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INNOVATION IN ENERGY

Emerging Technologies Poised to Decarbonize Energy Markets: Affordable and Reliable Solutions for a Low-Carbon Future

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Introduction

Beyond the clear environmental benefits of mitigating climate change, there is a strong economic case for investing in technologies that can help reduce greenhouse gas (GHG) emissions. In the past three years, the Trump Administration has initiated a rollback of environmental regulations, including those related to GHGs. However, this is likely to be a temporary trend, and increasingly stringent federal carbon regulations affecting multiple sectors of the economy can be expected in the coming years and decades. Private-sector entities seeking to gain a competitive advantage in this regulatory environment will need to make increasing investments in low-carbon technologies. Even in the absence of a strong federal regulatory presence, state and local GHG goals and regulations continue to require and incentivize low-carbon investments. As shown in Figure 1, many states have established GHG reduction targets for 2050 or sooner. To meet these standards, utilities and fuel suppliers will also have to expand their usage of low- and zero-carbon technologies.

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This paper examines three technologies that increase the competitiveness of low- and zero-carbon technologies versus carbon-intensive sources through the lens of reliability and affordability. The selected technology sectors include residential demand response (DR), microgrid optimization, and renewable natural gas (RNG). All three sectors have a low barrier to entry into existing markets, and deployment of these technologies will yield immediate environmental benefits. As more stringent government policies are put in place to encourage decarbonization, these technologies are likely to see expanded market opportunities. The diversity of approaches speaks to the wide-ranging needs of the energy transition, as well as the potential for creative solutions to these needs.

In addition to the regulatory sphere, consumer demand for GHG-reducing technologies is increasing. This includes everything from individual residential customers looking to limit their GHG footprint to large multinational corporations with aggressive renewable energy or carbon neutrality goals. Future federal regulations, existing and future state regulations, and consumer demand will require massive growth in decarbonizing technologies.

Although decarbonization is the driving force behind this market shift, it will not be the only factor in how investments are made—increasing the reliability and affordability of these technologies is equally important. Reliability is important because while we seek to develop technologies that will provide transformational change, the full economic benefits of the energy transition cannot be realized if businesses and customers do not have access to a reliable energy supply, which must be maintained by Independent System Operators (ISOs) on a minute-by-minute basis. Affordability is important because even the most effective decarbonization technologies will not achieve their full potential if they are too expensive to deploy. Therefore, any climate-centric investment strategy should focus on technologies that not only decarbonize, but radically increase the reliability and affordability of carbon-free and low-carbon energy.

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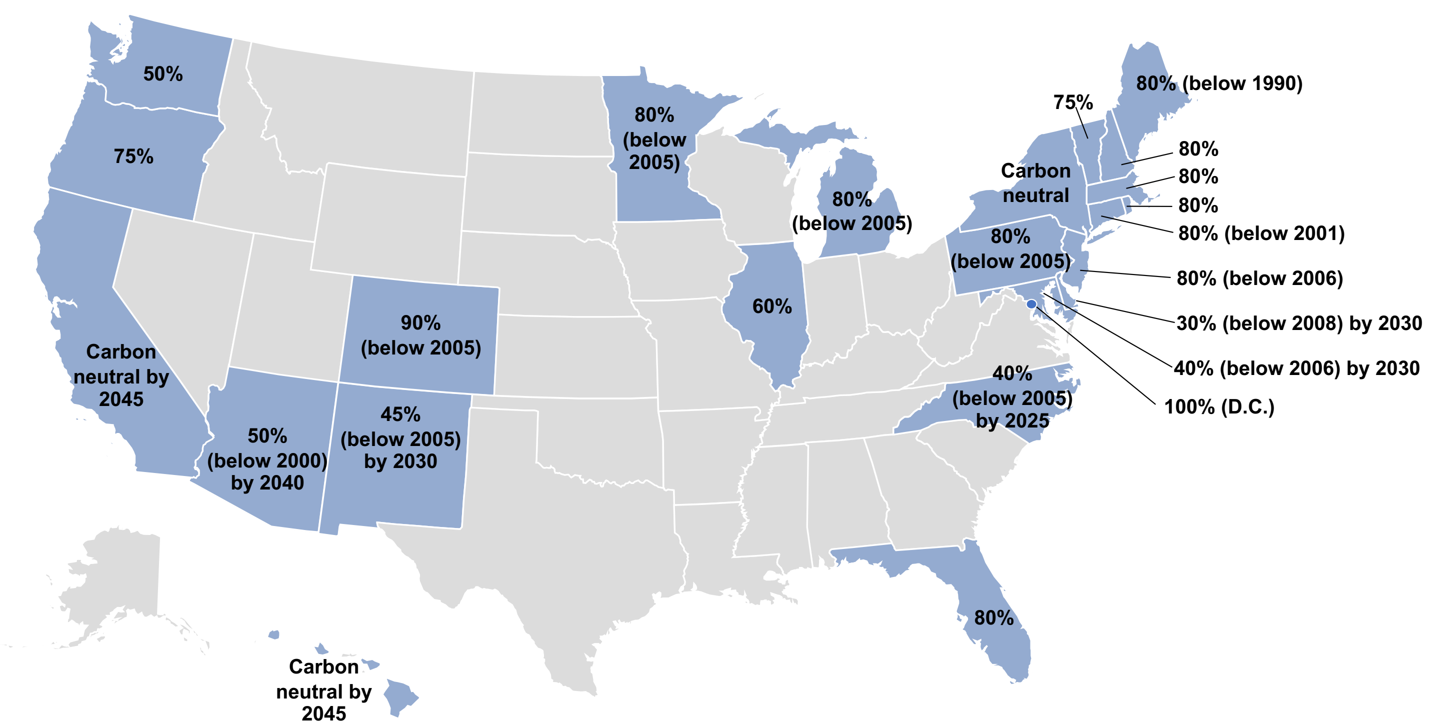
Figure 1: States' Long-term Greenhouse Gas Reduction Goals and Targets (by 2050 from 1990 baseline, unless otherwise noted) [1]



