can be located much further from the dispenser, in a location “behind the fence” in a restricted area to improve the safety of the installation.

The team is conducting testing of the lower stage of the cascade chilling system to inform the final design. This CO_2 stage will provide the final cooling before fuel delivery and will carry the requirement of achieving the final pre-cooling temperature. The cooling demand for this system is very transient and must respond quickly to changes in fueling flow rate. For this reason, the team decided it was important to test this stage alone prior to completing the design of the full test unit.

In 2024, the preliminary design of the full-scale chiller system completed, which included performing a Hazard and Operability study. The preliminary design yielded a peak power requirement of 120-130 kW with the ability to fill a 70 kg fueling system in 10 minutes at an ambient temperature of 20C. This unit is now under construction.

Status

The team is currently testing the heat exchanger test unit to create a model of heat exchanger performance and verify that the low stage refrigeration loop can handle the transient cooling load. Construction of the full test unit is underway with completion expected in Q1 2025.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Heavy-duty Hydrogen Vehicle Development and Deployment

Researchers will design, build, and demonstrate a hydrogen-fueled, zero-emissions regional-haul Class 8 vehicle in order to accelerate of the availability of such vehicles so that end users and fleet operators can reduce GHG emissions, enhance air quality, benefit from superior operating range, and have more competing product choices.

Project Description

The goal of this project is to design, build, and demonstrate a hydrogen-fueled, zero-emission regional-haul Class 8 vehicle. With major funding support from the California Energy Commission (CEC) and Southern California Gas Company (SoCalGas), the tactical objectives are to integrate an advanced hydrogen fuel cell, hydrogen storage, battery, motive, and control systems to collectively provide a zero-emission solution for the challenging duty cycle associated with drayage and regional-haul operations. UTD is partnering with CEC by providing co-funding to the CEC-prime-funded project, which will lower greenhouse gas emissions and criteria area pollutants for consumers and the environment. Key performance indicators of the project's success include:

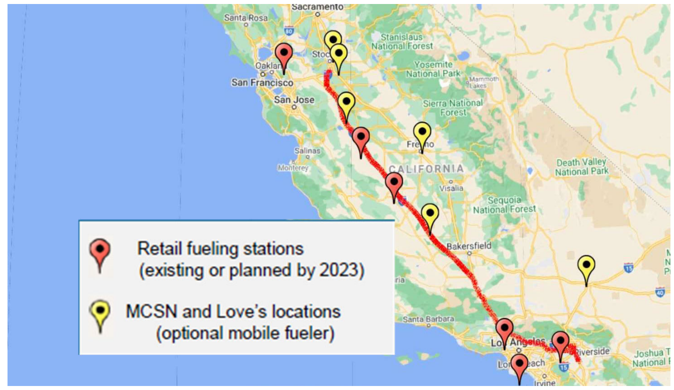
- Develop and demonstrate a Class 8 fuel cell truck that can achieve one-to-one replacement of diesel truck
- Improve performance, durability, and maintainability of a regional-haul fuel cell truck
- Demonstrate reduced total cost of ownership (TCO) and other benefits in order to encourage adoption

Benefits / Market Implications

The project seeks to demonstrate a zero-emission alternative for the current market of diesel trucks used for regional haul and powered by 15-liter engines rated at 455 hp / 1650 lb-ft and equipped with 300 gallons of fuel tanks.

A typical loaded trailer being moved along the 400-mile demonstration route can weigh 23,500 to 57,000 lbs. The vehicle typically returns with an empty trailer weighing 13,500 lbs. The 300-gallon onboard fuel storage offers a 1,500+ mile range, theoretically supporting two roundtrips, which is not likely a critical need for a typical fleet. Currently, no zero-emission technology offers this amount of onboard energy storage and projected operating range.

E-Axles ready for installation



The demonstration vehicle will overcome these barriers by storing 66.8kg of 700-bar hydrogen onboard, utilizing a 400-kW fuel cell, taking a strategic route with intra-route fueling in California's Central Valley, and employing a carefully-designed powertrain with components sized specifically for this duty cycle. US Department of Energy (DOE) national data suggests that 93% of the Class 8 trucks and 80% of their vehicle miles traveled (VMTs) can be served by vehicles with a 500-mile range. The 450-mile range vehicle will be able to perform both drayage and regional transport duties and the team has selected this application as not only a showcase of hydrogen fuel cell technology, but also because it can offer range that effectively covers most of intra-state California freight movement. The technology will also provide a substantial reduction in noise due to quieter powertrains and no need to use engine retarders on downgrades.

