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Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Advanced Manufacturing Office

Fall 2020 Combined Heat and Power (CHP) Virtual Workshop

Workshop Report

September 8–10, 2020

Within the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), the Advanced Manufacturing Office (AMO) partners with industry, small business, academia, and other stakeholders to identify and invest in emerging technologies with the potential to create high-quality domestic manufacturing jobs and enhance the global competitiveness of the United States.

This document was prepared for DOE-EERE's AMO as a collaborative effort by AMO and Energetics, under a contract with Boston Government Services.

Disclaimer

List of Acronyms

AI	Artificial intelligence
AMO	Advanced Manufacturing Office
BGE	Baltimore Gas & Electric
CEO	Chief executive officer
CHP	Combined heat and power
CHP TAP	Combined Heat and Power Technical Assistance Partnership
CPS	Capital resources, performance and scalability
DER	Distributed energy resource
DISPERSE	DIStributed Power Economic Rationale Selection
DOE	U.S. Department of Energy
EERE	U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy
HHV	Higher heating value
kW	Kilowatt
kWh	Kilowatt-hour
MEA	Maryland Energy Administration
MW	Megawatt
NREL	National Renewable Energy Laboratory
PUC	Public utility commission
RNG	Renewable natural gas
R&D	Research and development
UF	University of Florida

Executive Summary

The U.S. Department of Energy's (DOE's) Advanced Manufacturing Office held the *Fall 2020 Combined Heat and Power (CHP) Virtual Workshop* in September 2020. The workshop brought together more than 90 individuals representing manufacturers, end users, utilities, academia, government, and other stakeholders to discuss the potential role that energy-efficient combined heat and power (CHP) technologies can play in enhancing the energy flexibility and resilience of manufacturing facilities, as well as the advancements needed to bolster technology adoption.

This workshop report summarizes the presentations, panel discussions, and breakout group discussions that took place at this event. Note that the results presented here are a snapshot of the viewpoints of the experts who attended the workshop; they do not necessarily reflect the views of the broader CHP community.

Discussions at the workshop focused on exploring issues in three major areas: 1) priority research and development (R&D) needs to advance CHP technologies; 2) new and innovative approaches to overcoming non-technical barriers to CHP deployment; and 3) the future of thermal energy production in industry and what role CHP may play in that future.

Based on the common themes identified during the workshop, a number of high-priority areas emerged, as discussed below.

Electrification and Decarbonization: Decarbonization is a trend that will have a significant impact on the industrial sector and power systems in the years and decades ahead. One of the avenues to achieve decarbonization is electrification. These trends will play a major role in the viability of CHP systems and the type of technology development that is needed. As electrification of all thermal processes will be difficult, CHP systems will likely be among the most efficient ways to provide the needed thermal energy for many processes and applications. CHP systems powered by renewable and other alternative fuels, such as hydrogen, will have a role in a net-zero-carbon future. Development of smaller carbon capture systems suitable for integration with CHP systems was identified as a potential R&D area worthy of exploration.

Distributed Energy Resources: The future grid is expected to continue the trend toward more pockets of distributed energy resources. Many of these distributed generation systems will be part of local microgrids that operate independently of the power grid or can island whenever needed. These local or community energy systems increasingly rely on renewable technologies and/or energy storage, but many such systems are—and will likely continue to be—hybrid configurations that include dispatchable CHP systems to complement and support variable renewables and energy storage. Technologies to ensure seamless integration of CHP with renewable technologies, energy storage solutions, and microgrids are important.

More Diverse Fuel Sources for CHP: While natural gas is the overwhelming fuel of choice for CHP systems today, future systems are expected to rely on a more diverse input stream. Hydrogen is expected to be one of the largest displacers of fossil fuels, and use of other hydrogen carriers, such as ammonia, is also being explored. Another fuel that is expected to increase in use is renewable natural gas (RNG). Greater use of RNG will require more supply, and a more diverse waste input stream for RNG production will therefore be required. Improvements to RNG clean-up processes will also be necessary.

Utilization of Thermal Energy: For CHP viability, matching electric and thermal loads is important. The need to find cost-effective and innovative new ways to utilize thermal energy should be a high priority. Without a cost-effective way to employ thermal energy, a CHP project may not be financially viable. As circumstances vary greatly in different types of facilities and geographic locations, there is a need for a broad range of solutions. Owing to the diverse nature of potential CHP applications, the ability to modify heat/power ratios is another potentially promising R&D area.

Systems Integration: CHP systems will require new functionality to bring value to new applications, such as district heating systems and microgrids. Facilitating CHP's integration into other systems will require interoperable controls, interfaces, standards, and other advanced capabilities.

Financing Options and Ownership Models: There is a need to create and further develop CHP financing options and ownership models. Effective financing options might include energy as a service, cash flow positive financing, commercial property assessed clean energy, power purchase agreements, and new ownership models, such as utility ownership of CHP facilities.

Incentives: Cost savings from installing a CHP system are often enough to justify a project, but some entities require very short payback periods for all investments and are reluctant to pursue CHP. In these instances, financial incentives continue to be an effective tool to encourage CHP implementation. Thus, there is a need to increase or create new incentives. Currently financial incentives either are not available from certain utilities or states, or they fail to consider the full benefits of CHP. Examples of potentially effective approaches include long-term incentive programs, incentives that consider the carbon and non-energy benefits of CHP, expansion of existing incentives to include public entities, and incentives for utilities to assist in and coordinate CHP adoption.

Education, Engagement, and Recognition: CHP education should be readily available to all stakeholders involved in CHP (utilities, end users, building architects, the engineering community, regulators, etc.). CHP education needs to include details on the problems that CHP can solve and its importance to the grid of today and the future. Tools, discussion forums, and consulting services by impartial experts could increase end-user understanding of the often-complicated CHP development process and impacts of CHP installation. Training and workforce development, such as the development of a certification scheme for CHP experts is another potential avenue to pursue. Recognition through award programs could highlight the benefits of CHP and acknowledge companies that have implemented CHP.

Reducing Risk: Energy and environmental markets are rapidly changing, leading to a degree of market confusion and often causing paralysis in decision-making. Both real and perceived risk of taking action is too high to make energy changes for fear of making the wrong decision. This includes choosing to install a CHP plant. Risk reduction should be a major element in DOE education, outreach, and research. Continued emphasis on packaged, modular, and integrated CHP systems should remain a key focus of DOE's program.

In a recent project, DOE completed interviews with CHP site owners to gain insights into the market environment and major challenges to CHP adoption. The gathered input was utilized in the planning effort for the workshop, and results from the interviews are summarized in Appendix C of this report, *Key Insights on CHP Market Adoption – Results of End User Interviews*. Among the major findings of the interviews was that cost savings, resilience and reliability concerns, and organizational sustainability goals are key drivers for CHP adoption. Significant barriers to installing CHP include a strong desire for renewable fuel sources and technologies as well as complex permitting and regulatory processes for CHP installations.