1 C2ES, 2020. "U.S. State Greenhouse Gas Emissions Targets," https://www.c2es.org/document/greenhouse-gas-emissions-targets/

Strategic Objectives

Decarbonization: According to the most recent National Climate Assessment, global temperatures are currently on track to exceed an increase of 1.5°C in the next two decades.[2] Decarbonizing the energy economy may be the only way to stem a catastrophic level of warming, and it also presents a valuable financial opportunity. More than 2,800 American businesses, investors, cities, and organizations remain committed to the Paris Climate Change Accord despite President Donald Trump's withdrawal of the U.S. as a signatory. Twenty-one states and the District of Columbia also have long-term GHG emissions reduction targets, indicating that even without a strong federal response, the state-level policy environment will remain positive for decarbonizing technologies.[3]

Reliability: Reliability has been the driving factor determining energy policy since the current energy system was constructed.[4] Renewable energy technologies must maintain similar levels of reliability if they are to be widely adopted, and technologies which build upon existing renewable energy infrastructure to offset any reliability failures will be of utmost importance for the energy transition.

Affordability: The onset of hydraulic fracturing (fracking) in the U.S. has caused the cost of domestic natural gas, a GHG-emitting fuel source, to plummet.[5] Technologies must make renewable energy disruptively affordable to compete with natural gas and other, cheaper forms of energy.

Target Sectors

The remainder of this technology review focuses on three target sectors—residential demand response (DR), microgrid optimization, and renewable natural gas (RNG)—that contribute to the strategic objectives of decarbonization, reliability, and affordability. In addition to a brief overview of each technology and its purpose, key market opportunities and risks are discussed.

RESIDENTIAL DEMAND RESPONSE

As the penetration of renewable energy resources continues to rise, ISOs face increased challenges aligning supply and demand for electricity over the course of any given day. In areas with heavy reliance on solar, the evolving trends in net load are described as the "duck curve" (see Figure 2). The characteristic duck curve features a dip in net load in the middle of the day when solar generation reaches a maximum. In the evening when the sun sets and people return home from work, the net load on the system ramps steeply to its daily peak.

The steep ramp and high system peak require that additional ancillary services be available to the ISO, such as regulating reserves and load-following resources.[6] These services can adjust output on short or even instantaneous time scales to keep the grid operating at the correct frequency.[7] They receive special compensation and often rely on fossil fuels, making them expensive options that contribute carbon emissions.

Demand response (DR) is a tool for encouraging short-term reductions in energy use by end consumers. [7] In doing so, it can help firm up intermittent resources by shaving peak energy demand, flattening steep system peaks, and relieving localized network congestion stress.[6] Traditionally, DR has relied on large industrial or commercial resources.[7] Industrial factories and chains of commercial stores can be large enough individual end users to have a notable effect on net load. Furthermore, their use patterns tend to be more predictable and manageable. Less aggregation is needed to bid these types of energy consumers into the wholesale market, adding to their desirability as DR resources.[8] By contrast, residential resources are small on an individual basis, so aggregating them reliably has posed a challenge that is ripe for technological innovation.

2 USGCRP, 2018. "Fourth National Climate Assessment," https://www.globalchange.gov/nca4

3 Jenks, C., G. Van Horn, and S. Hill, 2019. "Update on State Clean Energy Policies," Concord, MA: MJ Bradley & Associates. December 16, 2019. https://www.mjbradley.com/sites/default/files/MJBA_Issue%20Brief_Update-on-State-Clean-Energy-Policies.pdf

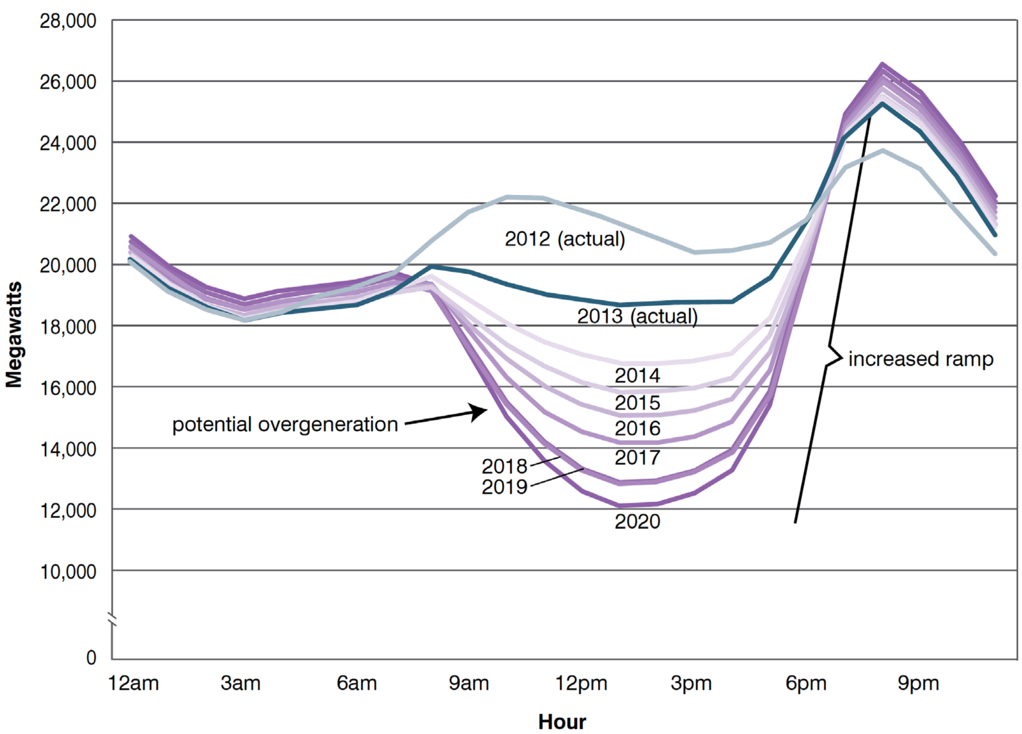
4 Grubler, Arnulf, Thomas Johansson, and Luis Mundaca. "The Global Energy System: Energy Primer." Stockholm, Sweden: International Institute for Applied Systems Analysis. Accessed February 20, 2020. https://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter1_lowres.pdf