Over the last decade, the cost of fuel cell technology has been lowered by approximately 85%. It is expected that this trend will support the market to attain DOE's cost target of $80 per kW through technological improvement and volume production. Hydrogen fuel cost remains a concern among fleet operators. By demonstrating the viability of hydrogen fuel cell trucks as a feasible zero-emission solution for long-distance operation, it will encourage the adoption of hydrogen-powered trucks and help create substantial demand for hydrogen as a transportation fuel.

According to a Total Cost of Operation (TCO) study by the National Renewable Energy Laboratory (NREL), fuel cell

Packaging of components under the hood

trucks could be cost-competitive with diesel trucks if the vehicle purchase price is $258,000 and hydrogen fuel prices are $4/kg.

Technical Concept & Approach

The project team will design, build, and demonstrate a hydrogen-fueled, zero-emissions regional-haul Class 8 vehicle. The vehicle design, development, and verification work will take 24 months of the project. The vehicle demonstration will take 12 months. The following tasks will be performed:

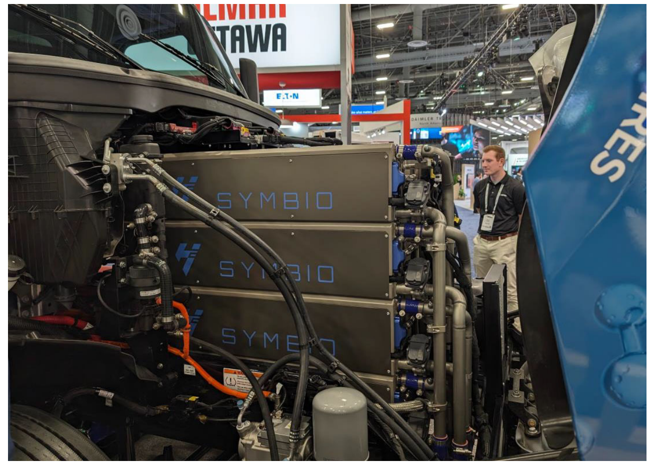
Vehicle Design, Build and Verification

The technical team will design and build the vehicle based on an existing Freightliner Cascadia platform. The task will include the definition of functional requirements, a study of design trade-offs, and computational and numerical engineering. Following the build, the team will commission and verify the vehicle prior to delivery to the fleet operator.

Demonstration, Data Collection and Analysis

Measurement and verification (M&V) activities will be performed and will leverage prior experience in data acquisition from advanced vehicle testing and data analysis.


Fuel Cell



Fuel cell stacks under the hood

Results

In 2023, a Hydrogen Safety Plan and Safety Analysis Report was developed, and the team had a project review with the CEC. Work was started to disassemble and convert the donor vehicle. Cooling and fuel cell subassemblies were assembled. Hydrogen tanks were received and installed. A fuel cell and component test and validation test bench were developed. The project team also collected baseline data from a diesel truck.

In 2024, thermal management systems, electrical and mechanical subsystems layout, control software design, safety design, and complete packaging design for all major components were completed. Additionally, the design and installation of the high- and low-voltage system architecture, development of the vehicle controller, and installation of the e-axles, and vehicle accessories has been finished. The vehicle build is complete and was displayed at the Advanced Clean Transportation (ACT) Expo in May 2024. The vehicle was started up as an EV (on batteries) and is undergoing commissioning of the fuel cell system. The team has selected the data collection/telematics system and is in the process of purchasing it.

Status

Next steps include: vehicle shakedown and commissioning of the high voltage and hydrogen systems; ordering and installation of data loggers; creating a fueling plan; and finalizing the fleet selected for field demonstration.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development

Adsorbed Natural Gas Vehicle Field Demonstration

Researchers tested six light duty vehicles deployed with Ingevity's NeuFuel™ lower pressure adsorbed natural gas (ANG) technology, and fueled by FuelMaker's FMQ 2.5 refueling system. The real-world fleet demonstrated: cost savings of 18-44% compared to gasoline; equivalent dispensed fuel cost of $1.93 per gallon gasoline equivalent, and 78% reduction in GHG emissions in optimal scenarios.

