Workshop Summary Report:

R&D for Dispatchable Distributed Energy Resources at Manufacturing Sites

U.S. Department of Energy

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Disclaimer

Table of Contents

Executive Summary

Requirements for the electric grid are evolving as new loads and generation sources are integrated into the distribution grid. The traditional architecture of the electricity system was based on large-scale generation remotely located from consumers, hierarchical control structures with minimal feedback, limited energy storage, and passive loads. However, the future grid will be different: it will have the ability to dynamically optimize distributed resources, rapidly detect and mitigate disturbances, engage millions (if not billions) of intelligent devices, integrate diverse generation sources (including renewables), integrate demand response and energy-efficiency resources, enable consumers to manage their electricity use and participate in markets, and provide strong protection against physical and cyber risks.[1] Distributed energy resources (DERs), including distributed renewables (such as solar photovoltaics) and dispatchable distributed generation (such as micro-turbines) will play a key role on the future grid, providing energy and grid services that are co-located with residential, commercial, and industrial loads.

Utilities and regulators have begun to evaluate the potential for leveraging DERs – including dispatchable distributed energy resources (D-DERs) owned by small and midsized manufacturing enterprises (SMEs) – to provide services to the grid. Past assessments of D-DERs concluded that these resources could increase electric system reliability, reduce peak power requirements, provide ancillary services (including spinning reserve, Volt/VAR support, and black start capability), improve power quality, reduce land use for transmission line rights-of-way, and increase grid resilience to adverse events (including terrorism and extreme weather)[2]. D-DERs located at SME sites could be especially valuable since, unlike solar and wind generation, the output of D-DERs can be precisely controlled and is available at any time during the day or night. Moreover, SMEs have substantial electric loads (1-20 megawatts), are familiar with D-DER technologies, and are located on distribution grids where deployment of other new technologies (such as solar photovoltaics and electric vehicles) will eventually have a dramatic impact on how the system operates. The untapped potential for SMEs to sell excess electricity back to the grid is promising: for example, the export potential for combined heat and power (CHP) units at SMEs is estimated at over 14.5 gigawatts (GW).[3]

While the potential benefits are compelling, additional capabilities will be needed in future D-DER technologies for these systems to play a larger role in providing services to the electricity grid. To explore what technical innovations are needed in D-DERs, the U.S. Department of Energy's (US DOE's) Advanced Manufacturing Office (AMO) sponsored a workshop in February 2016 in Austin, Texas. The workshop brought together experts from a variety of areas, including industrial consumers, distribution utilities, third-party aggregators, independent system operators (ISO), equipment suppliers, and academia and research. Discussion focused on key technical barriers that need to be addressed for D-DERs to play a larger role in providing services to the grid and the R&D pathways that have the greatest potential to overcome the barriers. Topic areas explored included advances needed in generation systems, forecasting and optimization tools, power conditioning systems, telemetry and network systems, sensors, controls, and data processing technologies.

Based on feedback from participants at the workshop, numerous emerging technology areas were identified that would enhance the ability of D-DERs to support the electric grid and increase the return on investment for SMEs that invest in D-DER systems. While many promising R&D pathways were identified, 29 action areas

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[1] U.S. Department of Energy. *Quadrennial Technology Review.* September 2015

[2] U.S. Department of Energy. *The Potential Benefits of Distributed Generation and Rate-related Issues that May Impede their Expansion.* February 2007

[3] U.S. Department of Energy. *Combined Heat and Power (CHP): Technical Potential in the United States*. March 2016

have the greatest potential to overcome the technical barriers that were identified during the workshop. These are outlined in Table 1, and further detail is provided in the body of this summary report.

<table>
<tr><th colspan="2">Opportunities in Generator Systems</th></tr>
<tr><th>R&D Pathways</th><th>Action Areas</th></tr>
<tr><td>Technologies that Increase D-DER Efficiency in Steady-state Operation</td><td>1. Ultra-lean-burn technology in stationary reciprocating engines
2. Exhaust gas cleanup systems for ultra-lean burn engines
3. Improved waste heat recovery systems
4. Lower-cost thermal energy storage systems
5. Systems that reform natural gas to enrich generator fuel</td></tr>
<tr><td>Technologies that Allow Manufacture of a Co-product (in Addition to Heat and Electricity)</td><td>6. Hydrogen or other transportation fuels through reformation
7. Water desalination using excess heat or electricity
8. Forecasting tools for demand for co-products</td></tr>
<tr><td>Technologies that Reduce D-DER System Cost</td><td>9. Standardized, modular generator components
10. Reduce maintenance costs, and/or extend generator life
11. Survey of DER deployment to reduce deployment risk</td></tr>
<tr><td>Technologies that Enable Participation in Transmission Grid Markets that Require Transient Operation</td><td>12. Thermal energy storage integrated with DERs
13. Battery energy storage integrated with DERs
14. Faster start-up times for lean-burn reciprocating engines
15. Increased efficiency for rich-burn reciprocating engines</td></tr>
<tr><td>Technologies that Enable Participation in Future Distribution Grid Markets</td><td>16. Power electronics to provide Volt/VAR support
17. Power electronics to provide increased power quality</td></tr>
<tr><td>Technologies to enhance D-DER resiliency</td><td>18. Bi-fuel generator capable of using diesel or natural gas</td></tr>
<tr><th colspan="2">Opportunities Behind the Meter</th></tr>
<tr><th>R&D Pathways</th><th>Goals and Actions</th></tr>
<tr><td>Technologies that Protect the Generator and Allow Greater Integration with the Distribution Grid</td><td>19. Power electronics with AC/DC fault protection
20. Standards to enable continuous connection with weak grid
21. Inverter technology with rapid response times
22. Reduced costs of large inverters typically used with D-DERs</td></tr>
<tr><td>Technologies that Enable Rapid on-off Switching of D-DERs</td><td>23. Enhanced switching or braking capability
24. Controls for multiple DERs at single SME site</td></tr>
<tr><td>Publications and/or Standards that Reduce D-DER Soft Costs</td><td>25. Study outlining best practices in distribution system interconnection for DERs, including equipment requirements</td></tr>
<tr><th colspan="2">Opportunities in the Rest of Plant</th></tr>
<tr><th>R&D Pathways</th><th>Goals and Actions</th></tr>
<tr><td>Technologies that Allow for Optimization and Control of Loads and Generation by SME or Aggregator</td><td>26. Low-cost, durable sensors for D-DERs
27. Low-cost secondary communications networks for D-DERs, particularly for units controlled by TPAs</td></tr>
<tr><td>Publications and/or Standards that Reduce D-DER Soft Costs</td><td>28. Study that provides transparency on costs for telemetry, metering and communications equipment</td></tr>
<tr><td>Forecasting Tools for SMEs and/or TPAs</td><td>29. Improved forecasting tools for on-site loads and generation</td></tr>
</table>

Table 1: Most Promising R&D Pathways and Action Areas for D-DER Technology

1. Introduction

Distributed energy resources (DERs) are growing rapidly in the United States and around the world. Global annual installed capacity of DERs reached 87.3 GW in 2014, and is projected to grow to 165.5 GW by 2023.[4] In the last five years, solar deployments alone have increased eightfold, with 7,260 megawatts (MW) of new solar capacity added in to the US electric grid in 2015, of which 43% was distributed solar.[5] Deployment of dispatchable distributed generators (D-DERs), including reciprocating engines, turbines, and fuel cells, has also been gaining momentum. For example, since 2010, 728 new combined heat and power (CHP) systems have been installed across the United States, adding nearly 2 GW of capacity to the US grid.[6] Of these units, nearly all (94%) were smaller than 10 MW, and many of these units were interconnected to a local distribution grid.