5 McBride, James, and Mohammed Aly Sergie, 2015. "Hydraulic Fracturing (Fracking) Backgrounder." Council on Foreign Relations. June 10, 2015. https://www.cfr.org/backgrounder/hydraulic-fracturing-fracking

6 National Renewable Energy Laboratory (NREL), 2016. Competitive Electricity Market Regulation in the United States: A Primer. Golden, Colorado. p. 14.

7 Muza, Rujeko, 2020. Residential Demand Response in Wholesale Markets. https://www.americanbar.org/groups/environment_energy_resources/publications/rader/20200203-residential-demand-response-in-wholesale-markets

Figure 2: California Independent System Operator (CAISO) Duck Curve [8]



set realistic energy saving goals for each consumer.

Residential DR products use data to understand and influence behavioral patterns as precisely and consistently as possible. The first challenge is in developing models that can accurately predict the energy use patterns of residential consumers. Subsequent hurdles are even more complex because they require the ability to influence human behavior rather than simply understand it. Residential DR aggregators must establish payout schemes that incent customers to join, set realistic and individualized goals for energy reduction, and retain a consistent user base.

TECHNOLOGY OVERVIEW

The ability to monitor and aggregate residential consumers relies on energy usage data acquired from smart meters. Smart meters provide customers and utilities with automated and detailed measurements of their energy use over the course of a day.[9] The need for smart meter data is two-fold. As a first step, it provides baseline customer-specific use trends over different times of the day, week, and year. The trends for expected use can then be applied to

> ***"Residential DR products use data to understand and influence behavioral patterns as precisely and consistently as possible. The first challenge is in developing models that can accurately predict the energy use patterns of residential consumers."***

Residential end users may be smaller and less reliable candidates for DR, but they represent a large enough sector of the market to warrant investment in promising technologies. In public and private forums, work is being done to develop algorithms that continuously learn and adapt to individual consumer preferences over time.[10,11] A California-based residential DR startup called OhmConnect has leveraged their own algorithms and software platform to sign up more than 500,000 customers and provide more than 2 million kilowatt-hours (kWh) in total energy savings.[12]

MARKET OPPORTUNITIES

The number of smart meters across the U.S. is continuing to rise, as shown in Figure 3. The Energy Information Administration (EIA) reports that 86.8 million have been installed as of 2018, covering approximately 68% of U.S. households.[13,14] This means that residential DR services not only have millions of potential customers today, but that nearly the entire U.S. market will be

8 Environmental Defense Fund (EDF), 2015. Putting Demand Response to Work for California, p.8. https://www.edf.org/sites/default/files/demand-response-california.pdf

9 California Public Utilities Commission (CPUC), n.d. The Benefits of Smart Meters. https://www.cpuc.ca.gov/General.aspx?id=4853

10 O'Neill, D., M. Levorato, A. Goldsmith and U. Mitra, "Residential Demand Response Using Reinforcement Learning," 2010. First IEEE International Conference on Smart Grid Communications, Gaithersburg, MD, 2010, pp. 409-414. https://doi.org/10.1109/SMARTGRID.2010.5622078

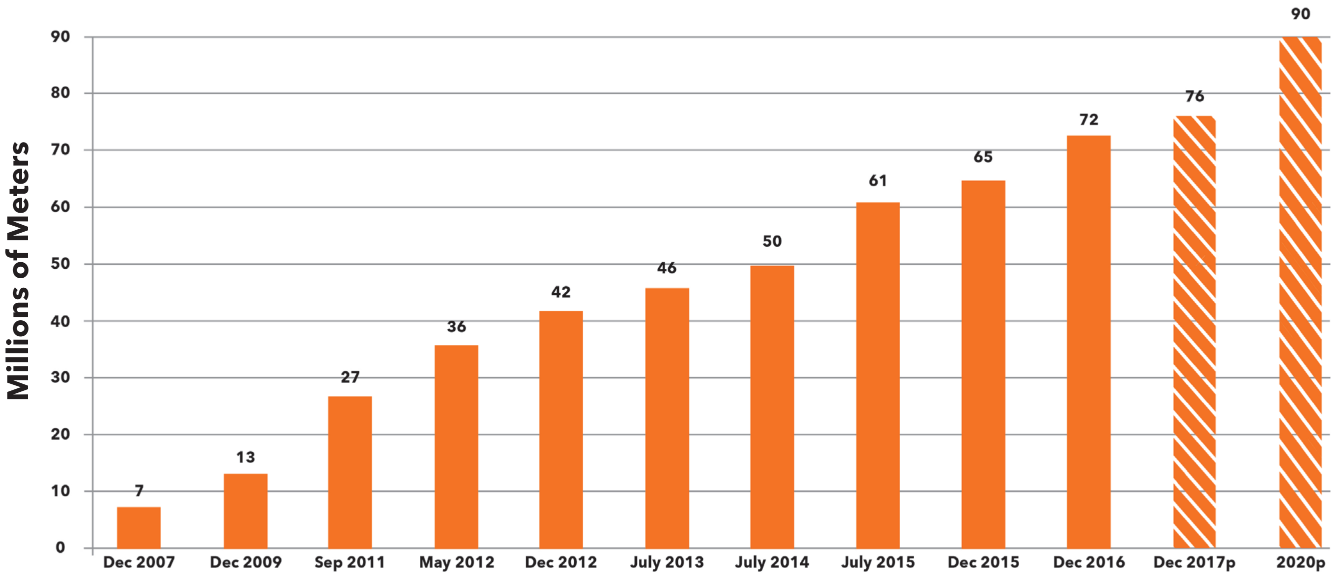
11 Lee, Sam, 2019. How does OhmConnect make money? OhmConnect, Inc. https://www.ohmconnect.com/faq/en/articles/1792744-how-does-ohmconnect-make-money