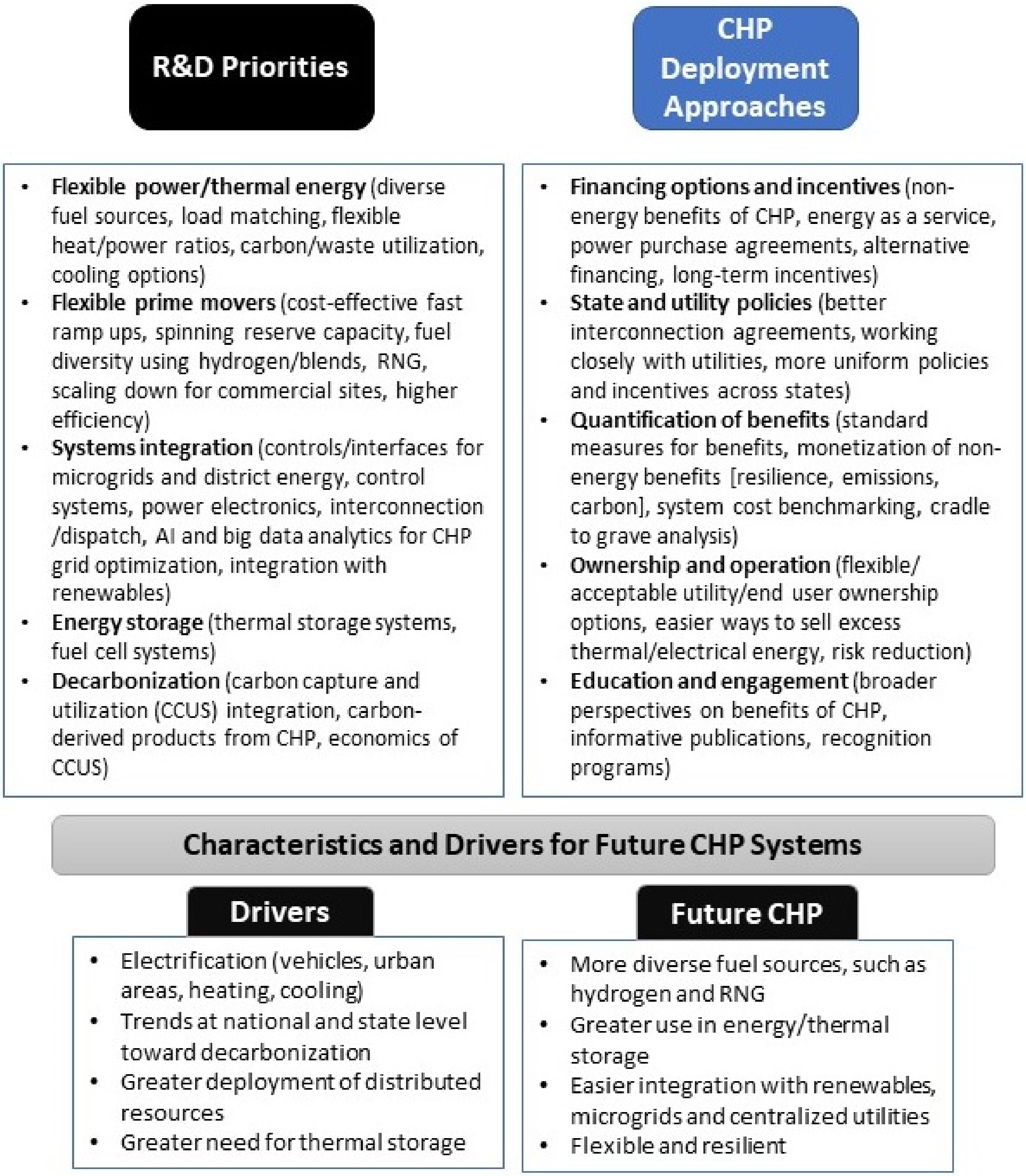

Figure E-1. Summary of key research priorities, deployment approaches, and future CHP system drivers and characteristics

Table of Contents

List of Figures

List of Tables

1 Background and Workshop Proceedings

Background

Combined heat and power (CHP)—sometimes called cogeneration—is an integrated set of technologies for the simultaneous, on-site production of electricity and heat. CHP technologies enable the use of thermal energy that would otherwise be wasted, resulting in a highly efficient power generation system with an overall efficiency of up to 85%. The high efficiency of CHP results in financial savings for the system owner by reducing the need to purchase grid electricity and generate steam or hot water using a separate boiler. CHP is also an energy solution that can reduce carbon emissions and improve resilience of critical infrastructure facilities (CHP Alliance 2021, 5).

There are over 4,600 CHP sites in the United States, providing nearly 81 gigawatts of electric generation capacity (DOE 2020a). Historically, CHP has been used most extensively in the industrial sector because of the large electric and heat demand at many manufacturing facilities. While the current CHP capacity in the United States is significant, it represents less than 10% of the total electric generating capacity, leaving much room for growth. In many other countries CHP plays a more significant role, with CHP representing more than 30% of generating capacity in countries such as Denmark, Finland, and the Netherlands. Among the well-known barriers to wider CHP adoption are an unclear utility value proposition, market and policy uncertainty, poor end-user awareness and uninformed economic decision-making, and local permitting and siting issues (DOE 2016, 1–5).

In the past, most CHP systems were sized and used to serve onsite loads. As the electric grid continues to change rapidly, the role of CHP is evolving. In many regions of the country, conventional base load plants are closing, and large amounts of variable renewable generation are being installed. In addition, various distributed energy resources (DERs)—such as rooftop solar, different types of generators, and batteries—are being added to the grid. As these changes are taking place, the grid needs to remain stable and resilient.

CHP can play an important role in this new and evolving grid. However, to meet the needs of the grid and to be able to harness new opportunities, future CHP systems will need to operate more flexibly and be able to feed power to the grid when needed. Future CHP systems may also provide capacity or ancillary services to ensure grid stability during adverse events. Such flexible CHP systems will need to be sized so that they can provide critical grid services in addition to meeting onsite loads, and the systems need to be able to interact seamlessly with the grid. While many of the technologies needed for flexible CHP systems are currently available, additional research and development (R&D) is needed to ensure the systems can be integrated into complete CHP packages that can interface seamlessly with the grid and remain affordable for their owners.

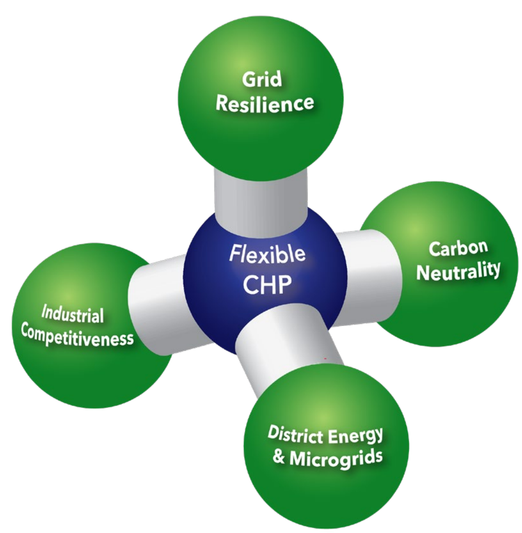

Figure 1.1. Goals of AMO's flexible CHP R&D portfolio

The primary goal of the Advanced Manufacturing Office's (AMO's) current CHP R&D project portfolio is to enable private-sector development of flexible CHP systems that can play a role in stabilizing the electric grid and improving its resilience. Four ongoing projects are developing power electronics and control systems that enable seamless interconnection of flexible CHP systems with the grid and allow the power generated by the CHP system to meet stringent requirements of grid operators. Three projects are developing modifications to existing prime mover technologies to make CHP systems more responsive to the demands of the modern electric grid. The CHP R&D

portfolio includes additional projects focused on advanced materials and other system improvements to increase the efficiency of prime mover technologies.[1]

AMO's CHP Deployment Program works with end users and stakeholders to provide fact-based and unbiased information on CHP technologies, including screenings and preliminary analysis to determine whether further analysis of a CHP system is warranted for a facility. AMO's outreach and technical assistance activities are primarily conducted by ten regional CHP Technical Assistance Partnerships (CHP TAPs).[2]

Workshop Overview

To better understand potential areas for future CHP R&D and other program activities, the U.S. Department of Energy (DOE) held the *Fall 2020 Combined Heat and Power (CHP) Virtual Workshop* on September 8–10, 2020.[3] Representatives from CHP component and system manufacturers, CHP end users, power electronics experts, electric and gas utilities, academia, DOE national laboratories, and non-governmental organizations gathered virtually to hear presentations by subject matter experts, to listen to informative panel discussions, and to participate in topical breakout sessions. The principal focus of the workshop was on the potential role that energy-efficient CHP technologies can play in enhancing the energy flexibility and resilience of manufacturing facilities, as well as the advancements needed to bolster technology adoption.

The workshop consisted of three afternoon sessions. During the first day, participants learned about the current AMO CHP portfolio and CHP market trends and heard from panels of CHP end users, utilities, and system suppliers. In the second afternoon, attendees participated in facilitated breakout sessions to provide input on CHP deployment barriers and R&D needs—both short-term and long-term. Participants also discussed trends that will impact thermal energy production in industry and the role CHP can play in this future. Breakout groups finished their work during the third day and reported on their deliberations and conclusions.

This workshop report summarizes the presentations, panel discussions, and breakout group discussions that took place at this event. Note that the results presented here are a snapshot of the viewpoints of the experts who attended the workshop; they do not necessarily reflect the views of the broader CHP community.

Presentations and Panel Discussions

Plenary and panel sessions featured invited experts from the national laboratories, industry, and other stakeholders. The presentations helped to assess the state of the art with respect to the specific challenges that industry faces in development and deployment of CHP technologies and systems. Presentations delivered at the workshop are available at energy.gov/eere/amo/downloads/fall-2020-combined-heat-and-power-chp-virtual-workshop.

Potential Impact of Flexible CHP on the Future Electric Grid in California

Mark Ruth, National Renewable Energy Laboratory

The National Renewable Energy Laboratory (NREL) and a multi-organizational team recently published a cost–benefit analysis that examines the potential impact of flexible CHP systems on the electric grid in California. Specifically, the analysis quantified and compared the cost of operating the grid in California with and without advanced CHP under modeled scenarios. Mark Ruth of NREL presented the methodology and outcomes of the analysis.