1.1 DERs and the Changing US Electric Grid

As shown in Figure 1, the US electric grid originally was designed to deliver power from large, centralized power plants to commercial, industrial and residential customers. Large generators supplied electricity to the transmission network, where it flowed over high-voltage power lines to substations, which stepped voltages down to lower levels (generally less than 60kV) and allowed for delivery to end users on the distribution network. In this model, power flows are largely unidirectional from producer to consumer, although some large industrial customers are also connected to the transmission network and can act as "prosumers:" that is, entities that both use and produce power. In deregulated markets, an independent system operator (ISO) manages the wholesale energy marketplace and ensures open access to the transmission network. Distribution utilities own and operate the distribution network, providing the infrastructure needed to supply electricity to end users in a particular service territory.

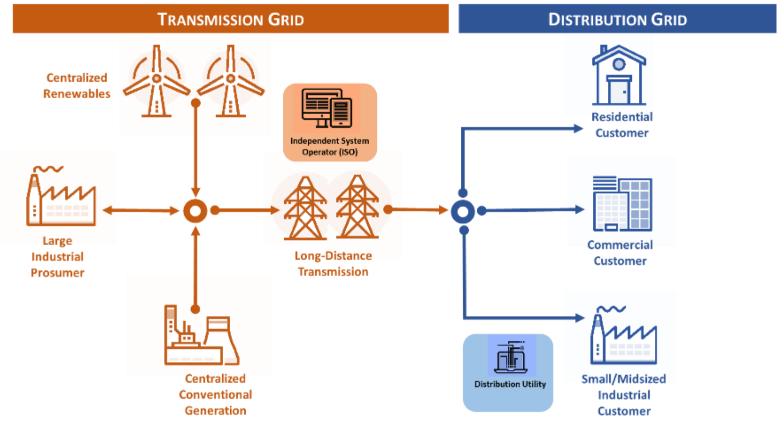

Figure 1: Traditional Electric Grid

However, requirements for the electric grid are evolving as new loads and generation sources are integrated on the distribution grid. Figure 2 outlines a future scenario in which the distribution grid appears radically different from the infrastructure that is in place today. New loads, such as electric vehicles, will be added and

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[4] Navigant Research, *Global Distributed Generation Deployment Forecast*, December 2014. Distributed generation is defined as solar PV (<1 MW), small wind turbines (<500 kW), stationary fuel cells, natural gas generator sets (<6 MW), and diesel generator sets (<6 MW).

[5] Solar Energy Industries Association. *Solar Market Insight 2015 Q4*. March 2016.Distributed solar is defined as modest-sized (<2 MW) rooftop photovoltaic deployments located at residential, commercial, and industrial sites and interconnected to the distribution grid.

[6] U.S. Department of Energy Combined Heat and Power Installation Database. https://doe.icfwebservices.com/chpdb/

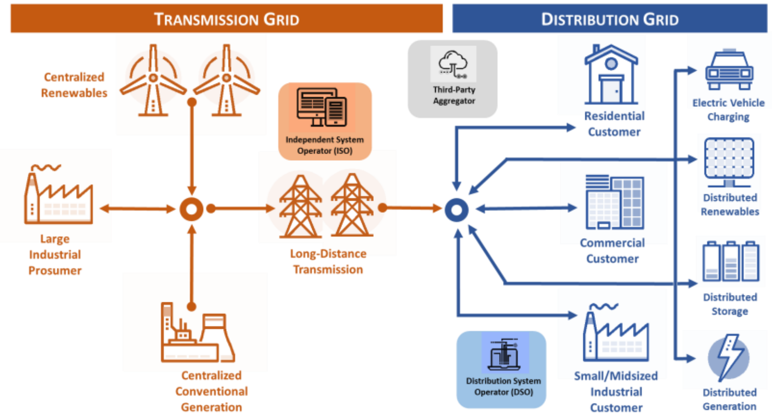

Figure 2: Future Electric Grid

will respond intelligently to signals from the grid, charging when demand is low and turning off when demand nears its peak. DERs, including distributed renewables (such as solar PV) and dispatchable distributed generation (such as reciprocating engines) will play a key role on the future grid, providing power that is co-located with residential, commercial, and industrial loads, and providing other services that increase the efficiency and reliability of the distribution grid. Distributed storage will also be deployed in the future; these units could be deployed on the customer-side or the utility-side of the meter, and will reduce transmission and distribution infrastructure requirements, maintain grid stability, and enhance resiliency of the electricity network. In this future scenario, many customers are prosumers, resulting in bi-directional power flows on many parts of the distribution network.

As deployments of DERs continue to grow, states including New York, California, and Texas are rethinking how these resources should interact with the electricity grid. A key objective of initiatives such as New York's Reforming the Energy Vision (REV) and Texas' Distributed Resource Energy and Ancillaries Market (DREAM) Task Force is to examine how DERs can play a greater role in increasing the efficiency and resiliency of the electric grid. In the future, customer-owned distributed generation assets are likely to play an expanded role on the electric grid by selling energy into wholesale markets, providing ancillary services such as frequency regulation, and supplying new products such as Volt/VAR support that support operation of the distribution network.

Yet few of the potential benefits of DERs have been realized on today's electric network, due mainly to existing market rules and regulatory structures that limit DER participation in electric grid markets. In fact, today's grid operators typically have limited interaction with small and mid-sized (~0.5 to 20 MW) generators, although some DERs participate in demand response and/or emergency response programs to reduce stress on large centralized generation facilities during periods of peak demand.

While proceedings are underway in several states, it remains unclear exactly how utility operating models, regulatory structures, and incentive frameworks will evolve in the future to accommodate DERs. However, what is certain is that DER penetration is growing, and tomorrow's distribution grid must be able to effectively integrate both dispatchable and variable DERs if it is to provide cleaner, more reliable, and more affordable electric power.

1.2 US DOE Interest in R&D for Dispatchable Distributed Energy Resources

For more than twenty years, the US Department of Energy's (US DOE's) Advanced Manufacturing Office (AMO) has worked closely with industry partners to research, develop, and deploy D-DER technologies, including CHP systems. As the role of D-DERs expands, AMO is exploring how best to prepare D-DER technology for tomorrow's electricity grid.