12 OhmConnect, 2019. OhmConnect Names New CEO After Hitting Major Milestones. PR Newswire. September 24, 2019. San Francisco, California. https://www.prnewswire.com/news-releases/ohmconnect-names-new-ceo-after-hitting-major-milestones-300924315.html

13 Energy Information Administration (EIA), 2018. Frequently Asked Questions: How many smart meters are installed in the United States, and who has them? U.S. Energy Information Administration, Washington, DC. https://www.eia.gov/tools/faqs/faq.php?id=108&t=3

accessible within the next ten years. Because these solutions are primarily software based, they do not require expensive capital investments to capture customers that already have smart meters.

Figure 3: U.S. Smart Meter Installations, 2007–2020p [14]



that shaving peaks by less than 2% in the PJM ISO would result in wholesale price reductions of 5–8%.[6] The study demonstrates that the incentives for a market framework are clearly present.[6] In the 2021–2022 capacity auction for PJM, DR services were awarded more than $180 million in capacity payments.[19]

California is a national leader in decarbonization policies, and residential DR services are particularly well-positioned for future growth in the state. DR aggregators are eligible for payment through the California Demand Response Auction Mechanism (DRAM), which is part of California's flexible capacity requirement within their resource adequacy program.[15,16] California's electricity supply already consists of more than one-third zero-carbon resources, and in 2018, the state set a goal of 100% zero-carbon resources by 2045.[17] Given the benefits that DR provides in firming intermittent resources, there is significant potential for the expansion of DR programs in states with higher renewable generation growth.[18]

Residential DR solutions also show promise in other markets outside of California. A 2007 study by the Brattle Group found

MARKET RISKS

Although the market upside for residential DR is enormous, there are substantial policy and operating risks to consider. In California, the DRAM program has been stuck in a pilot phase since 2015.[20] The California Public Utilities Commission (CPUC) found initial results of the pilot DRAM to be mixed and somewhat inconclusive, so the program has yet to be formalized.[19]

Beyond California, many markets currently lack the necessary auction and payment mechanisms to compensate residential DR providers. The model that OhmConnect has adopted uses venture capital to build and provide payouts to a consumer base as a proving point, before they have a means of getting compensated by utilities.[21] The approach is risky, but demonstrating success

14 Cooper, Adam, 2017. Electric Company Smart Meter Deployments: Foundation for a Smart Grid. The Edison Foundation Institute for Electric Innovation, December 2017. https://www.edisonfoundation.net/iei/publications/Documents/IEI_Smart%20Meter%20Report%202017_FINAL.pdf

15 Specht, Mark, 2019. What is Resource Adequacy? Three Requirements that Keep the Lights on in California. Union of Concerned Scientists, January 3, 2019. https://blog.ucsusa.org/mark-specht/resource-adequacy-in-california

16 Trabish, Herman, 2016. What to expect from California utilities' new aggregated demand response offerings. Utility Dive. January 26, 2016. https://www.utilitydive.com/news/what-to-expect-from-california-utilities-new-aggregated-demand-response-of/412614

17 California State Legislature, 2018. "SB-100 California Renewables Portfolio Standard Program: emissions of greenhouse gases." September 10, 2018. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB100

18 Hale, E. et al, 2018. "Potential Roles for Demand Response in High-Growth Electric Systems with Increasing Shares of Renewable Generation." National Renewable Energy Laboratory. December 2018. https://www.nrel.gov/docs/fy19osti/70630.pdf

19 Cohn, Lisa, 2018. Two Models, Two Outcomes for Demand Response in PJM, California. Microgrid Knowledge, June 15, 2018. https://microgridknowledge.com/demand-response-pjm-california

20 St. John, Jeff, 2017. California's DRAM Tops 200MW, as Utilities Pick Winners for Distributed Energy as Grid Resources. Greentech Media. July 26, 2017. https://www.greentechmedia.com/articles/read/californias-dram-tops-200mw-as-utilities-pick-winners-for-distributed-energ

21 St. John, Jeff, 2018. OhmConnect Reveals $15M in VC Funding and 100MW Stake in Behavioral Demand Response. Greentech Media. April 19, 2018. https://www.greentechmedia.com/articles/read/ohmconnect-reveals-15m-in-vc-funding-and-100mw-stake-in-behavioral-demand-r

encourages regulators to implement the necessary policies to enable such companies to flourish.

