February 28, 2022

Combined Heat and Power Alliance
David Gardiner, Executive Director
3100 Clarendon Blvd., Suite 800
Clarendon, VA 22201
703-717-5590
David@dgardiner.com

RE: DE-FOA-0002687: Request for Information on Industrial Decarbonization Priorities

The Combined Heat and Power Alliance (CHP Alliance) appreciates the opportunity to submit feedback to the Advanced Manufacturing Office (AMO) on issues related to research, development, demonstration, and deployment (RDD&D) of technologies to address the technical challenges related to emissions reductions and decarbonization of the U.S. industrial sector. Combined heat and power (CHP) technologies, especially those utilizing renewable and lower-carbon fuels, can enable significant emissions reductions across the industrial sector that will be critical to achieving the goal of net zero emissions by 2050.

About the CHP Alliance

The CHP Alliance is a diverse coalition with more than 70 members including equipment manufacturers and distributors, engineers, utilities, labor, contractors, non-profit organizations, and educational institutions.[1] Our members come together with the common purpose to educate all Americans about CHP and waste heat to power (WHP), and how CHP and WHP can make America's manufacturers and other businesses more competitive, reduce energy costs, enhance grid reliability, and reduce emissions.

C6.1 What emerging decarbonization technologies could have the most impact in the industrial sector over the next 5-10 years, and 10-20 years?

CHP is a proven and highly efficient technology that can reduce emissions using traditional fuels, and has the opportunity to reduce emissions even further using

[1] The Combined Heat and Power Alliance, "Who We Are," accessed February 28, 2022, https://chpalliance.org/about/.

emerging renewable and lower-carbon fuel technologies. In almost all regions of the U.S., CHP units installed through 2035 and operating through 2050 using natural gas are expected to cause a net reduction in carbon emissions over their system life.[2] For all states in the continental U.S., fossil fuel generators are used as marginal electric grid resources to serve incremental loads. But, when CHP is installed, grid requirements for these marginal resources are reduced. The emissions from the marginal resources are avoided, even with the CHP unit operating on natural gas.

CHP units are already deployed throughout the industrial sector and could transition to clean fuels in the near-term as these fuels become more accessible. Renewable and lower-carbon fuel technologies can serve as the primary fuel source for CHP systems and further reduce emissions across the industrial sector.

CHP 2.0

Historically, CHP units have run on traditional fuels, and many today use natural gas. This use of CHP can be thought of as "CHP 1.0," the first wave of CHP technologies that relied on fossil fuels. However, CHP units can be fueled by renewable and lower-carbon fuels, including biogas, renewable natural gas (RNG), hydrogen, and renewable propane, known as "CHP 2.0." Use of these fuels can allow CHP systems to reduce emissions even further than they do under CHP 1.0.

Fuels such as biogas and RNG are already being used in CHP systems, and additional existing systems could run on these fuels, providing a near-term solution for further emissions reductions. RNG, also known as biomethane, is most commonly produced from biogas that has been cleaned by removing CO2 and other trace gases. RNG can also be generated from the direct gasification or pyrolysis of biomass. The high methane content of RNG allows for full compatibility within natural gas appliances and pipeline systems. CHP fleets that run on natural gas require minimal upgrades to be fueled by RNG and would produce immediate emissions reductions by transitioning.

[2] In all regions except New York and California. "Combined Heat and Power Potential for Carbon Emission Reductions: National Assessment 2020-2050," ICF, July 2020, p. 4, http://consortia.myescenter.com/CHP/ESC_CHP_Emissions-Full_Study-ICF-071320.pdf.

According to an ICF study, RNG deployment could achieve as much as 235 MMT of GHG emissions reductions by 2040.[3]

Hydrogen fuel can serve as the primary fuel source for CHP systems and further reduce emissions across the industrial sector. CHP equipment manufacturers are working to make new units that can operate on 100% hydrogen fuel, and work is being done to increase the volume of hydrogen fuel that can be used in existing CHP systems. For example, gas turbine manufacturers are looking to provide equipment that can accommodate higher percentages of lower-carbon fuels: various companies in the U.S. and abroad are deploying or working on hydrogen-ready technology, and in 2019, a number of European companies committed to provide gas turbines that can handle 20% hydrogen content in fuel by 2020, and 100% by 2030.[4]

Hydrogen fuel is commonly produced through a thermal process known as natural gas reforming, or through electrolysis using domestic resources like nuclear power, biomass, solar, and wind.[5] There are different types of hydrogen that distinguish how it is produced, which has impacts on its overall emissions:

- Grey hydrogen is produced industrially from natural gas, generating significant carbon emissions;
- Blue hydrogen is also produced from natural gas, but its carbon emissions are captured and stored or reused; and
- Green hydrogen is generated though electrolysis of water by using renewable energy sources that do not produce carbon emissions.[6]

In a 2020 report, the Hydrogen Council estimated that hydrogen has the potential to achieve 18% of global end energy demand by 2050.[7] The amount of emissions

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[3] "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment," An American Gas Foundation Study Prepared by ICF, December 2019, https://gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf.
[4] Sonal Patel, "High-Volume Hydrogen Gas Turbines Take Share," *POWER*, May 1, 2019, https://www.powermag.com/high-volume-hydrogen-gas-turbines-take-shape/.
[5] "Hydrogen Fuel Basics," U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, Hydrogen and Fuel Cell Technologies Office, last accessed September 12, 2021, https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics.
[6] Noé van Hulst, "The clean hydrogen future has already begun," International Energy Agency, April 23, 2019, https://www.iea.org/commentaries/the-clean-hydrogen-future-has-already-begun.
[7] "Path to hydrogen competitiveness: A cost perspective," Hydrogen Council, January 20, 2020, https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf.

reductions that can be achieved by this increase in hydrogen use will depend on the source of the hydrogen fuel, as described above. Currently, 99% of global hydrogen is produced using fossil fuel sources, accounting for 830 Mt CO2/year, more than the entire country of Germany.[8] As the hydrogen economy grows, a switch towards lower-carbon hydrogen production options for both existing and added production could result in significant emissions reductions.

Renewable propane is chemically identical to conventional propane, and is produced from biomass-based feedstocks, including used cooking oil, animal fats, or 20% dimethyl ether.[9]

CHP's Efficiency

Properly designed CHP systems typically operate with an overall efficiency of 65-85%, with some approaching 90%.[10] CHP achieves these high efficiencies by recovering the waste heat byproduct of electricity generation as useful thermal energy for heating and cooling, a process that is particularly beneficial for energy-intensive industrial sectors. Because they operate efficiently, CHP systems combust less fuel to provide the same energy services, reducing all types of emissions including greenhouse gasses such as carbon, criteria pollutants, and hazardous air pollutants.

CHP systems will also use clean fuels efficiently, requiring less fuel inputs for the same energy outputs compared to other generation units.

CHP Deployment

Today, there is nearly 66 gigawatts (GW) of installed CHP at more than 1,200 industrial facilities across the country, which equates to 13% of U.S. industrial electric generating

[8] "The future for green hydrogen," Wood Mackenzie, October 25, 2019, https://www.woodmac.com/news/editorial/the-future-for-green-hydrogen/.
[9] "Propane Production and Distribution," U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, accessed February 28, 2022, https://afdc.energy.gov/fuels/propane_production.html.
[10] "Combined Heat and Power (CHP) Technical Potential in the United States," U.S. Department of Energy, March 2016, p. 3, www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf ; "CHP Benefits," U.S. Environmental Protection Agency Combined Heat and Power Partnership, last accessed February 2022, https://www.epa.gov/chp/chpbenefits.

capacity.[11] Using cleaner fuels such as RNG and clean hydrogen in these generation units can help industrial facilities reduce their emissions. Existing CHP systems, including ones installed today, can convert to 100% hydrogen at reasonable cost and with minimal downtime because these conversions can occur during scheduled overhauls.[12]

Historically, the top market sectors for CHP capacity include chemicals, petroleum refining, pulp and paper, and food processing. Within the last four years, the pulp and paper and chemical sectors led the way in new CHP capacity brought online, with over 5 GW and 3.5 GW installed respectively. All in all, existing CHP systems avoid over 210 million tons of CO_2 compared to separate production of heat and power.[13] Looking to the future, the Department of Energy has identified over 73 GW of remaining CHP technical potential capacity at over 50,000 industrial sites nationwide, including:[14]

- Chemicals – 24.2 GW,
- Petroleum – 10.6 GW,
- Food – 9.1 GW,
- Pulp and Paper – 7.3 GW,
- Primary Metals – 6.8 GW,
- Lumber – 3.3 GW, and
- Other – 11.7 GW.