According to the DOE Quadrennial Energy Review (QER), the grid of the future will have to accommodate and rely on an increasingly wide mix of resources, including central station and distributed generation, energy storage, and responsive loads. It should support a highly distributed architecture that integrates the bulk electric and distribution systems, and it should enable the operation of micro-grids that range from individual buildings to multi-firm industrial parks that are capable of operating in both integrated and autonomous modes.[7]

D-DERs owned by small and medium-sized commercial and industrial enterprises (SMEs) are an important component in this vision of the modernized grid. Therefore, utilities and regulators have begun to evaluate the potential for leveraging DERs (including D-DERs) to provide services to the grid. Past assessments of DERs concluded that these resources could increase electric system reliability, reduce peak power requirements, provide ancillary services (including spinning reserve, Volt/VAR support, and black start capability), improve power quality, reduce land use for transmission line rights-of-way, and increase grid resilience to adverse events (including terrorism and extreme weather)[8]. By enabling greater use of renewable resources, DERs can also reduce emissions from power generation. [9] D-DERs located at SMEs could be especially valuable since, unlike solar and wind generation, the output of D-DERs can be precisely controlled and is available at any time during the day or night. As an increasing amount of non-dispatchable variable renewable power enters the grid, D-DERs can help provide the operational flexibility needed for grid operators to maintain system stability. Finally, D-DERs such as natural gas reciprocating engines, CHP systems, and fuel cells can have capabilities enabled to provide automated or coordinated control to support grid operations when abnormal voltage and frequency conditions occur.

Existing D-DERs are an underutilized resources that could provide additional services to the electric grid, and there is substantial potential for future D-DER systems to offer grid services as well. For example, the combined heat and power (CHP) export technical potential for SMEs is estimated at over 14.5 GW.[10] Moreover, if technological improvements can be made to D-DER technology, the business case for SMEs to invest in additional D-DER could be enhanced, resulting in additional D-DER deployments and greater availability of distributed resources that can support the electric grid. SMEs are ideal candidates to provide support for tomorrow's electric grid: they have substantial electric loads (1-20 MW), are familiar with D-DER technologies, and are located on distribution grids where deployment of other new technologies (such as solar photovoltaics and electric vehicles) will eventually have a dramatic impact on how the system operates. Therefore, the US Department of Energy's Advanced Manufacturing Office (AMO) is exploring research and development (R&D) pathways to improve the performance and reduce the cost of D-DER systems located at SME sites.

In particular, targeted R&D can improve the business case for CHP (one type of D-DER) to serve as a resource for satisfying onsite power demands and as well as injecting electricity onto the grid. For many sites, CHP technologies provide manufacturing facilities, commercial and institutional buildings, and communities with cheaper, cleaner electricity while also providing more resilient and reliable electric power and thermal energy. CHP systems can achieve overall energy efficiencies of 75% or more, compared to separate

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[7] U.S. Department of Energy, *Quadrennial Energy Review*. April 2015

[8] U.S. Department of Energy. *The Potential Benefits of Distributed Generation and Rate-related Issues that May Impede their Expansion.* February 2007

[9] U.S. Department of Energy, *Quadrennial Technology Review*. September 2015

[10] U.S. Department of Energy, *Combined Heat and Power (CHP): Technical Potential in the United States*, March 2016. This potential represents a CHP unit sized to meet the thermal load, with the facility selling excess electricity back to the grid. CHP systems provide the most benefit when sized to meet all of the thermal demand of a given facility. Technical potential is in addition to existing CHP capacity.

production of heat and power, which collectively averages about 50% efficiency.[11] To encourage greater use of CHP technologies, a recent executive order set a national target of 40 GW of additional CHP capacity by 2020, an increase of nearly 50% above the current installed capacity of 83 GW.[12]

Through its Grid Modernization Initiative (GMI), DOE is coordinating a portfolio of activities to realize a future grid that is resilient, secure, sustainable, reliable, and flexible enough to provide an array of emerging services while remaining affordable to consumers. As part of this cross-cutting initiative, the Office of Energy Efficiency and Renewable Energy (EERE) has a variety of programs to integrate residential, commercial, and transportation customers to tomorrow’s distribution grid, but has not yet focused on strategies to integrate small to midsized industrials (see Figure 3).

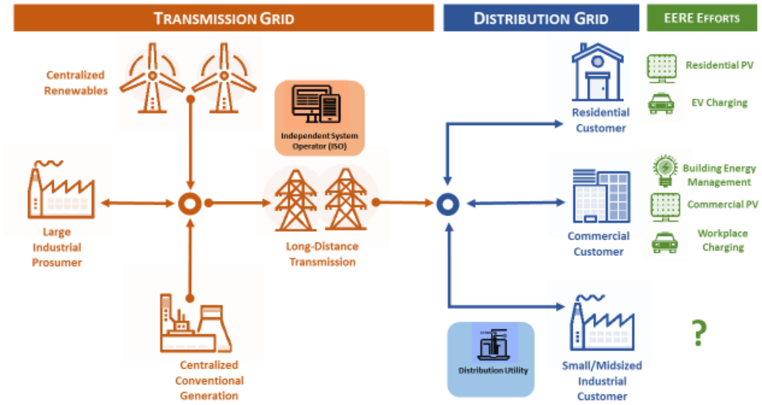

Figure 3: Current Grid and EERE Efforts

Large manufacturing plants already provide energy, capacity, and other services to the grid, although this support is mainly for the transmission network and is often in the form of demand reduction. At the distribution level, utilities and regulators have begun to evaluate the potential for leveraging DERs (including D-DERs owned by SMEs) to provide similar services. Small to midsized industrials represent an important area of “white space” worthy of further investigation. One objective of this workshop was to explore how technology R&D could enable greater SME participation in grid modernization.

1.3 Focus on Texas

Texas’ manufacturing sector includes nearly 18,000 firms producing over $230B worth of goods annually, including in energy-intensive sectors such as petroleum refining, chemicals, and primary metals production.[13] The state’s industrial power needs are served by a highly-competitive electricity sector that produces more electricity than any other state in the nation and incorporates over 32,000 GWh of wind generation annually.[14] After successfully integrating wind power on its state’s transmission grid, Texas is now adding solar to its transmission and distribution systems, interconnecting over 200 MW of solar in 2015 and placing itself in the top 10 of US states for solar deployments.[15] Installation of other DERs has been growing as well: as of 2014, the state had 17.5 GW in generation capacity from CHP installations, more than a third of which were small and mid-sized units (<10 MW) interconnected to the distribution grid.[16] As DER penetration continues to increase, the state’s electric grid is poised for rapid change.

According to Texas rules, DER units below 10 MW generally are not considered by the state’s system operator, the Electricity Reliability Council of Texas (ERCOT), in the planning and operation of Texas’

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[11] U.S. Department of Energy, *Quadrennial Technology Review*, September 2015

[12] U.S. Department of Energy, *Quadrennial Technology Review*, September 2015

[13] National Association of Manufacturers. *Texas Manufacturing Facts.* February 2015

[14] US Energy Information Administration. *Texas Energy Highlights.* 2014

[15] Solar Energy Industries Association. *Solar Market Insight 2015 Q4*. March 2016

[16] US DOE Combined Heat and Power Installation Database. https://doe.icfwebservices.com/chpdb/

wholesale electricity markets. Small and mid-sized generators can occasionally be called upon to provide energy during emergencies through ERCOT's Emergency Response Program, but otherwise are restricted from injecting power into the grid to participate in wholesale energy or ancillary services markets. While units above 1 MW are required to register with ERCOT, the ISO has limited visibility into the real-time activities of DERs, and no centralized dispatch of these resources is conducted during routine grid operations.