There are also challenges related to forecasting the future user base when bidding into capacity markets like DRAM. If a residential DR provider cannot secure adequate capacity in the auction, they may have to operate at a deficit and pay their customer base without receiving compensation in return.[22] If they overbid for capacity, they run the risk of not being able to meet their obligation. To succeed, residential DR companies need regulatory stability while they simultaneously work to fine-tune their algorithms for aggregating consumers, forecasting user trends, and awarding payouts.

STRATEGIC OBJECTIVES

Investment in residential DR contributes to the objectives of decarbonization, reliability, and affordability on multiple fronts. Residential DR encourages residential consumers to reduce their energy use during times of day when the grid relies on quick-ramping fossil fuel plants to meet peak demand. Eliminating the use of such plants reduces the amount of carbon entering the atmosphere. Further, residential DR can be dispatched to firm up intermittent renewable energy resources. In this capacity, residential DR can support the development of renewables and help with grid reliability as renewable penetration increases.

In terms of affordability, residential DR aggregators typically issue payments to their customers, so customers generate income rather than spending it. Those that aren't customers still benefit from such programs. By reducing the need for expensive peak generators and other ancillary services, residential DR can reduce the overall costs needed to keep the grid in balance, which in turn benefits all ratepayers.

MICROGRID OPTIMIZATION

Microgrids have been identified as a key tool in the energy transition for the last decade. The components of a microgrid make them endlessly customizable to address the needs of different communities and the changing needs of different states. However, there are still several obstacles preventing microgrids from becoming mainstream. While many microgrid systems deploy clean energy sources, they often supplement with a backup fossil fuel powered portable generator for better reliability. In addition, operating a microgrid can be a time-consuming task that requires specialized knowledge not possessed by most residential consumers. Finally, many public utilities are struggling to integrate microgrids successfully into their systems, primarily due to a lack of readily available data.

These issues cannot be resolved through investment in microgrid asset technology alone. Optimization software is quickly proving to be the most impactful area for microgrid investment that furthers decarbonization, affordability, and reliability goals. Optimization software allows the assets within a microgrid to "talk" with one another, creating an internal market that can more efficiently allocate energy resources within the microgrid. The savings and system smoothing generated by these efficiencies are invaluable to the integration of renewables into microgrid systems by both reducing the overall energy load and improving reliability enough that an additional carbon-intensive energy resource is not needed. Additionally, the intelligent nature of most of these software packages means that consumers are not required to manage the system themselves, reducing the regulatory burden significantly. And finally, as microgrids become more common, the data that optimization software collects will be an invaluable commodity for regulatory commissions in every state.

TECHNOLOGY OVERVIEW

Microgrid technology allows for a localized system of energy generators, energy storage, and load-drawing devices to operate in isolation from the broader electric grid. Microgrid systems face a few key challenges. They must independently manage supply and demand, which means avoiding over- and under-supply.[23] The side effects of mismanagement can include generators tripping offline or equipment malfunction and damage. The system must also be well calibrated to the appropriate conditions to trip into "island mode," in which it isolates itself from the rest of the grid. If the system is too responsive, it may enter island mode unnecessarily. On the other

22 Duesterberg, Matt, 2018. A Deep Dive into Energy Markets: The Nitty Gritty Details of How OhmConnect Gets Paid. OhmConnect, Inc., November 21, 2018. https://www.ohmconnect.com/thought-leadership/a-deep-dive-into-energy-markets-the-nitty-gritty-details-of-how-ohmconnect-gets-paid

23 DNV KEMA, 2014. Microgrids – Benefits, Models, Barriers and Suggested Policy Initiatives for the Commonwealth of Massachusetts. Massachusetts Clean Energy Center7 (MassCEC). February 3, 2014. Burlington, Massachusetts. http://nyssmartgrid.com/wp-content/uploads/Microgrids-Benefits-Models-Barriers-and-Suggested-Policy-Initiatives-for-the-Commonwealth-of-Massachusetts.pdf

hand, if it is too slow to isolate itself, the entire system risks going offline and requiring a black start, which compromises reliability and requires additional power to turn back on.[23] The high level of calibration required to manage a microgrid well means that good microgrid optimization software is essential to ensure the reliability of energy from the system.

> ***". . . a good optimization software package will be able to swiftly re-allocate resources without users experiencing an interruption in service."***

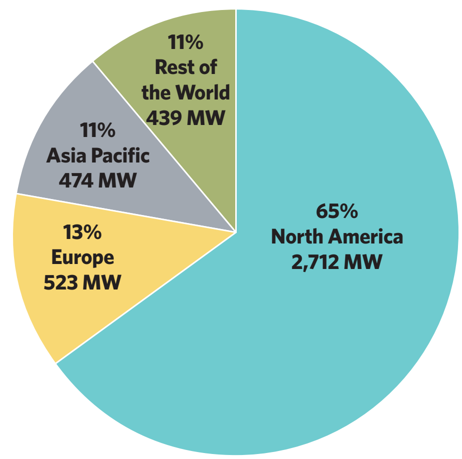
Most microgrid optimization software packages operate by having remote sensors that attach to each asset within the microgrid and communicate with a central computer. This computer then creates an internal "market" in which data from each asset is collected on a regular basis, including peak load times, usage rates, sub-optimal operation, and any internal errors. The computer then allocates resources within this market to meet demand as needed. The most important part of optimization software is that it gets smarter over time, so as the microgrid is used, it becomes better at allocating resources within the system.[24] This is especially important in the event an asset goes offline for any reason—a good optimization software package will be able to swiftly re-allocate resources without users experiencing an interruption in service.