Project Description

This project studied the total cost of operation and environmental benefits of operating light duty NGVs using Ingevity's NeuFuel™ lower pressure adsorbed natural gas (ANG) storage and lower-cost fuel dispenser. Ingevity, with support from APGA Research Foundation and their stakeholders, deployed six ANG light duty vehicles (pickup trucks and van) with the required fueling infrastructure and data acquisition systems in order to verify costs and benefits. The test plan gathered user feedback and data necessary to quantify environmental benefits.

Benefits / Market Implications

The primary target market impacted by ANG technology is small, dispersed, light and medium-duty (Class 2-6) fleets between 5 to 20 vehicles, particularly those fleets that have high-use duty cycles (>100 miles per day). Not only are these vehicles sometimes hard to electrify because of their high range demands, it is also challenging to justify building a full-scale Compressed Natural Gas (CNG) station because the capital cost is too high per vehicle. The economics of ANG are favorable thanks to an easy-to-install, affordable and compact BRC Fuelmaker FMQ 2.5 ANG fueling appliance.

Activated carbon-filled cylindrical tanks supplied by Ingevity are nested in the bed of a truck. These specially-designed tanks reduce the storage pressure of the natural gas without sacrificing the volume of gas stored. The ability of ANG's system to operate at 900 psi – compared to CNG's 3,600 psi – increases the methane adsorption capacity inside the cylinders while reducing compression energy. For example, ANG tanks hold twice the volume of natural gas at 900 psi as a conventional compressed natural gas tanks can hold. The lower operating pressure of the fueling appliance reduces the total cost of operation for the fleet owner. These features allow light duty vehicle fleets to effectively access and realize the benefits of Natural Gas Vehicles (NGVs). The lower operational pressure for ANG can provide a significant benefit for light and medium duty vehicles.

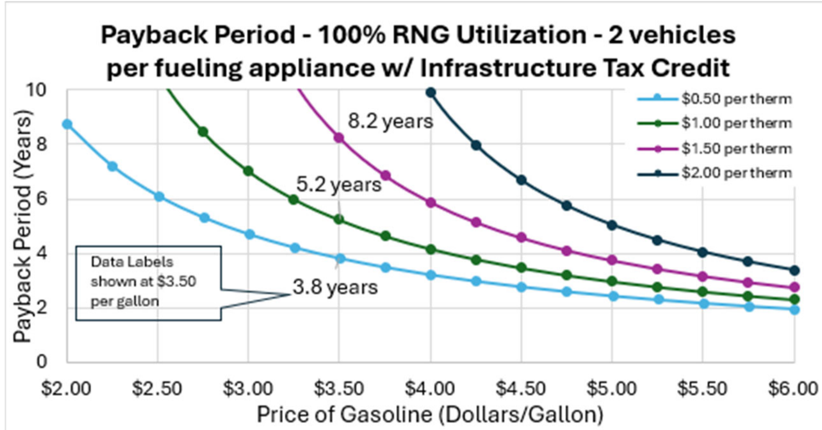
According to Ingevity, approximately 7 million light duty vehicles are sold in the U.S. every year that are underserved by alternative fuel options such as CNG. ANG has the potential to expand competitive options for end users.

Commercially-available vehicles and fueling systems include bi-fuel ANG trucks capable of serving 100% of average daily usage miles on natural gas alone, a flexible cylinder design which allows for a range of on-board natural gas storage (from 2 to 8 GGE), and the Fuelmaker FMQ 2.5 ANG fueling appliance. The Fuelmaker includes two fueling hoses (P9 nozzles), can service two trucks at once and fueling at a rate of approximately 1 GGE/hr, and is certified to meet the American National Standards Institute (ANSI) NGV 5.2 standard for vehicle fueling appliances.

According to Ingevity, total Cost of Operation (TCO) of a new FMQ 2.5 is estimated at $0.89 per GGE. Studies conducted for Ingevity also demonstrate that even CNG fueling compressors, designed to fill at 3,600 psi, that are repurposed to fuel at lower ANG pressures can have a TCO that falls within $1.00 per GGE.

Project results supported efforts to fill a key end user need for low-emission light-duty vehicles. ANG vehicles provide light duty fleets with an alternative fuel option which have different characteristics than electric vehicles. These vehicles can provide a reduction in greenhouse gas and other emissions over existing light duty vehicles.

Ingevity storage tanks in a truck bed.