Instead, Texas DER owners determine how and when to operate their systems. To the system operator, DER operation appears as a reduction in load at the resource node where it is located. Recently ERCOT has seen an increasing number of D-DERs attempting to "chase" zonal prices: owners start up their D-DER units to satisfy some or all of their own local loads as energy prices in their area increase. While this may be a logical financial decision for SMEs who are capable of self-generation and interested in reducing their energy bills, this type of behavior limits the system operator's ability to accurately forecast load, a situation that could become increasingly problematic as DER penetration grows. This is because accurate load forecasting not only is needed for reliably operating the system on a daily basis, but also for planning capacity expansions of generation and transmission in the future.

In its analysis of DERs, ERCOT's DREAM Task Force developed and evaluated several future scenarios with increasing levels of DER penetration. The Task Force's "DER Heavy" scenario examined the most extensive DER interaction with the electric grid, which included dispatch of DERs by the ISO and full participation of DERs in ERCOT energy and ancillary services markets. Particularly in the DER Heavy scenario, several technical and market challenges[17] were anticipated, including:

1. Monitoring infrastructure to track real-time DER status and the impact of DERs on the electric system
2. Control mechanisms to control DER output to avoid under/over generation and potential damage to distribution and transmission system equipment
3. Consistent interconnection processes and tariffs for DERs across various distribution utility service territories
4. Standardized techniques to value DER activity and assess DER's ability to reduce the costs of transmission and distribution grid infrastructure
5. Mechanism to incorporate DERs into nodal price formation in the ERCOT market

1.4 Workshop Summary

On February 10-11, 2016, the United States Department of Energy's Advanced Manufacturing Office (AMO) convened a group of stakeholders in Austin, TX, to discuss what additional functionality and characteristics would be needed from D-DER technologies in the future for these systems to be able to play a larger role in providing services to the electric grid. AMO also asked stakeholders to identify the R&D pathways with the greatest potential to overcome technical barriers.

Approximately 50 participants from various stakeholder sectors attended. (A list of attendees is included in Appendix A). Key stakeholder groups are shown in Figure 4, and included industrial SMEs, third-party aggregators (TPAs), researchers from academia and national laboratories with expertise in DERs and related grid technologies, independent system operators (ISOs), suppliers of DERs and related equipment, and distribution utilities. While the workshop discussion focused on the Texas electric grid, many of the issues

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[17] For a more complete discussion of these issues, see ERCOT's *Concept Paper on Distributed Energy Resources in the ERCOT Region.* August 2015

that were identified are more widely applicable throughout the United States, particularly in regions where DER penetration is increasing.

Plenary session presentations and panel discussions on the morning of February 10th covered the market, regulatory, and technical opportunities and challenges for D-DERs as well as the capabilities of selected technologies. In the afternoon, participants formed two breakout groups to briefly discuss key non-technical challenges for D-DERs to play a larger role in providing services to the grid. They then continued their breakout sessions, focusing on identifying the key technical barriers and the R&D pathways that had the greatest potential to overcome these barriers. Topic areas explored included advances needed in generation systems, forecasting and optimization tools, power conditioning systems, telemetry and network systems, sensors, controls, and data processing technologies.

Upon reconvening on the morning of February 11th, workshop participants refined their concepts for R&D pathways to overcome the technical barriers they had identified the previous day. Each breakout group then condensed their findings and delivered a summary to the entire group of workshop participants. Discussion followed, and then each attendee was given an opportunity to voice closing remarks before the meeting adjourned at noon on the second day. After the workshop, additional discussions were held during the week of February 22, 2016, with stakeholders who were unable to attend in-person, including SMEs, communications technology vendors, and TPAs. The following sections of this report summarize key areas identified by workshop participants in which emerging technologies could perform an important role in stimulating D-DERs to play a larger role in providing services to the grid.

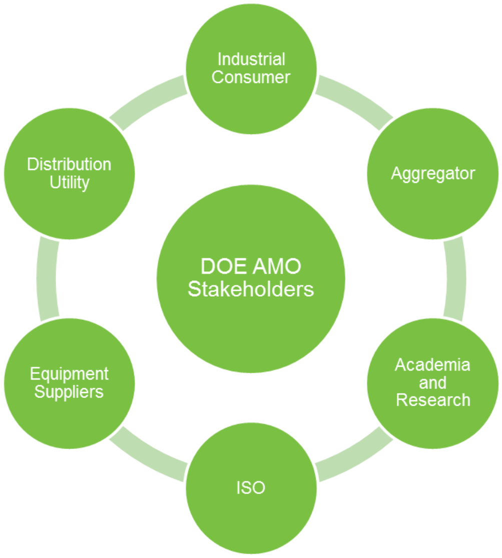

Figure 4: Key Stakeholder Groups

2. Opportunities in Generator Systems

2.1 Overview of Opportunities and Emerging Applications

The dispatchable distributed energy resources (D-DERs) discussed at the workshop included systems that used reciprocating engines, gas turbines and micro-turbines, and natural gas-fueled fuel cells. These systems can be deployed with or without heat recovery equipment, although for many users, use of both the electric and thermal output in a CHP configuration is essential to make the systems economically-viable. As with the purchase of any capital equipment, the decision whether to deploy a D-DER is based largely on its “business case” or expected return on investment. SMEs assess the current and future expected cost of electricity from the grid and also examine the current and future expected cost of thermal energy (such as steam for manufacturing processes). In addition, SMEs consider the value of additional D-DER benefits, including improved power quality and the ability to self-generate during grid outages. These benefits are weighed against the expected costs to purchase, install, and interconnect the D-DER, as well as the costs to operate the system over time, including fuel and maintenance. D-DER costs can vary substantially from site to site, and also depend on technology type: installed costs for gas turbine systems can be as low as \$1,200/kW, while costs for fuel cell systems can exceed \$6,000/kW.[18]

D-DER systems include the prime mover (such as a turbine), electric generator, heat recovery system, power conditioning systems (especially for fuel cells), and other balance of plant components. During the workshop, D-DER systems were referred to as "generator systems" to differentiate them from other technologies that do not directly generate electricity. Workshop participants discussed numerous technology innovations related to generator systems. Distinct innovations were proposed for all of the system components (prime mover, heat recovery system, power conditioning systems, etc.), but always with a consistent objective: to improve the D-DER's return on investment for its owner. Participants noted that improving the D-DER business case would make D-DERs more attractive for deployment by SMEs, thereby increasing installations and making D-DERs a more widespread resource for providing services to the electric grid. Improving the D-DER business case can be accomplished in a number of ways, including:

1. Increase system efficiency during steady-state operation, which decreases fuel consumption and operating costs
2. Redesign the generator system to provide additional products besides electricity and heat, such as hydrogen, that can be utilized in on-site manufacturing processes or sold to a third-party
3. Reduce the lifetime cost of generator systems by lowering capital cost, reducing operation and maintenance (O&M) costs, extending useful system life, or some combination of all of these
4. Enable new revenue streams from generator systems through participation in existing wholesale electricity markets, such as frequency regulation, or by offering services that may be purchased by an independent system operator in the future, such as black start capability
5. Enable new revenue streams from generator systems by offering services that may be purchased by the distribution utility in the future, such as Volt/VAR support
6. Provide enhanced fuel flexibility, such as the capability of running entirely on either a gaseous or liquid fuel

2.2 Key R&D Opportunity Areas

As noted earlier, workshop participants discussed a variety of innovations related to generator systems. This section does not attempt to capture every idea that was introduced during the breakout discussions, but summarizes the main opportunity areas for technology research and development that were identified during the workshop.