MARKET OPPORTUNITIES

A 2019 research report by Navigant projects that global microgrid capacity will grow from the current 3.5 GW to 20 GW by 2028.[25] According to the report, Asia Pacific is expected to see the largest overall market growth, but North America will continue to maintain capacity dominance, as shown in Figure 4.[25,26] Within the U.S., microgrids are becoming a key component of state climate resiliency and mitigation protocols. For example, Massachusetts recently passed the Climate Resiliency Act, which provides $100 million in funding towards municipal microgrid systems.[27]

With increased demand for microgrids themselves, microgrid optimization software is poised to follow. As installations increase, incumbent energy providers are likely to push for stricter regulations for microgrids, which are not currently regulated under the same protocols. While these regulations may pose a risk to the microgrid market, they also provide an opportunity for data collection and reporting. Companies that can employ their optimization software to meet state and federal requirements will be able to capitalize on this opportunity. Additionally, as installations become more common in the consumer sphere, the demand for technologies which lower the management burden of running a microgrid will only increase. Microgrid software which allows lay consumers to access the benefits of running a microgrid without a deep knowledge of energy markets will prove invaluable in the energy transition.

Figure 4: Total Microgrid Capacity by Region, World Markets: 4th Quarter, 2013 (MW) [26]



MARKET RISKS

As microgrids play an increasing role in energy markets, additional rules and regulations that ensure their safe operation and market participation may become necessary. These regulations could slow the deployment of microgrids or create rules that limit optimization software companies from installing their technology and monitoring customer equipment. The task of integrating microgrids with the existing electric grid is also challenging. In addition to coordinating the potentially destabilizing flow of electrons in and out of microgrids, market structures must be established to ensure that microgrids receive fair compensation for the energy

24 Rahimian, Mina, Lisa D. Iulo, and Jose M. Pinto Duarte, 2018 "A Review of Predictive Software for the Design of Community Microgrids." Review Article. Journal of Engineering. https://doi.org/10.1155/2018/5350981

25 Business Wire, 2019. Navigant Research Report Shows Global Microgrid Capacity Is Expected to Experience a Compound Annual Growth Rate of 21% Over the Next Decade. Navigant Research, November 14, 2019. https://www.businesswire.com/news/home/20191114005037/en/Navigant-Research-Report-Shows-Global-Microgrid-Capacity

26 Navigant Research, 2013. Microgrid Deployment Tracker 4Q13: Commercial/Industrial, Community/Utility, Institutional/Campus, Military, and Remote Microgrids: Operating, Planned, and Proposed Projects. Boulder, CO: Navigant Consulting.

27 Chesto, Jon, 2019. "DeLeo Touts $1.3b GreenWorks Program - The Boston Globe." May 28, 2019. https://www.bostonglobe.com/business/2019/05/27/deleo-touts-greenworks-program/xypRLDiOOGphnILb19OGBJ/story.html

and ancillary benefits they provide.[28] As microgrids that reduce system demand begin to compete with traditional supply resources, these incumbents will likely attempt to block market or regulatory changes that facilitate microgrid integration.

STRATEGIC OBJECTIVES

Investment in microgrid optimization software not only promises a huge growth opportunity, but generates progress towards decarbonization, affordability, and reliability goals that investment in microgrid asset technology cannot. Optimization software that improves the load efficiency of microgrid systems reduces the need for larger scale gas generators, creating greater opportunities for clean energy usage. In addition to promoting decarbonization in this manner, optimization software smooths operating dips within a system, increasing its reliability and reducing interruptions in service for users. Finally, while optimization software is often sold in packaged bundles to larger corporate consumers, the increasing prevalence of "plug-and-play" systems, such as those produced by Massachusetts-based startup Heila Technologies,[29] makes this software cheaper and more affordable for private consumers. Optimization software lowers the barriers of entry for would-be microgrid consumers, speeding up the energy transition away from a carbon-intensive macrogrid.

RENEWABLE NATURAL GAS

As states, corporations, and individuals have moved to reduce their GHG emissions, the first steps have usually been to use more renewable electricity and to decarbonize transportation. However, to achieve deep decarbonization, cuts will also need to be made to natural gas end uses such as space heating and industrial processes. Renewable natural gas has the potential to play a major role in reducing emissions where other strategies such as electrification are too expensive or not technically feasible. RNG produced using anaerobic digestion uses biogenic waste streams to create a natural gas that is interchangeable with conventional natural gas. While the vast majority of RNG is currently used as vehicle fuel, new policies and customer demand is driving increased production and use in other sectors.

TECHNOLOGY OVERVIEW

Anaerobic digestion is a naturally occurring process in which bacteria break down organic matter in an environment without oxygen. This process creates raw biogas, which is roughly 50% methane and 50% carbon dioxide. At sources like landfills and dairy farms, if this gas is not captured it is directly emitted to the atmosphere, contributing to GHG emissions. However, if this gas is captured and directed to an RNG upgrading facility, it can be cleaned and processed into pipeline quality natural gas. A wide range of technologies can be used to upgrade biogas, and the combination of required equipment is project specific and varies depending on feedstock and gas constituents. These technologies perform many functions, including removing carbon dioxide, removing chemical constituents that may damage end-use equipment or be harmful to human health, and upgrading the heating value of the gas. After processing, RNG can be interconnected into the natural gas pipeline system, introducing a renewable fuel into the existing infrastructure. Because RNG reduces direct methane emissions (a potent GHG) and directs it to a useful end use that converts most of it to carbon dioxide through combustion, the net lifecycle GHG emissions of RNG are less than those from conventional natural gas.

MARKET OPPORTUNITIES

RNG production is on the rise throughout the U.S and particularly in California. This is due to a suite of policies that reduce RNG production costs, incentivize RNG use, and mandate its incorporation into the natural gas fuel supply. These policies are primarily related to efforts to support decarbonization. These policies are expected to expand and spread geographically, positioning the industry for continued growth and success into the future.