Example installation of FuelMaker FMQ 2.5 ANG fuel dispenser

Technical Concept & Approach

The project team partnered with Ingevity and the American Public Gas Association Research Foundation (APGA RF) to deploy 6 ANG Vehicles (including Ford pickup trucks and vans) and the required fueling infrastructure. Ingevity worked with APGA RF and their stakeholders to locate and deploy the ANG vehicles either in three fleets. The project team worked together to develop the test plan and analyze the data collected from demonstration efforts, in order to verify user feedback, economics, and environmental benefits. Ingevity's work scope included identifying specific fleet (s) and vehicles to be deployed, deploying vehicles, and acquiring data.

Specific tasks for this project included:

Develop Test Plan

A test plan was developed to acquire the necessary data to calculate the total cost of operation for ANG systems deployed on the demonstration vehicles as well as the reductions in GHG emissions.

Data Analysis and Technical Report

On a regularly scheduled basis, using data supplied by Ingevity, information was analyzed to ensure that the test plan objectives were being satisfied. Findings were reviewed with APGA RF and Ingevity throughout the demonstration period. At the conclusion of the demonstration, a technical report was prepared covering the results and findings from the demonstration.

Results

The team received and reviewed Ingevity's calculations on CO2 emissions reductions based on the amount of RNG used for a single vehicle. Additional fleet data was identified to enhance the analysis the cost and emissions reductions. Ingevity collected records of about 44,000 miles of performance of the vehicles prior to the retrofit, in order to provide baseline fuel consumption data and calculations. About 11,000 miles of vehicle data with ANG system was collected over the data collection period. The results of the study showed that if 100% of the onboard RNG is utilized 5 days a week, 52 weeks per year, then each vehicle can save approximately $1,800 dollars in annual fuel costs and 11 short tons of GHG emissions, based on current average fuel costs of $3.50 a gallon of gasoline and $1.29 a therm of NG.

Status

The project is complete. A final report was issued to UTD members in November 2024.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Small-Scale Natural Gas SMR Technology Optimization with Carbon Capture

Researchers are optimizing a small scale steam methane reforming technology and developing an associated technology development plan for carbon capture. This technology will allow cost effective distributed generation of H_2 utilizing the natural gas distribution network while further reducing GHG emissions via carbon capture.

Project Description

The goal of this project is to optimize an existing small-scale steam methane reforming (SMR) technology which is currently capable of producing ~50 kg/day of hydrogen. The team will prepare a technology development plan for an efficient and affordable carbon capture (CC) technology that is suitable for subsequent experimental validation.

Technical options to modify the design and operation of the small-scale SMR to improve the economics of CC at small-scale will be investigated and analyzed. This investigation will build upon the findings from a project funded through the Low Carbon Resources Initiative (LCRI) on this topic and extensive expertise related to SMR and CC.

The goals of this project include demonstrating a 20% energy savings (MJ/kg H_2 produced basis) via a combination of: optimization of the SMR; optimization of the carbon capture to achieve at minimum a 90-95% capture rate and a CO_2 stream purity of 95% vol/vol, and creating an estimated cost of operation equal to the SMR module on a \$/kg H_2 basis.

Benefits / Market Implications

While vehicle electrification has achieved a measure of success in personal light-duty vehicles, electrification of heavy-duty vehicles, such as semi-tractors and heavy duty offroad vehicles, confronts barriers in onboard energy storage capacity and very large electrical power delivery rates, on the order of 1 MW. Hydrogen generated from renewable natural gas offers an alternative approach and end user option for transportation, residential, commercial, and other end users.

Deployment of hydrogen fueling infrastructure expansion in North America has been slow compared to other regions of the world, but recent federal legislation such as the recent Inflation Reduction Act and other types of state support programs are further encouraging expansion of clean hydrogen production technology and capacity. However, in order to be supported by the Inflation Reduction Act, strict GHG emissions standards (e.g. kg CO_2e/kg H_2 produced) must be met.

This project, if successful, would eventually help a utility and its customers address GHG reduction goals in an economical manner. On-site natural gas reforming provides an effective avenue to leverage the existing natural gas distribution network in order to produce hydrogen at point-of-use in support of market transformation. Incorporating carbon capture in small-scale SMR will further reduce the carbon intensity of hydrogen produced on-site.