2.2.1 Technologies that Improve the Business Case for D-DERs by Increasing Efficiency in Steady-state Operation

Action #1: Leverage advancements in lean-burn automotive engines, including plasma ignition, corona ignition, laser ignition, and turbulent jet ignition systems to increase the efficiency of stationary reciprocating engines

Lean-burn engines operate with a higher air-to-fuel ratio, attaining higher fuel efficiency due to more complete fuel burn, increased ratio of specific heats of the working fluid, reduced throttling losses, and higher engine compression ratios. In use in the automotive sector since the 1980s, lean-burn technology continues to improve, particularly as automakers strive to attain increasingly strict fuel economy and emissions regulations. However, as air/fuel mixtures in lean-burn engines get more dilute, fuel ignition

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[18] U.S. Environmental Protection Agency Combined Heat and Power Partnership. *Catalog of CHP Technologies.* March 2015

becomes increasingly challenging. New ignition technologies can replace the conventional spark plug, which ignites fuel in one location using a small electrical arc, with devices that ignite fuel in multiple locations in the combustion zone. The objective of plasma ignition (which generates a pulse of ions and thus a larger ignition kernel), corona ignition (which generates multiple ion streams), laser ignition (which produces short but powerful flashes regardless of the pressure in the combustion chamber) and turbulent jet ignition (which produces distributed, fast moving jets of hot gas) and other advanced ignition systems is to achieve more rapid, stable, and complete combustion, yielding fuel economy gains of 10% or more. Much of the work in new lean-burn technologies, however, has been in gasoline engines for the light-duty vehicle segment, so effort will be needed to realize the same fuel efficiency improvements in natural-gas-fueled reciprocating engines for stationary power generation.

Action #2: Develop exhaust gas cleanup systems for ultra-lean-burn engines that address future potential emissions regulations, including tighter NO_x standards and methane slip

The high air-to-fuel ratio in lean burn engines results in lower combustion temperatures that decrease emissions of nitrogen oxides (NO_x) but yield higher emissions of hydrocarbons and carbon monoxide. To treat exhaust, conventional three-way catalyst systems cannot be used since they operate only with systems where air-to-fuel ratios are close to stoichiometric. Particularly for natural gas lean-burn engines, exhaust after-treatment systems such as selective catalytic reduction (SCR) are required to reduce pollutants to regulated levels, adding both cost and complexity to generator systems. Meeting strict NO_x regulations is already challenging for reciprocating engines, especially in regions such as the Los Angeles air basin where a .07 lb./MW-hr limit is imposed. Meeting future NO_x regulations will require further advances in emissions control technology, particularly in catalysts that operate at the lower exhaust temperatures that result from ultra-lean-burn combustion. In addition, future regulations could include limits on pollutants that are currently unregulated, including methane (a result of incomplete combustion of natural gas fuel) and ammonia (a result of over-injection of urea/water solution or inefficiency in catalytic ammonia oxidation in the SCR system). Addressing methane and ammonia slip will not only require advancements in exhaust after-treatment systems, but may also require changes to in-cylinder designs and investment in systems capable of managing more complex engine operating modes.

Action #3: Develop improved waste heat recovery systems, including more effective heat exchangers and chillers, that also have smaller footprints

Waste heat recovery systems increase the efficiency of a generator system by extracting heat that would otherwise be discarded to the environment and using that heat for additional electricity generation or to satisfy local thermal loads. Waste heat recovery is not new in power generation: reciprocating engines and turbines yield exhaust streams in the 250-650C range, and many large D-DER operators use steam boilers or other thermal conversion technologies to extract additional benefit from this resource. However, waste heat recovery systems tend to be best-suited for larger generators; scaling these systems down to operate cost-effectively with smaller (<10 MW) generators can be more challenging. In addition, SMEs often have limited physical space at their facility, making it more difficult to site bulky heat exchangers and other waste heat recovery components. Opportunities exist, therefore, to develop more compact heat exchangers and chiller components with improved heat transfer coefficients that have smaller physical footprints and are more suitable for deployment with modest-sized generators favored by many SMEs. New materials are one area of potential R&D, but additive manufacturing may also play an important role by enabling improved heat transfer through new geometries and/or surface finishes that cannot currently be produced using subtractive techniques.

Action #4: Develop lower-cost high-temperature thermal energy storage systems

One way to increase steady-state efficiency is to ensure that all the heat generated from a CHP system is fully utilized. If thermal loads do not exist when heat is generated, the heat can be stored for later use. Past projects have demonstrated the integration of D-DERs with thermal storage, generally at low temperatures (<150°C) using water as the storage medium. However, far fewer systems have shown the potential for high-temperature thermal storage (>500°C) in conjunction with a D-DER. Exhaust from turbines and reciprocating engines is a high-quality thermal resource that can be used to do more than heat water; it can also reduce the energy inputs required for high-temperature industrial processes. While traditional molten salt storage technologies may be used in conjunction with D-DERs, additional high-temperature storage media are also needed that match the temperatures required by industrial processes.

Action #5: Develop and pilot thermochemical exhaust heat recuperation systems that reform natural gas to enrich generator fuel

Enrichment of natural gas fuel with hydrogen has been shown to improve fuel efficiency and reduce NO_x emissions in heavy-duty vehicle engines when combined with high levels of exhaust gas recirculation (EGR).[19] This same approach could be applied to stationary reciprocating engines. Relatively few SME facilities are likely to have a hydrogen source, but natural gas can be reformed on-site through partial oxidation, steam reforming, or autothermal reforming, ideally using waste heat from the generator. In this type of thermochemical exhaust heat recuperation system, syngas (which consists of roughly 75% hydrogen) is then injected into the generator fuel stream, where it facilitates more optimal combustion and permits higher levels of EGR, which reduces combustion temperatures and NO_x generation. The introduction of hydrogen in the intake stream also improves the flame speeds of the mixture, thus increasing knock resistance. Experimental results with vehicle engines suggest that efficiency gains of as much as 10% are possible with simultaneous reductions in emissions. In addition, other approaches have been proposed that eliminate the need for external reforming, including dedicated EGR using in-cylinder reforming.[20] However, research is needed to validate these concepts in stationary engines using natural gas fuel.