The analysis ran cost models evaluating the impact of adding CHP under four scenarios: Reference, Traditional, Advanced, and Combined. The Reference scenario included no additional CHP above the current

[1] More information about AMO's CHP R&D portfolio is available at https://www.energy.gov/eere/amo/combined-heat-and-power-chp.
[2] More information about AMO's CHP Deployment Program activities is available at https://betterbuildingssolutioncenter.energy.gov/chp.
[3] The workshop was held virtually because of the COVID-19 pandemic.

CHP capacity in California. The Traditional scenario modeled the deployment of traditional CHP units in locations where traditional CHP is economically viable. In the Advanced scenario, advanced CHP units were deployed in locations where traditional CHP is economically viable. The Combined scenario modeled the grid such that traditional or advanced CHP was deployed, depending which was more advantageous to the end user.

The analysis team estimated potential improvements from CHP technologies (in terms of cost and performance) and used DISPERSE modeling software to identify locations where those CHP technologies reduce owner costs. NREL then used PLEXOS, a simulation software designed for energy market analysis, to generate cost models and analyze the impacts of adding CHP at those sites.

Mr. Ruth presented key findings from the analysis, which determined that scenarios with additional CHP could generate revenues to CHP owners from the types of energy and ancillary services that are compensated by most electricity markets. Owing to economies of scale, larger CHP systems (5+ MW) represent the greatest opportunities. In particular, the Advanced scenario estimates that larger CHP systems can increase revenue to site owners across the state by $760 million. If rules and regulations allow for them, capacity payments also hold great potential for CHP owners and may increase income by 20%–100%.

The analysis also found that additional CHP can benefit California grid operators by reducing grid operating costs by over $700 million, or 5% of total cost. Under the Advanced scenario, CHP capacity can more than double in California if a six-year payback is acceptable. The analysis also projects that adding traditional and advanced CHP can eliminate grid stress, or the number of hours that grid operators might consider not offering power or dipping into contingencies. Without additional CHP, California utilities face 4–23 hours of grid stress annually. Advanced CHP also reduces California Independent System Operator costs by offsetting imports, increasing the grid's resilience, and eliminating grid stress.

State of the CHP Industry and Market Trends

Bruce Hedman, Entropy Research, LLC

Drawing from long-term experience supporting AMO CHP activities and analysis, Bruce Hedman of Entropy Research, LLC, presented the current status and market trends for CHP in the United States. The presentation covered recent growth in non-traditional CHP markets that use smaller (less than 20 MW) systems, CHP's role in increasing resilience in critical infrastructure and microgrids, shifts in utility CHP offerings, and industry challenges.

In the past five years, industrial installations accounted for 61% of new CHP capacity, while non-traditional CHP markets such as multifamily housing, hospitals, schools, office buildings, and food processors accounted for 88% of new installations. These non-traditional markets increasingly utilize smaller pre-designed, pre-tested CHP units.

Showing a breakdown of existing CHP capacity and technical potential across several industrial and commercial sectors, Dr. Hedman noted that non-traditional markets have great potential for additional CHP growth. However, challenges in developing these markets involve issues with system performance and limited availability of technical resources. Packaged CHP systems can eliminate some challenges because their standardized designs make system selection and installation easier and more streamlined. DOE's CHP eCatalog aims to reduce the risks for end users and vendors by recognized packaged CHP systems that meet minimum DOE performance requirements.

Dr. Hedman also highlighted the role of resilience in driving recent CHP installations in critical infrastructure, such as hospitals, water/wastewater treatment plants, and nursing homes. With the increase in costly weather events and climate disasters, CHP offers a solution to maintaining heating/cooling and power while avoiding outages that could affect health and safety.

CHP systems are also increasingly providing microgrids with efficient, resilient baseload power and thermal energy. Hybrid installations that pair CHP with other DER technologies have grown in the past five years. The most common DER technologies paired with CHP in microgrids include solar, storage, and non-CHP diesel generators.

Another recent trend is that utilities are increasingly interested in CHP to connect with customers, optimize distribution systems, and generate additional revenue. Twenty-one gas or electric utilities in the United States offer CHP programs ranging from technical assistance to incentives. In addition, utility-owned and operated CHP systems are supplying power to the grid and enabling the utility to sell steam to the customer at a discounted rate through a service agreement.

Dr. Hedman concluded the presentation with challenges to CHP, ranging from lack of end-user awareness to market and technical barriers. CHP projects tend to be complex and costly. The benefits of resilience are hard to monetize. Technical challenges include integration with the grid, which will be an increasingly important focus area with the expansion of smart grids. In addition, decarbonization initiatives will pressure the CHP industry to reduce emissions and reliance on natural gas.

INDUSTRY PANEL: End-User Perspective

Patti Garland (Moderator), CHP Technical Assistance Partnerships (TAP) Coordinator, U.S. Department of Energy. Ms. Garland introduced panel speakers who provided first hand perspectives at sites from three different market sectors: a hospital, a food processing plant, and a university.

Bobby Baird, Director of Facility Operations, University of Florida Health Systems. Shands Hospital at the University of Florida (UF) operates a robust CHP plant consisting of a 4.3 MW recuperated combustion turbine, various generators, a backup boiler, 4,200 tons of cooling, and a diesel generator. The plant is 80% efficient, with several redundancies to ensure reliability. One of the main drivers for CHP at UF included increasing resilience, primarily through islanding. The CHP plant also adds flexibility and ability to self-generate all the hospital campus's loads with natural gas and to develop capacity to provide district cooling to the non-hospital facilities (hotel and office buildings). The CHP system has increased UF's purchasing power for natural gas, thanks to the ability to buy natural gas at the same rates that local utilities pay. Mr. Baird also noted that the technical assistance from the regional CHP TAP made implementation more attractive.

Among the lessons learned, Mr. Baird emphasized that higher reliability comes with higher costs. He also emphasized that contracts should clearly address four "As": define who has authority, who is accountable, who conducts approvals, and how everything is accessed.

Andy Lempera, Supply Chain Sustainability Director, PepsiCo Beverage North America. PepsiCo maintains several CHP systems across the organization, including one at its Gatorade facility in Indianapolis, Indiana. Compared to solar and other technologies, PepsiCo considers CHP the best investment toward its corporate goals for sustainability and greenhouse gas emissions reduction. The Gatorade facility's 3.6 MW system consists of three engines (1.2 MW) that run on natural gas and provide nearly all of the plant's annual electricity consumption on a load-following basis. This project cost $6 million in capital expenditures and provides $1.5 million in annual utility savings. The facility works closely with its utility and can export power for a short time but does not receive payment for it. The CHP system can also operate in island mode at a reduced capacity. Mr. Lempera described how the system's components use the input energy to provide power and steam back to the plant. The plant is currently at 85% efficiency and working toward mid-90% overall efficiency. He highlighted the condensing economizer as the key component for increasing the system's overall thermal output to the plant.

In closing, Mr. Lempera cited some project challenges. Changes in billing structure (from high kilowatt-hour/low demand charges to low-cost kilowatt-hour/high demand charges) have pressured the plant to run at least two engines or risk losing the savings. Extra interconnection fees were higher than originally anticipated.

Joan Kowal, Senior Director, Utility Resilience and Strategies, Emory University. Emory University in Atlanta, Georgia, developed a self-generation target of 10% by 2025 as part of updating its resilience and sustainability plans. When a boiler replacement was needed to support its hospital expansion, Emory implemented a 1 MW steam turbine generator. This installation increases resilience by enabling Emory to run an additional boiler when utility power is lost. Emory can also export power from the steam plant into the electric distribution system.

Emory worked closely with its local utility, Georgia Power, to identify self-generation opportunities within the state's regulated market. They approached the public utility commission (PUC) about mirroring a microgrid project in which Duke Energy owns and operates a CHP system and sells the steam output to Clemson University. However, the PUC ruled that insufficient information was presented to justify Georgia Power's investment in a substation serving Emory and surrounding neighborhoods.

Despite this outcome, Emory is taking a phased approach toward its self-generation target. Phase 1 included replacing its plans for a 2.5 MW standby diesel generator for a new research building and using that capital for CHP. Ms. Kowal mentioned that Emory received several vendor proposals for this project, indicating that smaller-scale investments in distributed energy are also appealing; large applications are not the only attractive projects.

INDUSTRY PANEL: Utility Perspective

Bruce Hedman (Moderator), Entropy Research, LLC. Dr. Hedman introduced the presenters from three different utility approaches to CHP: an established incentive program, a dual electric and gas utility considering CHP in meeting its net-zero-carbon goals, and a utility owning and operating asset-based CHP at customer sites.