28 Johnson, L., 2018. "Grid Operators Describe Challenges of Distributed Energy Aggregation to FERC." Greentech Media. April 11, 2018. https://www.greentechmedia.com/articles/read/grid-operators-describe-challenges-of-distributed-energy-aggregation

29 Heila Technologies. "Home | Heila Technologies." Accessed February 20, 2020. https://www.heilaiq.com

The two largest RNG incentives are the federal Renewable Fuel Standard (RFS) and California's Low-Carbon Fuel Standard (LCFS), both of which require increasing volumes of renewable fuel to be used in the transportation sector. RNG is one of the most valuable renewable fuels under both programs, providing significant monetary support for RNG producers. As shown in Figure 5, RNG sold into the RFS currently has a value of $11/thousand cubic feet (Mcf). Figure 6, which presents current LCFS prices for RNG by feedstock, shows that RNG is worth up to nearly $55/Mcf depending on feedstock. RNG producers selling gas into the California transportation fuel market can take advantage of both incentives, selling RNG for almost $66/Mcf, or more than 25 times the current Henry Hub natural gas price. The RFS and LCFS regulations provide investment certainty by ensuring not only a market for RNG but also a strong financial incentive.

RNG Producers in California are particularly well positioned as the state has established incentives for RNG infrastructure and mandates for integrating RNG into the natural gas fuel supply. These policies help offset RNG development's high capital costs and create demand. California's incentive programs include utility rate recovery for up to $5 million of interconnection infrastructure investments at individual dairy RNG projects[31] and a pool of $319 million for other RNG infrastructure investments at 45 identified dairy RNG projects.[32] California is also in the process of implementing a pilot program that requires gas utilities to connect at least five dairy RNG cluster projects to their pipeline networks.[32]

Although California is leading the development of policies to foster RNG growth, emerging policies in other states will point to continued industry growth nationwide. As reflected earlier in Figure 1, numerous states have aggressive GHG reduction targets.

Figure 5: RNG Prices Under the Renewable Fuel Standard [30]

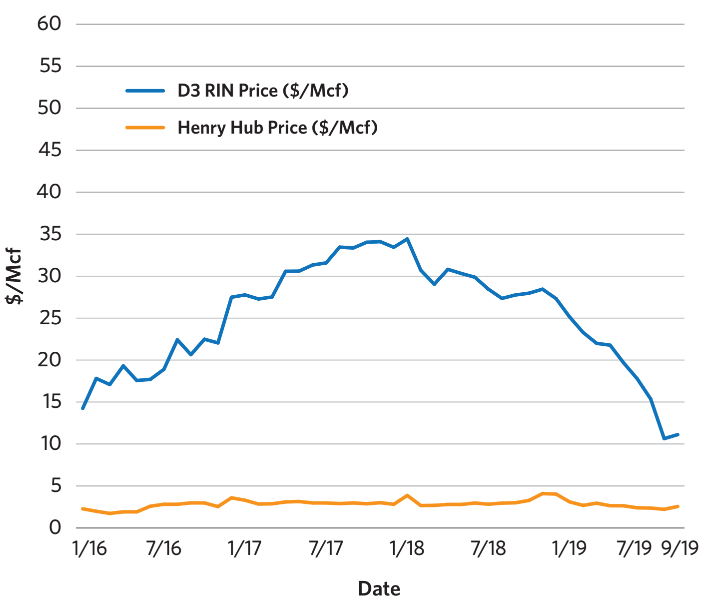
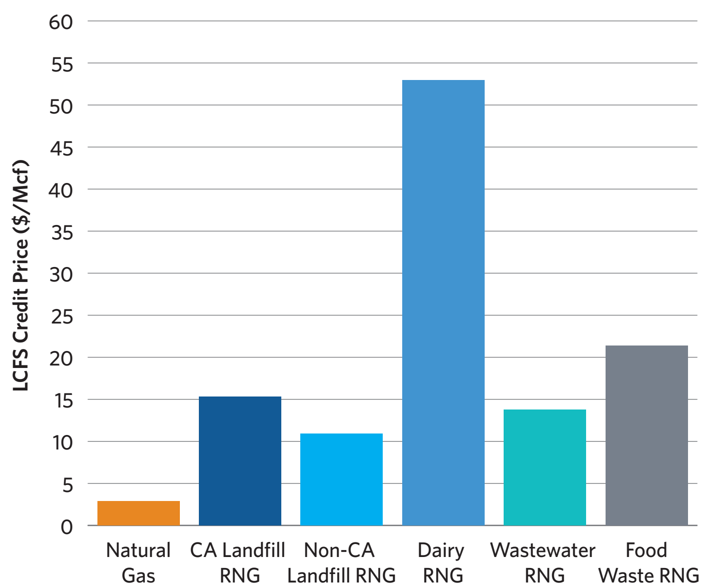


Figure 6: LCFS RNG Prices by Feedstock [33]



30 U.S. EPA, 2019. "RIN Trades and Price Information," https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information

31 California State Legislature, 2016. "AB-2313 Renewable Natural Gas: monetary incentive program for biomethane projects: pipeline infrastructure." September 24, 2016. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB2313

32 California Public Utilities Commission, 2017. "Decision Establishing Implementation and Selection Framework to Implement the Dairy Biomethane Pilots Required by Senate Bill 1883." December 18, 2017. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M201/K352/201352373.PDF

33 California Air Resources Board, 2019. "Monthly LCFS Credit Transfer Activity Report for December 2019," https://ww3.arb.ca.gov/fuels/lcfs/credit/Dec%202019%20-%20Monthly%20Credit%20Transfer%20Activity.pdf

States are increasingly turning to RNG to make progress towards these goals. California, Nevada, Oregon, and Washington have all passed laws requiring or authorizing the development of renewable gas standards that would require utilities to meet specific percentages of the natural gas they supply to customers with RNG. Proposed rules that did not pass in New York and Connecticut are expected to be reintroduced in 2020. Regulations that mandate RNG purchases provide additional investment certainty and mitigate concerns related to finding buyers willing to pay the price premium for RNG.