2.2.2 Technologies that Improve the D-DER Business Case Through Manufacture of a Co-Product (in Addition to Heat and Electricity)

Action #6: Develop and pilot systems that produce transportation fuels using waste heat for reformation

D-DERs are traditionally viewed as providing two outputs: electricity for local electrical loads and heat for local thermal loads. However, waste heat from generators also can be used in reforming processes to convert natural gas into syngas that can then be upgraded into transportation fuels, including hydrogen, gasoline, and diesel fuel. These fuels could be used locally to operate an SME's own vehicle fleet, or they could be sold to a third-party to provide an additional revenue source. While this type of technology could be particularly attractive for SMEs who are large consumers of motor fuels, it is important to recognize that a fairly complex equipment train (including catalytic reactors and separators) is required to convert natural gas into liquid transportation fuels. Equipment for production of hydrogen fuel is somewhat less complex, although compressors and pressure vessels would be needed for gas storage. Potential research areas could include syngas production technologies that utilize existing prime movers (such as in-cylinder reformation) or that minimize the capital investment required to produce co-products. Few SMEs are interested in installing

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[19] For example, see Hosseini, et. al. "Natural gas spark ignition engine efficiency and NOx emission improvement using extreme exhaust gas recirculation enabled by partial reforming." *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automotive Engineering,* 222, 12, pp. 2497-2510, 2008

[20] Chadwell, et. al. "A Demonstration of Dedicated EGR on a 2.0 L GDI Engine." SAE International Journal of Engines 7, 1, pp. 434-447, May 2014

specialized equipment that is unrelated their core business areas, unless the equipment is reliable, easy to operate, and has a clear return on investment. While transportation fuels could be an important co-product from D-DERs, substantial development and demonstration of fuel production systems is needed before they will be adopted by a large number of SMEs.

Action #7: Develop and pilot systems that produce fresh water through desalination using waste heat

Just as waste heat from D-DERs can be used to produce transportation fuels, it can also be utilized to produce fresh water at facilities with access to seawater or saline aquifers. In areas of the United States that suffer from stressed water supplies, this may be an attractive option, particularly for SMEs that use large amounts of fresh water in their industrial processes. Small-scale (4-6m^3/day) modular desalination units that use membrane distillation are already commercially-available.[21] In addition, a variety of other technologies, including vacuum distillation and forward osmosis, have been proposed as the basis for small-scale systems that could be co-located with D-DERs. However, as noted earlier, an SME's primary concern is efficient manufacture of its core products, not production of other goods such as fresh water. Modular desalination units must have a clear return on investment, operate reliably, and be easy to run and maintain before they will be widely deployed by SMEs. Additional development and demonstrations are likely needed to attain this level of performance.

Action #8: Develop forecasting and optimization tools that allow an SME to simultaneously deliver electricity, thermal energy, and co-products

SMEs who add equipment to produce co-products from D-DERs must then determine how much of the co-product to produce. Demand for the co-product must be balanced against the need to satisfy local electric and thermal loads, as well as the need to supply electricity to the grid to satisfy bids in wholesale energy markets or resource commitments made to the distribution utility. While tools currently exist to forecast site electrical loads, in the future SMEs will need more sophisticated forecasting technology that generates a comprehensive demand forecast for electricity, thermal energy, and co-products. The forecast could then be used to optimize D-DER operation, determining how much electricity, thermal energy, and co-products to produce at a given time to maximize economic returns. While improved forecasting and optimization tools are needed, there was some debate among workshop participants about who would use these tools and whether they could be "open source" tools that were made widely-available once they were developed. Some SMEs have begun to rely on third-party aggregators (TPAs) or energy management companies to forecast load and optimize D-DER operation, and it is likely that SMEs with more complex energy challenges (including those producing co-products on-site) would seek assistance from these third parties. While TPAs are interested in improving their forecasting models and optimization algorithms, these tools are considered a source of competitive advantage and therefore would unlikely be released publicly even if developed with US DOE assistance.

2.2.3 Technologies that Improve the D-DER Business Case through Reduction in System Cost

Action #9: Develop modular D-DER with standardized generator system components

Workshop participants noted that installed costs for a given D-DER technology vary substantially from site to site, and attributed some of this variation to the high degree of system customization that often occurs. While some customers have truly unique system requirements that demand special attention, many D-DER

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[21] For example, see SolarSpring MMD Desalination Systems Product Specification Sheet. http://www.solarspring.de/fileadmin/templates/solarspring/Downloads/MMD_DesalinationSystems_SolarSpring2011.pdf

deployments could benefit from greater standardization in the equipment that is used. For example, in CHP systems, components including the prime mover, electric generator, heat recovery systems, chillers, thermal storage systems, and power conditioning systems are typically selected and then integrated "in the field." However, if a standard set of components were chosen, factory integration and testing could be performed on those components before delivery. The result would be a cheaper, more reliable turnkey system that would improve the business case for D-DERs.

Action #10: Develop D-DERs with longer maintenance intervals, lower maintenance costs, and longer useful lives

Operations and maintenance (O&M) costs (not including fuel) can range from less than $.01/kWh for rotating machinery to nearly $.04/kWh for high-temperature fuel cells.[22] While these costs may appear modest, it is important to note that average wholesale energy prices were below $.04/kWh in ERCOT in 2015. Thus, generators must have very low operating costs to remain competitive. Technologies that extend maintenance intervals can increase D-DER capacity factors and ensure that generators are online during the periods when prices are most attractive. In some cases, required maintenance may not be to the prime mover itself, but rather to other components such as exhaust after-treatment systems. Technologies such as passive SCR[23], for example, would eliminate the need to periodically add urea/water solution to the emissions control system, reducing both the materials and labor required during system maintenance. In addition, innovations are needed to extend the operating intervals for both rotating machines and fuel cells before overhauls of major components are needed. Solid oxide fuel cells, for example, typically require replacement of stack components after 2-3 years of usage, and the combined cost of parts and labor can substantially alter the return on investment for these systems.

Action #11: Conduct survey of regional D-DER deployment (with best practices) to reduce deployment risk for potential D-DER owners

Like solar PV installations, D-DER projects include substantial "soft costs:" non-hardware expenses including costs for system design, permitting, site preparation, installation, and interconnection to the grid. While typical hardware costs for a 1-4 MW stationary turbines are $400-800/kWh, installed costs for those turbines exceed $2500 when a full accounting for soft costs is included.[25] Interconnection to the distribution grid can be particularly costly depending on level of study the local utility requires and the type of ancillary equipment (such as transfer trip systems) the utility deems necessary to install in conjunction with the D-DER. In addition, soft costs can vary substantially from one location to another, even when the same generation technology is used. Thus, the cost of D-DER deployment can be somewhat unpredictable, especially for SMEs who have not previously interconnected generation equipment. While greater uniformity in local permitting requirements and utility interconnection procedures is needed in the long-term to boost D-DER deployment, shorter-term actions can also assist owners and potential owners of D-DER equipment. One recommendation is a survey of existing D-DER deployments that catalogs costs (both hardware and soft costs), summarizes interconnection procedures, and outlines best practices in permitting and installation of D-DER systems. This survey would reduce risk for SMEs who are considering D-DER deployment by establishing a clear cost baseline that is grounded in real deployments.