James Libertini, Product Manager, Baltimore Gas & Electric. In 2012, Baltimore Gas & Electric (BGE) launched its CHP incentive program as part of its energy efficiency offerings. The incentive structure currently offers $1,200/kW for systems less than 1 MW and $900/kW for systems greater than 1 MW, with a project cap of $2.5 million per customer. The timing of payments is based on three milestones: 10% payment after design, 30% upon commissioning (subject to inspection), and 60% production payment. The program requires a 65% higher heating value (HHV) efficiency, and 100% of the generation must be used on-site.

BGE's CHP incentive program features a customized customer engagement approach, focusing on identifying and educating its target customers at all levels of the organization while also ensuring that different segments of the market are reached. Challenges to participation have included the customer's focus on financials (cost of electricity and gas) while overlooking the importance of sustainability goals and resilience needs. Mr. Libertini noted that emphasizing greenhouse gas reduction during these discussions can help drive customer decision-making processes. High initial costs are also a barrier, but incentives and technical resources from BGE and its third-party liaisons help offset these costs. For example, BGE's partnership with the Maryland Energy Administration (MEA) enables customers to access MEA's CHP incentives, in addition to BGE's. DOE and the CHP TAPs help BGE reach customers and conduct feasibility studies. Mr. Libertini also expects that increasing availability of packaged systems will simplify customer implementation processes. A final component of BGE's program is maintaining a team of engineers dedicated to providing field support and to addressing customer technical challenges.

James Leidel, Principal Markets Technical Consultant, DTE Energy. DTE Energy in Michigan is a dual utility with most of its business on the electric side and a smaller portion on the gas side. CHP is not currently included in DTE's large and well-funded efficiency program offerings. Historically, the electricity side has viewed CHP as a threat to electricity revenue, compounded with the added costs from gas transport. However, DTE is reconsidering CHP in light of its recent commitment to achieve net-zero carbon by 2050 and the chief executive officer's (CEO's) statements on climate change. After a large customer implemented CHP, Mr. Leidel's team at DTE Energy ran a model that calculated that, at a price of $60 per ton of carbon dioxide, the utility would break even with the losses in electricity revenue. The model did not factor in other value streams, such as the elimination of electric transmission and delivery losses, demand reduction for constrained substations, and fulfillment of the state's 2% energy efficiency mandate. Monetizing these value streams could greatly increase the profitability of CHP for a dual utility. Although the electric side of the utility has not embraced CHP yet, Mr. Leidel is hopeful about making the case for CHP's ability to achieve DTE Energy's net-zero-carbon goals.

Zachary Kuznar, Managing Director of Distributed Generation Business Development, Duke Energy. Duke Energy is an electric utility with service areas in six states and commercial renewables business in fourteen states. Mr. Kuznar shared two examples of utility-owned and -operated CHP facilities at Clemson University in South Carolina and Purdue University in Indiana. In each project, Duke Energy owns and operates a natural gas CHP facility located on the university's campus. The electricity generated by the CHP system is not directly consumed by the university; the electricity flows back to the Duke Energy electric system. In both cases, the university purchases the steam from Duke Energy, and the steam revenue offsets the fuel costs for Duke Energy customers. The CHP facility is designed to provide backup power and can island the campus during grid outages; the university pays for this capability through an extra facilities charge. The Clemson project began operation in 2019, and the Purdue project is expected to come online in late 2021 or early 2022.

Mr. Kuznar highlighted these non-traditional business models and university partnerships as examples to overcome customer reluctance to spend money on electricity generation infrastructure. These utility–customer partnerships deliver value not only to the utility that owns the asset but also to the offtaker and the rest of the utility's customers.

INDUSTRY PANEL: Supplier Perspective

Richard Sweetser (Moderator), President, Exergy Partners Corporation. Mr. Sweetser introduced the panel of suppliers, each of whom presented his company, his company's role in U.S. CHP markets, current and future challenges facing the company's CHP equipment, and how the company will future-proof its CHP product lines.

Aaron Tasin, Vice President of Sales, 2G Energy, Inc. Headquartered in Germany, 2G Energy is a relatively new company, with $30 million in annual revenue, selling 20–30 engines per year, ranging from 60 kW to 2.5 MW. The company has installed more 120 CHP plants in the United States. 2G Energy sees its role in the CHP market as a premium packager that emulates what the eCatalog promotes and ensures that the systems are complete solutions for the customers. Notable market challenges for its equipment include long interconnection processes with the grid (6–8 months). In addition, CEOs want short payback periods of 2–3 years, which is difficult to achieve when factoring in utility demand and standby charges. Local incentives are helpful but are often not enough to make the paybacks that companies want. 2G Energy conducts R&D to future-proof its equipment, such as developing 100% hydrogen-powered engines. The company has also designed its own emissions control system, its own Organic Rankine Cycle, and other solutions.

John Hibler, Large Electric Power Standard Engineering Manager, Caterpillar. Engines and combustion turbines (through Solar Turbines) make up approximately one-third of Caterpillar's business. Caterpillar offers CHP solutions between 400 kW and 10,000 kW, and its standardized solutions range from 400 kW to 2500 kW. These technologies can use a variety of fuels for many different customer end uses. Although CHP is popular internationally, the low cost of energy in the United States has inhibited domestic implementation. Regulations and policies on interconnection, air permits, emissions, and resilience vary by state, and even locally, which creates challenges in designing standardized solutions. These ever-changing requirements also make it difficult to design for future conditions. To overcome this barrier, Caterpillar maintains an 80/20 design rule for its systems: 80% of the design can be standard, and the company works with the customer on the remaining 20% based on the location's regulatory requirements. Another implementation barrier is a lack of sales and service representatives with extensive CHP experience. To improve customer confidence in its systems, the company also offers financing on all CHP solutions and has invested in training its sales and service staff on CHP equipment. Caterpillar's plans for future-proofing its equipment include prioritizing solutions to increase electrical and thermal efficiencies, along with R&D to integrate renewable hybrid solutions with standard CHP.

Chris Lyons, Manager, Solar Turbines (a subsidiary of Caterpillar). Since 1960, Solar Turbines has been producing combustion turbines and has sold more than 16,000 worldwide, ranging from 1–23 MW. The company shares challenges that are common among CHP equipment suppliers, including uncertainty about the fuels that will be used in 20 years. In addition, the low cost of natural gas makes the economic benefits of CHP difficult to convey to customers. In the future, solutions will be needed to increase fuel flexibility and adapt to future energy sources. CHP as an anchor to microgrids could be very beneficial, but the technologies need to be more flexible and responsive to be effective. Additional challenges for equipment designers include uncertainty about future policies on carbon pricing, regulations, and other requirements. To future-proof its products, Solar Turbines is pursuing several technological advances, including a roadmap to develop a 100% low-emission hydrogen-powered turbine by 2030. The company is also standardizing its modular power plant packages to reduce the overall cost to customers. R&D efforts are under way to develop solutions in the areas of carbon capture capabilities, expanded digital controls, utilization of lower thermal heat sources, and power boost to meet short-term peak demands.

Workshop Process and Breakout Sessions

The workshop brought together CHP component and system manufacturers, CHP end users, power electronics experts, and electric and gas utilities to provide input on potential areas for future DOE R&D and program activities for CHP. Breakout sessions covered the following topics:

- **Priority R&D Needs.** AMO's current R&D portfolio focuses on several flexible CHP opportunities. This session identified development needs for other emerging technologies to help increase CHP system deployment and utilization.
- **Increased CHP System Deployment.** Barriers to CHP implementation include well-known non-technical areas: policies, regulations, and financial challenges. Participants discussed solutions that can help overcome these non-technical barriers.
- **Future of Industry Thermal Energy Production and the Role of CHP Systems**. This session identified expected trends that will affect thermal energy production, as well as how industry will generate its thermal energy needs in 2040 and beyond.

Participants in each parallel breakout session answered questions related to the above topics. Responses have been combined to develop the breakout session summaries presented in Chapter 2.

Appendices A and B contain the meeting agenda and list of workshop participants, respectively.

2 Summary of Results

A. Priority Research and Development Needs

FOCUS QUESTION *Besides development of flexible CHP systems, what are other emerging technology development needs that would help increase deployment and utilization of CHP systems?*

During this session, participants discussed technology development areas that have the potential to increase future deployment of CHP systems. During this discussion, the conversation focused on several overarching themes, as described below.