WHP

Waste heat to power (WHP), also known as "bottoming-cycle CHP," uses waste heat from industrial processes to generate electricity with no additional fuel and no incremental emissions. In a WHP system, fuel is used to produce useful thermal energy for an industrial process. The heat not used for that process, the "waste heat," is then utilized to produce electricity. No additional fuel is used to produce the electricity, meaning that there are no incremental emissions associated with the electricity production. As of 2016, there were 469 megawatts (MW) of existing WHP capacity at 75

[11] The Combined Heat and Power Alliance, "Factsheet: CHP and American Manufacturing," October 2020, https://chpalliance.org/resources/combined-heat-and-power-chp-and-american-manufacturing/.
[12] A CHP system overhaul typically occur every 8-10 years for a unit that runs continuously.
[13] David Jones, ICF. "CHP State of the Market." National Summit on CHP, State of the Market panel, September 13, 2021.
[14] "Combined Heat and Power (CHP) Technical Potential in the United States," U.S. Department of Energy.

sites across the U.S., mostly used in primary metals and refining applications.[15] In addition, as of 2016, WHP's technical potential is estimated to be 7.6 GW across all facility types, with petroleum, metal, and non-metallic mineral markets having the highest amount of technical potential.[16]

C6.2 What primary factors are driving decisions on demonstrations of new technologies that reduce GHG emissions? Which promising technologies are most appropriate for demonstrating in the U.S. marketplace? Which technologies are ready for pilot plant scale-up, and which are ready for commercial demonstration?

As noted above, CHP systems are already deployed in various industries, and some systems already use biogas or RNG. Since RNG allows for full compatibility within natural gas appliances and pipeline systems, CHP units that run on natural gas require minimal upgrades to be fueled by RNG.

Work is being done to increase the volume of hydrogen fuel that can be used in CHP systems, and some systems can already use hydrogen fuel. Demonstration projects could show how new CHP units can use high percentages of clean hydrogen fuel and how existing CHP units can transition to this fuel. The lack of knowledge around clean hydrogen-fueled CHP systems and how these systems can reduce emissions may hinder deployment.

C6.4 What limiting factors or challenges do these crosscutting technology areas face regarding broad deployment in the United States?

The ability of CHP systems to use clean fuels is limited by clean fuel availability and transportation. While CHP systems can run on biogas and RNG and some can already run with some percentage of hydrogen fuel, challenges remain in obtaining sufficient quantities of and transporting these fuels. Using existing gas pipeline infrastructure to transport and deliver these fuels and "green" the entire gas system has the potential to be a low-cost emissions reduction option, but further research and analysis is needed to determine what system retrofits or upgrades may be required.

[15] Combined Heat and Power (CHP) Technical Potential in the United States," U.S. Department of Energy, p. 18.
[16] Combined Heat and Power (CHP) Technical Potential in the United States," U.S. Department of Energy, p. 28.

Biogas and RNG are viable low-carbon fuel alternatives, yet their deployment has been relatively lacking. The U.S. currently has more than 2,200 sites producing biogas with 860 of these locations using the biogas they produce.[17] However, the American Biogas Council estimates there are 13,500 sites with biogas production potential, primarily at animal farms and wastewater treatment facilities.[18] The majority of biogas deployment to date has been through landfill gas collection, which comprises nearly 90% of total production.[19] The livestock industry is responsible for one-third of total methane emissions in the U.S., and represents a significant untapped market for biogas production.

The availability of clean hydrogen is also a limiting factor. As noted above, currently 99% of global hydrogen is produced using fossil fuel sources.[20] Further development of clean hydrogen resources is needed to show potential users that this technology is viable and will be accessible to them as they move to decarbonize their energy sources.

Transporting large volumes of hydrogen poses additional challenges given its different properties as compared to natural gas and RNG, and current research is examining how existing gas infrastructure can accommodate the distribution of hydrogen gas.[21] Hydrogen transportation and storage is a challenge to widespread hydrogen fuel adoption in the near term. The initial capital costs of new pipeline construction for hydrogen gas are a barrier to expanding hydrogen pipeline delivery infrastructure. Transporting gaseous hydrogen through existing pipelines may be a low-cost option for hydrogen delivery, though further research is needed, and being conducted, on the implications of transporting hydrogen through existing pipelines.

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[17] Anna Simet and Katie Fletcher, "Biogas Advances in the US," *Biomass Magazine*, January 27, 2017, http://biomassmagazine.com/articles/14135/biogas-advances-in-the-us.