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[22] U.S. Environmental Protection Agency Combined Heat and Power Partnership. *Catalog of CHP Technologies.* March 2015

[23] For additional information, see Kim, et. al. *Catalyst Design for Urea-less Passive Ammonia SCR Lean-Burn SIDI Aftertreatment System.* Presentation at 2010 DEER Conference. September 28, 2010

[25] US Department of Energy. *Onsite Distributed Generation Systems for Laboratories.* September 2011

2.2.4 Technologies that Enable Participation in Transmission Grid Markets (such as 5-minute Ramping) that Require Transient Operation, Often at Partial Load

Action #12: Integrate thermal energy storage with D-DERs to decouple electric output from thermal output

CHP units generally are sized for specific electric and thermal outputs, and are run at under steady-state conditions to attain high efficiency as well as to comply with local emissions regulations. Certain grid services, however, require frequent changes in the amount of delivered power. For example, frequency regulation responds to a 4-second signal in the ERCOT market, so generators providing this service must be prepared to vary their output every four seconds according to automatic generation control (AGC) signal guidance. With increasing renewables penetration, "flexible" generation that can vary its output is likely to become more important in the future. New products and compensation schemes, such as a proposed five-minute ramping reserves service in the ERCOT market, are likely to develop to reward generation resources that can vary output and respond quickly to changing energy needs on the electricity grid. To increase the responsiveness of CHP systems, these systems can be paired with thermal storage. When additional electricity is required, less heat can be generated by the CHP system and local thermal loads can be served by stored heat. When less electricity is needed, the system can generate additional heat and store this resource for later use. While combining thermal storage and CHP is not a new concept, thermal storage is not typically utilized to allow for regular variation in CHP electricity output, and demonstrations of this concept would be beneficial to illustrate the potential for CHP systems to serve as flexible grid assets.

Action #13: Integrate battery energy storage with D-DERs to decouple electric output from thermal output

Similar to the discussion of thermal energy storage above, battery storage can also be integrated with D-DERs to enable these units to accommodate regular fluctuations in output necessary to provide certain grid services. When properly sized, a storage battery could respond quickly to changes in generation requirements, while the D-DER output could change more slowly to preserve operating efficiency and ensure compliance with emissions regulations. Demonstrations of this concept would be beneficial to illustrate the potential for CHP systems to serve as flexible grid assets, and would emphasize joint control and optimization of the D-DER and storage device to deliver a coordinated response for grid support.

Action #14: Reduce startup times for ultra-lean burn engines and improve load-stepping capability

As flexibility becomes increasingly important for D-DERs, rapid cold start and hot start for reciprocating engines will be essential so the units can be turned off during periods of lower electricity demand and rapidly turned back on when load increases. While conventional rich burn engines have rapid startup times (< 1 minute to rated power), lean-burn engines require longer startup times (< 10 minutes to rated power under hot start conditions) due mainly to their lower combustion temperatures and longer periods needed for stabilization of lubricants and coolant systems. In markets such as ERCOT where real-time prices are calculated on a five-minute basis, generators that can be brought online within 1-2 minutes can respond quickly to high prices, thus increasing revenue for the D-DER owner and improving the business case for D-DERs while also helping to moderate high prices within the wholesale market region.

Action #15: Improve the efficiency of rich-burn engines without sacrificing transient load performance and rapid start capability

Rich-burn engines operate at near stoichiometric air-fuel ratio and employ an inexpensive three-way catalyst for mitigating emissions of nitrogen-oxides, carbon monoxide and unburned hydrocarbons. Rich-burn engines can be valuable grid support assets as they are able to start rapidly when compared to lean-burn engines. Rich-burn engines are also more effective than lean-burn engines for applications that require rapid load stepping (or load changes). However, the efficiency of the rich-burn engines is lower than lean burn engines, often by 10% or more for smaller-sized (1-2 MW) engines. However, new combustion technologies such as stoichiometric spark-assisted compression ignition (SACI), which employs a large amount of cooled exhaust gas recirculation (EGR), can be used to improve the efficiency of rich-burn engines. The SACI combustion strategy uses a combination of auto-ignition and flame propagation to facilitate reliable combustion when the unburned gas temperature is too low for stable auto-ignition and the gas mixture is too dilute for stable flame propagation. SACI combustion with cooled EGR can yield better efficiency than a traditional spark-ignited rich-burn engine. NO_x emissions under this combustion mode are lower due to lower combustion temperatures and since the mixture burns at stoichiometry, and an inexpensive three-way catalyst can still be implemented to mitigate emissions. Advanced combustion strategies such as SACI are currently under development for automotive applications, but additional R&D is needed to extend these approaches to natural-gas-fueled engines for stationary generation.

2.2.5 Technologies that Enable Participation in Future Distribution Grid Markets

Action #16: Develop D-DER systems that provide Volt/VAR support for the distribution system

Reactive power (VAR) is a component of alternating current (AC) electricity that sustains voltage levels on the transmission and distribution grid. Reactive power is provided by dynamic resources, such as large centralized generators, as well a static resources such as static VAR compensators and capacitor banks. While D-DERs generally do not provide Volt/VAR support on today's distribution system, in the future these resources could assist in sustaining distribution system voltage. Using D-DERs for Volt/VAR support would provide several benefits, including reducing the need for static VAR resources on the distribution network, and also freeing up space on transmission lines as less reactive power is sent from central station generators.[26] In addition, the dynamic VAR resource from local D-DERs could provide more rapid response to voltage anomalies that occur on the distribution grid, providing better stabilization during contingency events than the static resources that are in place today.[27] Both generators and power conditioning systems can provide reactive power, and work remains to identify the best integrated D-DER solution to provide Volt/VAR support to the distribution network. Potential technical challenges include monitoring and control to ensure rapid D-DER response to changing reactive power conditions, development of power conditioning systems with very fast (<10 ms) times, as well as development of cost-effective power electronics that integrate with small generators. Participants also noted that substantial non-technical challenges exist in this area: distribution utilities are not accustomed to relying on third-parties for Volt/VAR support, and compensation schemes do not exist within Texas utility grids to compensate D-DER owners for providing this service.

Action #17: Develop D-DER systems that provide increased power quality for the distribution system

Just as D-DERs can provide reactive power, they also can play an important role in moderating power quality issues on the distribution grid, including voltage sags, phase imbalances, frequency excursions, and other disturbances. While these incidents tend to be very rapid, their consequences can be substantial: one estimate places the annual economic impact of these "momentary interruptions" for the United States at over $50B.[28] Because many power quality issues originate in customer loads or in resources on the

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[26] US Department of Energy. *The Potential Benefits of Distributed Generation and Rate-related Issues That May Impede Their Expansion.* February 2007

[27] US Department of Energy. *The Potential Benefits of Distributed Generation and Rate-related Issues That May Impede Their Expansion.* February 2007

[28] LaCommare and Eto. *Understanding the Cost of Power Interruptions to U.S. Electricity Consumers.* Lawrence Berkeley National Laboratory Publication 55718. September 2004

distribution grid, they are often best addressed by local distributed solutions.[29] D-DERs, therefore, could play an important role in maintaining power quality on the distribution grid. However, as noted earlier in the discussion of Volt/VAR support, integrated D-DER/power electronics solutions that are cost-effective and that offer very rapid response to grid abnormalities must be developed to provide this service. In addition, a new mechanism will need to be devised in order for D-DER owners to be compensated for providing this service to the distribution grid.