MARKET RISKS

Although RNG can provide significant GHG benefits, it is more expensive than fossil natural gas. These higher costs are the result of the infrastructure needed to collect and upgrade raw biogas to RNG and then inject it into existing natural gas pipelines. For example, an RNG processing facility at a large dairy farm costs approximately $8 million,[34] while the cost of a pipeline interconnection could range from $1.5 million to $3.5 million.[35] This results in higher supply costs. Vermont Gas estimates that its costs to supply RNG to customers ranges from $15 to $25/Mcf, depending on the source, compared to an average price of $3 for fossil gas.[36] Raising over $10 million for capital costs presents an obstacle to RNG production development, especially if there are no customers willing to commit to purchase the gas at its higher price point. Fortunately, many of the policy developments described above are expected to help offset the higher upfront costs of RNG and allow increasing volumes to be integrated in the natural gas supply chain.

Another factor restricting the role of RNG is limited feedstocks. There are only so many manure, wastewater, municipal solid waste, food waste, and other biogenic waste streams to draw from. Further, RNG faces competition over these feedstocks from other uses such as direct biogas consumption and liquid renewable fuels. There is therefore a technical potential for RNG, which, while larger than its economic potential, is inherently restricted. A 2014 NREL study estimated that biogenic waste feedstocks could produce up to 756 billion cubic feet of RNG, enough to meet 17% of 2017 U.S. residential natural gas demand.[37] If RNG produced through processes other than anaerobic digestion (e.g., thermal gasification) is included, potential volumes increase significantly. However, because RNG derived from anaerobic digestion will never be able to displace conventional natural gas, policy makers should ensure that it is ultimately directed to end uses that will provide the greatest GHG benefit.

> ***"While RNG is more expensive than traditional natural gas, it is more appropriate to compare it to other decarbonization strategies."***

STRATEGIC OBJECTIVES

It is also important to note how the economics of RNG relate to the two objectives of reliability and affordability. In terms of reliability, RNG provides an alternative, local supply of natural gas. In a time of capacity constraints and opposition to new pipeline construction, adding RNG to the pipeline network can help ease tight supply during times of peak demand. This is exemplified by Consolidated Edison's recent request for non-pipeline solutions in New York, which, in addition to strategies such as increased storage and improved efficiency, selected three RNG projects to address peak demand concerns.[38] While RNG is more expensive than traditional natural gas, it is more appropriate to compare it to other decarbonization strategies. Electrification of natural gas end uses is a commonly proposed decarbonization strategy. However, due to the costs required to decarbonize the electric supply, upgrade transmission equipment, and replace end-use equipment, RNG is often a lower cost solution that provides greater near-term GHG reductions.[39] RNG also allows for continued use of existing natural gas infrastructure. Increased electrification will lead to a lower number of customers being responsible for maintaining the pipeline system, leading to higher costs. These costs are more likely to fall on low-income customers. RNG can therefore provide lower-cost reliability improvements and in many situations represents a lowest-cost decarbonization strategy.

34 Lowell, Dana, 2019. "Renewable Natural Gas Project Economics." M.J. Bradley & Associates. July 2019. https://mjbradley.com/sites/default/files/RNGEconomics07152019.pdf

35 The Public Utilities Commission of the State of California, 2015. Decision Regarding the Costs of Compliance with Decision 14-01-034 and Adoption of Biomethane Promotion Policies and Program, Decision 15-06-029. June 11, 2015. "CPUC Decision 15-06-029" http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M152/K572/152572023.PDF

36 Vermont Gas Systems, 2018. "Renewable Natural Gas Program Manual." April 26, 2018. https://www.vermontgas.com/wp-content/uploads/2018/09/VGS-RNG-Manual-Final-V-1.01.pdf

37 Saur, Genevieve and Milbrandt, Anelia, 2014. "Renewable Hydrogen Potential from Biogas in the United States." National Renewable Energy Laboratory. July 2014. https://www.nrel.gov/docs/fy14osti/60283.pdf

38 Consolidated Edison, 2019. "June 2019 Company Update." June 2019. https://investor.conedison.com/static-files/41f32524-8a25-44c4-a36f-793a3a23d091

39 Navigant, 2018. "Analysis of the Role of Gas for a Low-Carbon California Future." July 24, 2018. https://www.socalgas.com/1443741887279/SoCalGas_Renewable_Gas_Final-Report.pdf

Conclusion

The acceleration of consumer and regulatory demand for GHG-reducing technologies has primed the market for decarbonization. With the grid in transition, fossil fuel sources are still cheaper and easier to regulate than their clean energy counterparts. Any decarbonization strategy should prioritize technologies that pinpoint these weaknesses to broaden the reach of clean energy technologies. A strategic decarbonization portfolio should cover both transitional needs—such as those met by RNG—as well as operational needs—such as those met by microgrid optimization software and residential demand response. Technologies that can simultaneously address issues of grid reliability and energy affordability are likely to see quicker uptake and expansion within existing markets, which better serves the broader goal of decarbonization. While this paper lays out three technologies with the potential to make significant contributions towards decarbonization, a wide portfolio of solutions will need to be implemented to ensure a secure and affordable low-carbon future.

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