[18] "Why Biogas?," American Biogas Council, last accessed September 17, 2021, https://americanbiogascouncil.org/wp-content/uploads/2019/05/ABC-Handout-2019apr-vP3-1.pdf.

[19] "Report extract: An introduction to biogas and biomethane," International Energy Agency, last accessed September 17, 2021, https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane.

[20] "The future for green hydrogen," Wood Mackenzie.

[21] "Hydrogen Pipelines," U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, Hydrogen and Fuel Cell Technologies Office, last accessed September 12, 2021, https://www.energy.gov/eere/fuelcells/hydrogen-pipelines.

Renewable propane is produced from biomass-based feedstocks, but is currently produced in limited quantities at biodiesel refineries.[22] Life cycle GHG emissions for renewable propane are approximately half of conventional propane, according to estimates from the Propane Education & Research Council (PERC).[23]

There are also barriers to the deployment of CHP systems. Key economic and financial barriers to the accelerated adoption of CHP include internal competition for capital, the "split-incentive" between capital improvement and operation and management budgets, securing low-cost financing due to financial risks, and lack of financing instruments such as Master Limited Partnerships.[24]

Installation of CHP systems typically requires a significant upfront investment which can eclipse long-term benefits. Insufficient capital and internal competition for capital prevent many facilities from installing CHP systems, even when such a system has an attractive financial return.[25] A company may also be hesitant to make investments outside of its core business and may require an even higher rate of return compared to other, more familiar capital investments.[26] Internal accounting practices that separate plant operation and maintenance budgets from capital improvements, resulting in costs and savings accruing to different budgets, can also make it difficult to demonstrate the financial benefits of a system.[27] Facilities may also have a hard time finding favorable financing for a long-term investment in the facility upgrade.[28]

C6.5 What DOE resources would be most beneficial to accelerate decarbonization?

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[22] "Propane Basics," U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, June 2021, https://afdc.energy.gov/files/u/publication/propane_basics.pdf.
[23] "Propane Basics," U.S. Department of Energy Office of Energy Efficiency & Renewable Energy.
[24] "Barriers to Industrial Energy Efficiency," U.S. Department of Energy, June 2015, https://www.energy.gov/sites/prod/files/2015/06/f23/EXEC-2014-005846_5%20Study__0.pdf; "Barriers to Industrial Energy Efficiency: Report to Congress," U.S. Department of Energy, June 2015, p. 9-10. https://www.energy.gov/sites/prod/files/2015/06/f23/EXEC-2014-005846_6%20Report_signed_0.pdf.
[25] "Barriers to Industrial Energy Efficiency," U.S. Department of Energy, p. 95.
[26] "Barriers to Industrial Energy Efficiency," U.S. Department of Energy, p. 96.
[27] "Barriers to Industrial Energy Efficiency," U.S. Department of Energy, p. 97.
[28] "Barriers to Industrial Energy Efficiency," U.S. Department of Energy, p. 97.

RDD&D

More RDD&D on clean fuels and their applications in CHP units is needed. Greening the gas system with high volumes of clean hydrogen fuel can allow CHP systems to use these clean fuels efficiently. CHP manufacturers are working to increase the volume of hydrogen fuel that can be used in CHP units to 100%, and some units can already use lesser percentages of hydrogen fuel. However, the cost, transportation, and delivery of this fuel remains a challenge.

Supporting RDD&D of clean hydrogen in the gas system could help to accelerate decarbonization, with the following considerations:

- **Transportation**: The existing gas pipeline system may provide a cost-effective way to transport clean hydrogen, but additional research is required to determine what quantities of hydrogen can safely be transported or what retrofits may be required.
- **Distributed generation**: Distributed generation technologies such as CHP can be deployed at the point of clean hydrogen production, allowing the use of hydrogen fuel in CHP systems and the realization of corresponding emissions benefits while the development of hydrogen-ready pipelines is still underway.
- **Use**: While research and development of hydrogen-ready CHP technologies is ongoing, technology manufacturers and end users will need support evaluating what amount of hydrogen current equipment can use, identifying the retrofits and upgrades needed to ensure the adjustment of existing equipment for hydrogen use is easy and affordable, and the development and deployment of new equipment as required.

Technical Assistance

The CHP Technical Assistance Partnerships (TAPs) are a valuable resource providing education and information about CHP to numerous industrial sites throughout the country. Disseminating additional information about how clean fuels can be used in CHP systems and the technical capabilities of existing systems to transition to clean fuels would help to support decarbonization for both new CHP units as well as existing units.