Flexible CHP Power/Thermal Energy Optimization: It was generally recognized that a balance is needed between electrical and thermal loads within future CHP systems. Future CHP systems will find wider applicability in situations where thermal loads can be identified and utilized effectively. The need for better and more cost-effective cooling solutions was noted as a common theme. Recommendations included the need to enable diversification of loads for CHP systems, including novel application areas where CHP has not previously been used.

Systems Integration: CHP systems will require new functionality to bring value in different contexts, including district heating systems and microgrids. Participants stressed the importance of controls, interfaces, and standards for aiding integration of CHP into other systems. Utilization of artificial intelligence (AI) and big data to track and predict grid conditions was noted as a specific potential area for R&D.

Flexible Prime Movers and Complementary Technologies: Further improvements to prime mover technologies are needed, especially as CHP systems will need to have the capability to more frequently ramp up and down to respond to variability in renewable energy generation and other changes in grid conditions. Advances in other complementary technologies, including energy storage solutions, will also aid the deployment of CHP systems. Use of hydrogen as an energy storage medium and fuel source is of particular interest to the CHP community. Cost-effective carbon capture solutions suitable for CHP applications would be of great benefit as industry and the power systems move toward decarbonization.

Other Considerations: Participants noted that a number of advances are needed within the sector, though many of these advances may not be technical in nature or specific to certain technologies. Needs such as workforce development, testing infrastructure, system cost reduction, environmental impact considerations, decarbonization, and other industry trends all influence the future adoption rate of CHP. Further electrification of energy systems could increase the need for CHP in many applications, beyond heavy industry.

Table 2.1. Priority R&D

Flexible Power/Thermal Energy Optimization

- Matching thermal and electric loads
- Improved technologies that can flexibly modify heat/power ratios
- Technologies that maintain efficiency across a range of load factors
- CHP in resilient/local food systems, e.g., indoor and urban growing systems
- Additional ways to generate revenue streams (exhaust gas treatment for other uses, carbon reutilization, capacity for spinning reserve capability, etc.)
- Cooling and heating applications to expand the number of potential host sites

System Integration

- More practical approaches for integrating CHP into microgrids
- Standards for microgrid controls to alleviate complexity and simplify operator choices

- Integration of CHP into district energy systems
- Approaches for integrating CHP and renewables
- Development of electronic interfaces between CHP and other systems
- “Grid-friendly” systems, including improving responsiveness to grid needs, incorporating support for ancillary grid services (reactive power, etc.), making CHP dispatchable, and tying dispatch to markets
- Smart and simple standardized controls for interconnections and utilization with other energy supply (e.g., solar), especially for commercial users (e.g., supermarkets)
- AI and big data to track/predict grid conditions; AI to support smart/optimized systems with CHP and DERs
- Ways to address moratoriums on carbon-based fuels (natural gas, coal) and greater push for renewables
- Ways to promote CHP as price of fuel cells and batteries continues to go down
- Ability to promote CHP as part of an integrated solution for electrification and thermal energy

Standards

- Standards development on performance measures (e.g., exergy, heat quality)
- Modeling and capital resources, performance and scalability (CPS) analysis (systems analysis for integration with respect to site and other conditions/requirements to optimize performance)
- Standard for a CHP plant – base plant benefits/benchmarking for comparison

Flexible Prime Movers

- Improvements to prime movers and controls
- Prime mover agility to enable increased use of CHP to support variable sources such as renewables (e.g., go from 0% to 100% power in 10 seconds using batteries, fly wheels, etc.); flexible prime movers (can be more limiting than power electronics)
- Ability for any size CHP system to cost-effectively speed up ramp time from cold start and ramp-down as needed (e.g., when cloud cover goes away), which adds capacity for spinning reserve capability
- Improvement in existing prime mover efficiencies (e.g., additional 5%)
- Replacement of some or all fuel in combustion systems with hydrogen; engines that are continually adaptable to varying hydrogen content; ability to address high blends used for boilers
- Research and analysis on RNG potential as a flexible fuel (technical and economic)
- Scaling technology downward for typical commercial sites/smaller systems/micro CHP

Energy Storage

- Reliable fuel cells (hydrogen storage, power)
- Thermal storage systems, including high-temperature storage
- Better utilization and optimization of current technologies (e.g., thermal energy storage tanks and other subsystems)

Carbon Capture and Decarbonization

- Decarbonization and goals for cost-effective carbon reduction; economic analysis/comparison of decarbonization pathways
- Carbon capture technologies in plants; carbon-derived value adds/products from CHP
- Carbon capture and utilization technologies: specific to CHP, close to sites, smaller-scale design (for 5–20 MW CHP systems)

Supporting Infrastructure

- Greater availability of test sites needed to accelerate technology development

- Improved design knowledge and engineering for CHP (technology developer knowledge not always transferred to design firms)

Cost Reduction Efforts

- Improved CHP economics through reduced maintenance costs (extended spark plug lifetimes, improved lubricating oil durability, etc.)
- Methods to minimize system deployment cost

B. Deployment of Combined Heat and Power Systems

FOCUS QUESTION: *The non-technical barriers are well known (policy, regulations, financial) – What new approaches can be taken to address them? (e.g., New business models? New technical assistance approaches?)*

During this session, participants discussed approaches for overcoming non-technical barriers to increase CHP adoption and deployment. Several themes were identified, as discussed below.

Financing Options and Incentives: One of the most common themes was increasing or creating CHP financing options and tax incentives. Either incentives were not available from certain utilities/states, or they failed to consider the full benefits of CHP. Examples of potentially effective incentives include using long-term incentive programs (as short-term programs are more challenging for CHP due to the extended project development cycle); implementing incentives that consider the financial and carbon benefits of CHP (beyond energy benefits); expanding incentives to include public entities and facilities; and offering incentives for utilities to assist in and coordinate CHP adoption (utility representatives working with end users and designers). Feed-in tariffs have been successfully used in Germany and Demark. Financing options beyond utility rebate programs might include energy as a service, cash flow positive financing, commercial property assessed clean energy, or power purchase agreements. Different financing and ownership options are possible, such as end users partnering with utilities to offset both initial and operation costs.

Education, Engagement, and Recognition: Need for education for all parties involved in CHP (utilities, end users, building architects, engineering community, etc.) was also a common theme as a non-technical barrier. Overall, CHP education needs to include details on the problems that CHP can solve and its importance to the grid of today and the future. Tools, consulting services, and discussion forums could increase end user understanding of CHP installation impacts by providing more details on the overall expected cost and factors such as standby charges, load charges, and rates based on territory classification. Engaging directly with PUCs, regulators, and other parties would help them better understand CHP's positive impacts and benefits for facilities, utilities, and communities. One form of education could be recognition through award programs (similar to ENERGY STAR) that could highlight CHP's benefits and acknowledge those companies that have implemented CHP.

Greater support of CHP deployment could come from informative CHP publications from impartial sources (such as the government), targeted and accessible to different parties outside the pool of CHP experts (end users, utilities, design firms, etc.). There is a need for a holistic, multi-stakeholder study on innovative financing options for CHP, including contracting terms and options. More studies on the benefits of flexible CHP and other applications would increase knowledge and could help inform R&D and policy. Expanding the pool of independent experts is another resource to provide unbiased knowledge to those seeking more information on CHP.

Training and Workforce Development: New and expanded efforts on training and workforce development are needed for the CHP industry, and these efforts would benefit from increased education and outreach. Consultants or engineers need better education on CHP, as there is often disconnect between the internal teams handling the building design and utility considerations. CHP should be considered directly in building design. One possibility to achieve this could involve the CHP TAPs providing training to design firms on how to develop CHP to meet their customers' needs from the beginning of the design process. In general, expanding the pool of independent CHP experts would offer another resource to interested parties in terms of unbiased, educational information. Developing a certification scheme for CHP experts is another potential avenue, possibly through an organization such as the Electrical Generating Systems Association or Association of Energy Engineers.

Quantification of Benefits: CHP benefits beyond energy savings need to be better quantified to encourage deployment. Examples of non-energy benefits include increased resilience, impacts on grid congestion, and carbon reduction. However, quantification methods are lacking. To demonstrate CHP value, it would be beneficial to have a standard set of measures on resilience, emissions reductions, output-based emission standards, and the price of carbon. For end users to gain support for implementing CHP (whether from management, PUCs, the general community, or others), better defined and quantified resilience benefits are needed (e.g., financial benefits for facilities that can withstand weather events using CHP or microgrids). The value and cost of resilience and carbon reduction are important factors to consider in the return on investment for a CHP system. While DOE's CHP eCatalog provides performance data, including system cost benchmarks would enable easier CHP system proposal evaluation.