Technical Concept & Approach

The project will identify, analyze, and define a detailed technology development plan for lower cost carbon capture on small-scale SMR systems. The following tasks will be performed:

Process Modeling

The project team will evaluate and utilize the most appropriate process modeling software to analyze the performance of several configuration alternatives for the small-scale SMR

(Left) SMR unit at the H2@Scale site at UT Austin, (Right) UT Provost Sharon Wood cutting the ribbon to open the facility.

device, and compare the performance merits of each, especially taking into consideration CO_2 concentration in the emissions and process efficiency.

Predict Performance of Carbon Capture

Referencing the prediction of improved flue gas concentration, the team will recommend a carbon capture approach. The team will estimate the cost, energy, and material balance of the proposed solution. Commercially available carbon capture technologies as well as novel designs or novel development of existing designs will be considered.

The team will also perform simulated system design and testing of several configurations using chemical process modeling software. These results will be used to predict optimized system designs and performance.

"One of the first questions we get in every tour of the H2@Scale site is, 'Are you capturing the carbon from the SMR?' The small-scale SMR technology promises to be an enabling hydrogen solution for many applications, but a challenge remains in reducing its carbon emissions. We look forward to the results of this UTD project and being able to answer the carbon capture question with a 'Yes!'"

- Michael Lewis
Director of the Center for Electromechanics
The University of Texas at Austin

Results

The project team conducted literature research on current state of carbon capture technologies, which found that the typical SMR generates 9 kg CO_2 per 1 kg of H_2. At the scale planned for this project (~50 kg/day of H_2), about 450 kg/day or ~0.5-ton/day of CO_2 will be generated. For comparison, a typical power plant has a several hundred MW power output and the CO_2 from a flue gas output stream for each 1MW of electrical output is roughly 20-ton CO_2/day.

The team created a draft simulation for the SMR, capturing major equipment and process flows, reactions, separations, and process conditions. This baseline highlighted several performance limitations of the current small scale SMR, including: methane conversion of only 74%; heating efficiency of the reformer less than 60%; and excess catalyst present in the reformer.

The team identified poor heating efficiency of the reformer as one of the most significant limitations, and has identified specific opportunities to improve this aspect by redesigning the heat application. One option that the project team is currently assessing is the feasibility to apply an electric reformer to this small scale application. This may result in an extra 8 kg/day of H_2 production.

The team considered other process improvements as well. For example, one specific item identified was to consider using membrane-based systems to remove the water after the shift reactor instead of the current chiller system. After evaluating a dehydration membrane and a condensing membrane (used to recover water and waste heat from flue gas exhaust), it was determined that the condensing membrane would present significant challenges to couple with this technology. The dehydration membrane proved promising given the high temperature of the outlet shift gas is within the ideal operating range of this membrane, so the team moved forward with that solution. Potential savings could be 20-30% of the total energy of the current SMR system.

The team started evaluating the CC process and potential solutions. There are three unique locations where CO_2 exists: the flue gas; the feed to the PSA; and the PSA outlet. Each stream varies in CO_2 content as well as other components and details are provided below for each stream. The SMR Flue Gas has 5-13 vol% CO_2, the feed to the PSA contains ~13 vol% CO_2, and the PSA outlet contains ~39 vol% CO_2.

Each of these streams presents its own benefits and challenges. If a natural gas burner is used, the most likely option for CC would be on the total flue gas line given its high flow rate. The flue gas composition at the high end is identical to that of a coal-fired power plant, so several technologies that have already been demonstrated at this scale through the U.S. Department of Energy's Carbon Management program may be considered. If electric heating were used instead of the current approach, then CC would need to happen on the PSA inlet or outlet. The PSA inlet would utilize technology already demonstrated for syngas clean up but the PSA outlet would be more likely without a natural gas burner given the high concentration of CO_2 and low concentration of H_2. Removing CO_2 from this stream would need to be further investigated in a system where natural gas is no longer used to heat the process.

Status

The team is conducting sensitivity analysis on the SMR operation to implement the dehydration membrane (using commercial and advanced membranes), operate the SMR at natural gas pressures up to 450 psig, conceptualize the reactor redesign, and electrify the reformer heating. One of the CC technologies to be considered in this study will likely be the ROTA-CAP intensified carbon capture technology.

For more information:

Rich Kooy, P.E.
Vice President, Operations
Utilization Technology Development NFP
Phone: 1-847/768-0512
rkooy@utd-co.org

Utilization Technology Development, NFP

1700 S Mount Prospect Rd
Des Plaines, IL 60018

Info@UTD-co.org
847-544-3400

www.utd-co.org