State and Utility Policies: A common non-technical problem in the CHP industry is a misalignment in states' approaches to supporting CHP. Differences between national, state, and local models for CHP deployment or implementation (taking into consideration varying conditions and environments) should be rectified, though it is acknowledged that this would be challenging. Coordination between states on interconnection policies and standards is needed; having a standardized approach (as the photovoltaic industry is pursuing) could help drive down implementation time and costs.

Ownership and Operational Options: During the workshop, numerous ideas emerged on how to overcome ownership and operations barriers. Utility ownership of CHP at all sizes (not just larger systems) should be promoted as beneficial for both utilities and end users. Providing end users with an easier way to sell electricity or thermal energy across the fence (where allowed) could improve their overall return on investment. CHP providers could offer more services (e.g., design–build service and full service, including maintenance) to end users that want a more hands-off approach to their CHP. Also, the business models for an end user to have an outside party own and operate CHP equipment on the end user's property exist (energy as a service, power purchase agreements, etc.), but end users still need to be convinced of the direct benefits to them.

Table 2.2. Approaches/Actions to Overcome Non-Technical Barriers to CHP Deployment

Financing Options and Incentives

- Identify incentives that take non-energy CHP benefits into full account (resilience, carbon, etc.)
- Enable financing options beyond rebate programs: energy as a service, cash flow positive financing, commercial property assessed clean energy, or power purchase agreements
- Promote the use of long-term incentive programs instead of short-term (not as fitting for CHP)
- Offer other financing and ownership options (e.g., end users partnering with utilities)
- Address the concern that corporate payback targets are typically too short to justify CHP
- Conduct a holistic, multi-stakeholder study on innovative CHP financing options

State, Local, and Utility Policies

- Address barriers to working with electric utilities and acting as independent power producers; overcome poor or misleading examples of CHP installations
- Overcome difficult or limiting interconnection agreements; address interconnection requirements and policies that vary from state to state
- Make it easier for system owners to sell electricity and/or thermal energy "across the fence"
- Find ways to harmonize or navigate differing national, state, and local models for deployment and implementation
- Foster uniform level and type of support/promotion for CHP (which differs from state to state)

Quantification of Benefits

- Develop standard measures to demonstrate CHP value beyond energy outputs, including resilience, emissions reduction, output-based emissions standards, price of carbon

- Quantify/monetize other CHP benefits such as resilience, reduced grid congestion, and deferred grid maintenance
- Create compelling CHP stories for management, PUCs, and the general public, using better defined and quantified resilience benefits
- Address the lack of system cost benchmarking in DOE's CHP eCatalog
- Conduct holistic cradle-to-grave analysis (emissions, energy, economics) to pitch CHP as a viable, efficient technology compared with alternatives

Ownership and Operational Options

- Encourage more flexible ownership options; promote utility ownership beyond larger CHP systems
- Find less challenging ways for end users to sell excess electricity or thermal energy across the fence (depending on restrictions)
- Overcome perceptions of end users, who are often reluctant to have CHP on their property if it is owned/operated by an outside party
- Move CHP into early-design facility/community design for heat and power, rather than continuing consideration of CHP only at the end of the design process

Education, Engagement, and Recognition

- Expand CHP education to include details on problems CHP can solve and its importance to the grid today and in the future
- Expand tools, platforms, and consultant expertise with the goal of educating and informing end users about different CHP factors (overall cost, standby and load charges, rates by territory, etc.)
- Enable more direct engagement with PUCs and regulators to educate them on the positive impacts and benefits of CHP
- Explore development of a recognition program (similar to ENERGY STAR)
- Develop informative publications about CHP from independent sources targeted to the general public and scientific community (non-CHP experts)

Training and Workforce Development

- Improve CHP education/awareness of building consultants/engineers, who are poorly informed or do not consider the benefits/challenges of CHP from the beginning of the design process
    - Have CHP TAPs provide some type of training
- Address the lack of a certification program for CHP experts
- Expand the general pool of unbiased, independent CHP experts who can help end users evaluate their technology options

C. Future of Industry Thermal Energy Production and the Role of Combined Heat and Power Systems

FOCUS QUESTION: *Looking further into the future (20 years and more), what are the expected trends that will impact thermal energy production in industry? How will industry generate the thermal energy it needs in 2040 and beyond?*

During this session, participants provided insights on changes in the industrial, electrical, and transportation sectors that will transform the future of thermal energy production and end uses. The discussion centered on the themes discussed below.

Electrification and Decarbonization: A trend in the energy industry is a drive to greater decarbonization. As more electricity production comes from renewable sources, electrification will help push zero-carbon energy into the industrial and transportation sectors. Even heating and cooling systems, which are more efficient when powered directly through other thermal energy production methods, may see electrification using technologies such as microwave and inductive heating.

Burning of fuels will maintain a share of thermal energy production in many industrial and energy-intensive processes that are difficult to electrify. The push for decarbonization, however, will encourage greater efficiency improvements to thermal energy production. Carbon capture devices can help certain thermal energy sources remain viable in a future with low-carbon requirements. Thermal energy is also expected to come from cleaner input fuels such as RNG and other waste-to-energy pathways.

Distributed Energy Systems: The future grid is expected to continue the trend toward more pockets of distributed energy systems. To adapt to the shift in grid generation, thermal energy systems of the future will be smaller in scale. It is also expected that they will provide a large amount of energy strictly as thermal energy for heating and cooling applications rather than using heat to produce more electrical energy. The designs of thermal energy systems will need to be flexible and adaptable to the diverse distributed energy needs and circumstances that exist around the country. Improvements in grid integration technologies will be needed to allow thermal energy units to share their energy production outside of distributed systems to enable better system efficiencies and economics.

Table 2.3. Future Trends in Thermal Energy Production
Electrification and Decarbonization • Trends toward greater electrification drive the adoption of different types of heating and drying methods such as microwave heating, inductive heating, and electric steam production at industrial scale. • There are new and emerging opportunities for decarbonization of fuel-based thermal energy production on the exhaust side rather than the combustion side, including utilization in agriculture and conversion to useful by-products. • Urban areas will be more likely to electrify if thermal energy production is harder/more costly to implement at the site. • Carbon capture combined with combustion-based thermal energy will be more viable in a low-carbon future. • A role will remain for fuel-based thermal energy production in the future, as electrification is not practical in all applications.
Distributed Energy Systems • Typical future thermal energy production units will be smaller and distributed.

- Many units will be installed at the district or community level (islanded solutions), with most energy produced for thermal applications rather than conversion to electricity.
- The shift of the grid toward distributed resources will necessitate changes in transmission and distribution infrastructure and improvements in grid management devices.

Renewable Integration

- More thermal energy systems will be used in conjunction with renewable resources using a hybrid model.
- The increase in renewable penetration will raise the value of spinning reserves by 2040; CHP systems used for thermal energy production can provide this service and serve as standby generation assets.

Thermal Storage

- Thermal storage will be more common, serving as an enabling storage technology.
- Heating and cooling systems integrated with thermal energy storage (e.g., ice systems) will become more common.

Fuel Sources

- Regulations may remove natural gas from some regional markets.
- Manufacturers and other producers will be looking for ways to achieve net-zero-carbon from thermal energy production, leading to use of new fuels.
- Hydrogen, syngas, and RNG are expected to increase their share of supply into thermal energy systems; waste-to-energy systems are also expected to be more common.

Change in End Uses

- High-temperature processes can be difficult to electrify and will likely remain powered by traditional thermal energy processes, albeit with a new fuel mix.
- It will be possible to recover waste heat (of variable quality) for many more uses.
- Systems will be designed to cascade high-temperature processes into lower-temperature ones, achieving greater efficiency.
- A shifting electricity use landscape will change grid needs over time (e.g., increased teleworking, greater cooling needs due to rising temperatures).
- Use of thermal cooling technologies could increase as higher temperatures necessitate efficient, low-carbon cooling methods.
- Thermal energy production will find more uses in critical infrastructure such as hospitals.

FOCUS QUESTION: *What role can CHP play in this future? What will marketable CHP systems look like in 2040 and beyond?*

Discussion centered around CHP as a potentially dominant form of thermal energy production in the future. Compared with other production technologies, CHP is cost-competitive, has higher efficiencies, and can be downsized for small system requirements. These attributes could contribute to CHP's becoming one of the most installed new approaches to thermal energy generation in the future. The discussion centered on the themes discussed below.

More Diverse Fuel Sources for CHP: While natural gas is the overwhelming fuel of choice for CHP systems today, future systems are expected to rely on a more diverse input stream. Hydrogen is expected to be one of the largest displacers of fossil fuels. This will be enabled through improvements in hydrogen production technologies as well as the systems used to transport and store hydrogen. The drive for hydrogen use is expected to be more prevalent outside the United States where natural gas is not as plentiful. Another fuel that is expected to see more widespread use is renewable natural gas (RNG). Greater use of RNG will require more supply, and a more diverse waste input stream for RNG production will therefore be required. Improvements to RNG clean-up processes will also be necessary to achieve a low-carbon lifecycle for CHP systems utilizing these fuels.

Favorable CHP Economics: As one of the lowest-carbon-emitting forms of thermal energy production, any future policy changes to limit carbon emissions or apply a price on carbon will have less of an impact on CHP than on other technologies. The efficiency, flexibility, and reliability of CHP systems will likely cause a change in utility attitudes that will result in a greater share of utility ownership of CHP. Additionally, an increase in the use of thermal energy storage will allow CHP units to be sized smaller for specific use cases but produce energy more often, which will improve the overall economics of new systems. Renewable energy systems can work well in tandem with CHP, and pairing their installation can lower the overall cost of both technologies, providing reliable clean energy cost-effectively. Also, improvements to automated operation and control of CHP systems will allow small owners to produce energy for others without the headaches typically associated with putting electricity back on the grid. Better grid integration will allow for more effective utilization of CHP systems.

Table 2.4. Future Characteristics of CHP

Diversity of CHP Fuel Sources

- Choice of fuel for CHP systems will shift away from todays' reliance on natural gas.
- Hydrogen is expected to displace a large portion of fossil fuel use, as improvements are made to hydrogen production technologies and transport and storage infrastructure.
- Traditional natural gas will be replaced by RNG as trends toward net-zero-carbon systems grow; increased vehicle electrification could shift use of RNG more toward CHP and industry applications rather than transportation.
- RNG production will come from a more diverse waste input stream, resulting in a greater penetration of waste-to-energy systems; improvements to RNG clean-up can drive toward true zero-carbon CHP systems.

Favorable CHP Economics

- CHP will remain a low-carbon-emitting form of electrical generation due to its high efficiency and diverse fuel mix.
- A shift in utility attitudes to accept a greater number of CHP systems will benefit future deployment of the technology.
- Increased penetration of thermal energy storage systems will help reduce the size of CHP systems but will not decrease their run time, which strengthens return on investment.
- CHP can improve the economics of renewables via load balancing, increasing CHP's role in renewable generation expansion.
- Easier CHP integration will allow local system operators to provide thermal and electrical energy to more consumers without having to operate like producers, increasing run time, use, and benefits of CHP systems without increasing cost.

Flexibility, Resilience, and Efficiency

- CHP will serve as a source of resilience and support for variable renewable production.
- Flexible CHP systems will be necessary to match thermal and electrical loads efficiently at both distributed and large scale.

- Thermal energy utilization will be more prevalent at localized and smaller scales through CHP and waste heat reuse.
- Most CHP applications will continue to beat combined cycle systems in efficiency.
- The operating design of CHP will continue to shift from primarily steam systems to incorporate more hot water systems.

Integration with Microgrids

- CHP will enable more microgrids, providing a consistent supply of energy to distributed systems.
- CHP can be a part of hybrid systems with multiple energy production technologies through the use of advanced controls, AI, and other integration technologies.
- CHP systems will be designed to interface with site loads and microgrids easily.

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Appendix A. Agenda

Fall 2020 Combined Heat and Power (CHP) Virtual Workshop

Hosted by the DOE/EERE Advanced Manufacturing Office (AMO)

September 8-10, 2020

FINAL AGENDA

DAY 1: September 8	
Time	**Activity**
1:00 PM – 1:05 PM	**Welcoming Remarks** • Bob Gemmer, U.S. Department of Energy
1:05 PM – 1:30 PM	**Overview of AMO CHP Program and R&D Portfolio** • Bob Gemmer, U.S. Department of Energy
1:30 PM – 2:00 PM	**Flexible CHP: Modeling Potential Impacts** • Mark Ruth, National Renewable Energy Laboratory
2:00 PM – 2:30 PM	**CHP Market Trends** • Bruce Hedman, Entropy Research
2:30 PM – 2:50 PM	**Break**
2:50 PM – 3:30 PM	**Panel Session: End Users Experience (Patti Garland)** 1. Bobby Baird – University of Florida Health, Shands Hospital 2. Andy Lempera – PepsiCo Gatorade Plant 3. Joan Kowal – Emory University
3:30 PM – 4:10 PM	**Panel Session: Utility Perspective (Bruce Hedman)** 1. James Libertini – Baltimore Gas and Electric 2. James Leidel – DTE Energy **3.** Zachary Kuznar – Duke Energy
4:10 PM – 4:50 PM	**Panel Session: Supplier Perspective (Rich Sweetser)** 1. Aaron Tasin – 2G Energy Inc. 2. John Hibler – Caterpillar 3. Chris Lyons – Solar Turbines Incorporated
4:50 PM – 5:00 PM	**Closing Comments and Instructions for Day 2** • Bob Gemmer
5:00 PM	**Adjourn**

<table>
<tr><th colspan="2">DAY 2: September 9</th></tr>
<tr><th>Time</th><th>Activity</th></tr>
<tr><td>1:00 PM – 1:15 PM</td><td>Welcoming Remarks and Breakout Session Instructions
Bob Gemmer and Joan Pellegrino, Energetics</td></tr>
<tr><td>1:15 PM</td><td>Move to Breakout “Rooms”</td></tr>
<tr><td>1:15 PM – 2:15 PM</td><td>Concurrent Breakout Session 1: Priority R&D Needs
Besides development of flexible CHP systems, what are other emerging technology development needs that would help increase deployment and utilization of CHP systems?
High heat to power CHP
Thermal storage
Thermal heat pump systems
Alternate fuels
Other value streams aside from heat and power
Others?</td></tr>
<tr><td>2:15 PM – 3:15 PM</td><td>Concurrent Breakout Session 2: Increased Deployment of CHP Systems
The non-technical barriers are well-known
Policy
Regulations
Financial
What new approaches can be taken to address them?
New business models?
New technical assistance approaches?</td></tr>
<tr><td>3:15 PM – 3:45 PM</td><td>Break</td></tr>
<tr><td>3:45 PM – 4:45 PM</td><td>Concurrent Breakout Session 3: Future of Industry Thermal Energy Production and the Role of CHP Systems
Looking further into the future (20 years and more), what are the expected trends that will impact thermal energy production in industry? How will industry generate the thermal energy it needs in 2040 and beyond?
What role can CHP play in this future? What will marketable CHP systems look like in 2040 and beyond?</td></tr>
<tr><td>4:45 PM – 5:00 PM</td><td>Closing Remarks and Plans for Day 3 - Facilitators</td></tr>
<tr><td>5:00 PM</td><td>Adjourn</td></tr>
</table>

DAY 3: September 10	
Time	**Activity**
1:00 PM – 1:10 PM	**Convene in Plenary Session and Prepare to Move to Breakouts**
1:10 PM – 2:30 PM	**Concurrent Breakout Sessions (continued)** • Review and discuss Day 2 inputs • Prepare breakout session report-out presentations
2:30 PM – 2:45 PM	**Break and Reconvene Plenary Session**
2:45 PM – 3:45 PM	**Plenary Session** • Breakout session report-outs
3:45 PM – 4:00 PM	**Next Steps and Concluding Remarks** • Bob Gemmer
4:00 PM	**Adjourn Workshop**

Appendix B. Workshop Participants

Name	Organization
Kate Anderson	National Renewable Energy Laboratory
Don Ayers	Capstone Turbine Corporation
Todd Bandhauer	Colorado State University
Bill Becker	National Renewable Energy Laboratory
Michael Bergstrom	UMC
Chris Bixby	Clarke Energy USA
Jim Black	National Energy Technology Laboratory
Aaron Bolhous	CHA Consulting, Inc.
Thomas Bourgeois	Pace University Energy & Climate Center
Robert Bouwens	Siemens Energy
Bill Castor	Siemens Energy
Gregg Coffin	University of Missouri
Robert Conway	Charles Equipment Energy Systems
Christopher Csernyei	CHA Consulting, Inc.
Pamela de los Reyes	Energetics
Jacob Delimont	Southwest Research Institute
Jen Derstine	Capstone Turbine Corporation
Robert Dibble	University of California, Berkeley
Caroline Dollinger	Energetics
Mark Dougherty	Kelly Generator & Equipment, Inc.
Owen Duffy	Kraft Power Corporation
Blake Ellis	Burns & McDonnell
Dennis Euers	Wunderlich–Malec Engineering, Inc.
Jamey Evans	Advanced Manufacturing Office , U.S. Department of Energy
Adam Galczynski	UGI Utilities
Kimberly Garcia	Cleaver–Brooks
Patti Garland	Elberti Engineering
Robert Gemmer	Advanced Manufacturing Office, U.S. Department of Energy

Name	Organization
Lauren Giles	Energetics
Sreenath Gupta	Argonne National Laboratory
Anne Hampson	Advanced Manufacturing Office, U.S. Department of Energy
Clay Hardenburger	Interstate Power Systems
Comas Haynes	Georgia Tech
Bruce Hedman	Entropy Research, LLC
John Hibler	Caterpillar Inc.
Keith Jamison	Energetics
Eduardo Juvera	The University of Texas at Austin
Meegan Kelly	ICF International
Joan Kowal	Emory University
Steve Krug	CHP-Funder.com and WorldCogenerationDay.org
Anand Kulkarni	Siemens Corporation
Matthew Lane	CHA Canada
Mike Larson	DTE Energy Services
James Leidel	DTE Energy
Andy Lempera	PepsiCo
James Libertini	BGE
Benjamin Locke	Tecogen
John Loetscher	Erlanger Health System
Chris Lyons	Solar Turbines/Caterpillar Inc.
Tommi Makila	Energetics
James McLeish	CHA Consulting, Inc.
Paul Miles	PECO, an Exelon Company
Kieran Mitchell	Caribou Biofuels, Inc.
Eric Moe	dJoule LLC/UMC
David Montgomery	Caterpillar Inc.
Scott Morgan	Energetics
Ibrahima Ndiaye	GE Research

Name	Organization
Connor Nolan	Wunderlich–Malec Engineering, Inc.
Dan Olis	National Renewable Energy Laboratory
Gordon Olson	Capstone Turbine
Thomas Orourke	Eversource
Carlos Pabon	AB Energy USA
Joan Pellegrino	Energetics
Paolo Pezzini	Ames Laboratory, U.S. Department of Energy
Bruce Pint	Oak Ridge National Laboratory
Christopher Potter	Architect of the Capitol
Uday Purani	Cummins Inc.
Gordon Rundle	Citizens Thermal Energy
Mark Ruth	National Renewable Energy Laboratory
Ridah Sabouni	Energetics
Miguel Sierra Aznar	Noble Thermodynamic Systems, Inc.
Doug Straub	National Energy Technology Laboratory
Richard Sweetser	Exergy Partners Corp.
Aaron Tasin	2G Energy Inc
Emmanuel Taylor	Energetics
Robert Thornton	International District Energy Association
Vestal Tutterow	Lawrence Berkeley National Laboratory
Kevin Van Detta	Leidos Engineering
Paul VanGelder	CHA Consulting Inc.
David Voss	Solar Turbines
Fred Wang	University of Tennessee, Knoxville
Daniel White	AB Energy USA
Mark Wild	Citizens Energy Group
Jim Zurlo	Waukesha Gas Engines

(Note: A total of 91 individuals participated in the workshop; 7 participants declined to share their information.)

Appendix C. Key Insights on Combined Heat and Power Market Adoption – Results of Site Owner Interviews

In a recently completed DOE activity (separate from the workshop), CHP site owners were interviewed to gain insights into the market environment and the major challenges to CHP adoption (DOE 2020b). The process involved creating a set of targeted questions, identifying innovative CHP sites, interviewing site owners, and analyzing and consolidating data. The key questions posed to site owners are listed in the sidebar.

> **Overarching Interview Questions for CHP Site Owners**
>
> - What are the main market barriers to installing/expanding CHP?
> - How are those barriers being overcome?
> - How are technology innovations in CHP being achieved?

The questions were designed to gain a better understanding of the kinds of challenges faced by site owners trying to stand up a CHP project, how those challenges were overcome, and what barriers still exist. The interview process included 16 sites encompassing both district energy and CHP sites selected from institutions that have engaged with the DOE CHP TAPs and whose systems include advanced or novel features such as selling excess power to the grid, island mode capability, or use of alternative fuels. These sites provided valuable information about their systems, setup, unique or innovative features, and approaches to overcoming barriers. Interviews also generated advice and recommendations to others considering CHP installation. The sites were diverse: nine universities, two medical centers, one government institution, and four industrial sites.

The highlights of interview results are shown in *Table 2.5 Key Interview Results from CHP Site Owners*, with key themes summarized below.

Reasons to Adopt CHP: Economics and sustainability were often cited as an important part of the decision process in opting for CHP. Related to cost, the declining price of natural gas was another factor. In addition, reliability and resilience were mentioned frequently, often because of unacceptable reliability issues with local grids. For large systems, space (i.e., real estate needed for the system footprint) was cited as a reason for CHP adoption, as it would accommodate expansion while consuming less space than separate boilers and engines.

Barriers to CHP Adoption: CHP users cited scarcity of supply as a barrier to using RNG; many were unaware of other renewable fuel options or found them expensive. Another issue is the complex permitting and regulatory processes (often involving local, federal, and utility organizations), which can lead to significant delays and costs.

Grid Interconnection Issues: Selling electricity to the grid presents a spectrum of challenges, including the complexities of navigating interconnection agreements and requirements. In deregulated markets, CHP competes with renewables and other alternative or distributed resources; sites may have to maintain a "must-run" status if selling electricity to the local utility. Grid connection can also affect reliability, i.e., disruptions on the grid can carry over to the local CHP site.

Site Innovations: Site owners are pursuing the use of renewable or alternative fuel sources, ranging from biofuels mixed with traditional fossil fuels to local landfill gas resources. The ability to go to island mode, in which the site owner can operate independently of the grid, is a way to guard against disruptions and improve overall reliability.

Deployment Assistance: Federal or local governments could help foster CHP deployment in several ways. Helping site owners connect with utilities through established partnerships can foster CHP adoption via increased utility involvement. Promotional materials or business case/cost–benefit analyses would be helpful to energy and plant engineers, who often have to make the case for CHP to their leadership. While alternative fuels are of interest to site owners, cost is often cited as a barrier in adopting RNG; lower prices would foster use of this fuel. Many sites do not know how to maximize system efficiency while using renewable energy technologies that are intermittent, such as solar. While storage could be a technical solution, the associated costs remain prohibitive.

Having operators and subject matter experts who are highly trained in CHP is a key driver of success on advanced CHP projects. Highly trained staff in this field are scarce. Site owners need comprehensive operations and maintenance training programs to help educate engineers and operators.

Table 2.5 Key Interview Results from CHP Site Owners

Reasons to Adopt CHP

- Economics and cost
- Resilience and reliability
- Sustainability and environmental goals
- Planned expansion (meeting demand needs)
- Achieving high levels of efficiency
- Efficient use of real estate
- Lower natural gas prices (making CHP more attractive economically)

Overarching Barriers

- Difficulties in securing funding for large or medium-sized CHP projects
- Lack of highly trained CHP subject matter experts who understand the benefits of CHP and how to size systems and operate them for maximum efficiency and site benefits
- Limited renewable energy supply options
- Delayed and/or costly permitting processes or regulations (i.e., utility, local construction, or other governing organizations)

Grid Interconnection Issues

- Regulatory processes that are complex, time consuming, and costly (Federal Energy Regulatory Commission, state/local regulatory bodies)
- Coming to an acceptable agreement with the local utility over power purchase agreements, interconnection, or other types of agreements that affect selling electricity to the grid
- Diverting thermal energy to produce more electricity, resulting in lower system efficiency and more costly produced electricity; this can make selling electricity to the grid unattractive
- Deregulated markets in which CHP sites have to compete with renewable energy and maintain a "must-run" status if supplying power to the grid; this can be challenging for host sites whose primary focus is meeting their own energy needs
- Potential impacts on site reliability if tied into the grid (i.e., if the grid trips, site operations can be affected—especially problematic for industrial sites)

Advanced and Novel Approaches

- Universities
  - Use of excess thermal energy in summer to heat underground rocks that serve as a heat source for heat pumps in winter
  - Multi-fuel mix, with one-third fixed-price woody biomass and over half natural gas
- Industry
  - Landfill gas as fuel (beverage manufacturer)
  - Ability to go to island mode (ethanol plant)
  - Combined power to municipality and local paper mill, positioned on a platform to withstand hurricane storm surges

Deployment Assistance

- Facilitating utility partnerships
- Providing information about CHP benefits and the business case
- Lowering alternative fuel costs and securing supply (e.g., RNG, waste heat)
- Maximizing use of a turbine for efficiency while using renewables
- Providing affordable storage solutions
- Helping to educate and train CHP subject matter experts, site owners, and onsite staff
- Developing a best practice checklist for installing CHP systems from an engineering perspective

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