2.2.6 Technologies for enhanced D-DER resiliency during emergencies

Action #18: Develop bi-fuel reciprocating engine technology

Reciprocating engines are typically optimized for a particular fuel. While compression ignition engines have been developed that operate on a mixture of diesel and CNG (such as diesel pilot-injection engines), these units cannot operate exclusively on natural gas. A bi-fuel engine that was capable of running exclusively on CNG and exclusively on diesel would offer increased flexibility, particularly when providing backup power. This D-DER would be fueled with natural gas during normal operation, but could be operating using diesel fuel during emergency events, especially events such as earthquakes or other natural disasters in which the natural gas transmission network was compromised. Using this technology, D-DERs would be better positioned to continue to generate electricity during extreme grid events, and to serve as black start resources for grid recovery after natural disasters. However, the technology to allow use of either a gaseous or liquid fuel in a compression ignition engine will be challenging to develop, and it was noted that at least one manufacturer abandoned development of this technology due to limited market demand. Further, bi-fuel D-DERs could encounter regulatory resistance due to the potential for fuel switching and increased emissions during normal operation.

3. Opportunities behind the Meter

3.1 Overview of Opportunities and Emerging Applications

Power conditioning systems and switchgear enable generating hardware to deliver electricity to the grid. Power electronics technologies convert electric power from one form to another; for example, converting between direct current (DC) and alternating current (AC), converting between different voltage levels, and/or providing specific power qualities required by loads. Only a small fraction of D-DERs on the grid today are directly integrated with power electronics devices, but we are likely to see much higher penetration levels of power electronics-based generators in the future.[30] Workshop participants highlighted a few ways that these devices could improve the D-DER business case for SMEs.

First, power conditioning systems can allow D-DERs to provide grid stability by remaining connected during abnormal grid conditions (such as brief periods of low voltage) while ensuring safety by de-energizing or isolating and islanding during longer-duration events when the distribution grid goes down. These capabilities could serve a dual purpose of improving the revenue potential of the D-DER while protecting the generator systems from damage that could result in costly missed production runs and/or equipment repairs. Second, power electronics could allow D-DERs to contribute to the overall stability of the grid through both frequency

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[29] US Department of Energy. *The Potential Benefits of Distributed Generation and Rate-related Issues That May Impede Their Expansion.* February 2007

[30] National Institute of Standards and Technology. Power Conditioning Systems for Renewables, Storage, and Microgrids. http://www.nist.gov/el/smartgrid/powercon.cfm

and Volt-VAR support to improve the overall power factor, potentially adding valuable revenue streams to SMEs' operations where these services can be sold into wholesale markets. Third, power electronics and switches are needed to enable rapid on-off switching of D-DERs, which will be important as SMEs manage an increasing number of onsite DERs.

However, power electronics and switching can account for a significant part of the total capital cost of a typical D-DER system, in some cases as much as 40%. In addition, power electronics are often the least reliable part of the system, often failing after less than five years of operation.[31] Poor reliability of any component can negatively impact the business case for D-DERs, both by reducing capacity factor and by requiring costly equipment replacements. Therefore, improving the return on investment for future D-DERs that incorporate power electronics will require development of converters, inverters, and switches that are more reliable and less costly. In addition, technical advancements are needed that afford greater protection of distributed generators from grid abnormalities, and that enable rapid on-off switching of D-DER to allow greater integration with the distribution grid.

3.2 Key R&D Opportunity Areas

As noted earlier, workshop participants discussed a variety of innovations related to power conditioning systems and switchgear and assessed how these devices could improve the D-DER business case for SMEs. While this section does not capture every idea that was introduced during the breakout discussions, it outlines the main opportunity areas for technology research and development that were identified during the workshop.

3.2.1 Technologies that Protect the Generator and Allow Greater Integration with the Distribution Grid

Action #19: Develop power electronics with more robust AC/DC fault protection and the ability to isolate D-DERs from grid voltage abnormalities and allow ride through of under/over voltage

The interface between the distribution grid and D-DER needs to be robust enough to withstand many different abnormal grid conditions such as faults, frequency distribution, and voltage sags. During short duration events, D-DERs should remain online, protecting themselves from anomalies and supporting the distribution system when possible. During longer events, D-DERs should be able to separate from the grid, continuing to serve local loads while avoiding back feeding of power onto the de-energized distribution system circuit. Both rotating machine generators and fuel cells require protection. In addition, power electronics reliability needs to be improved: converters are the most common piece of equipment to fail on the electric grid system.

Action #20: Improve inverter/generator communication and standards to stay connected to the grid during abnormalities and maintain synchronous operation of generator system

Abnormal conditions can cause inverters to trip offline. This is particularly the case at high levels of DER penetration where it is a challenge to maintain reliability with many inverters stacked together. Current interconnection standards address issues such as response to abnormal conditions, power quality and islanding, but are not tailored to D-DERs that would need to maintain connection and synchronous operation.

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[31] W. Kramer, S. Chakraborty, B. Kroposki, and H. Thomas, *Advanced Power Electronic Interfaces for Distributed Energy Systems, Part 1: Systems and Topologies*, Technical Report NREL/TP-581-42672, March 2008

Such improvements could reduce hazards when a connected inverter feeds into an unpowered grid and prevent loss of revenue when an inverter unnecessarily disconnects from an active grid.

Action #21: Develop inverter technology with rapid response time within 20-30 Hz (1/2 cycle at most) that provides synthetic inertia, governor response[32], and phase balancing with VAR injection and allows for communication and networking between interface and grid operator

Abnormalities in frequency can be very expensive; therefore there is an opportunity for generators to provide frequency regulation service. However, current inverter technology reads data at approximately four-second intervals, which is insufficient: inverter technology needs to respond within ½ cycle. With a more rapid response time, the generator could provide synthetic inertia, governor response, and Volt-VAR support in markets where these services are either required for interconnection or where providers can receive compensation. In particular, wider adoption of silicon carbide-based semiconductors could allow increased inverter switching frequencies, leading to faster response to controls. Future inverters for D-DERs also require improved communication and networking with the distribution grid operator so that the operator can have a granular level of real-time visibility in order to dispatch these services. However, unlike conventional generation, synthetic inertia could be programmed in the inverter.

Action #22: Reduce costs of large inverters typically used with D-DER units greater than 1 MW

The cost of inverters used for power conditioning on larger DER units can be prohibitive. This can have a negative impact on the D-DER business case for SMEs who are considering connecting their generator to the grid for dispatchable electricity. Since a more limited number of power electronics devices are made at this size, costs remain high, but could come down if more of these units were produced driving economies of scale. However, technological advances could be made such as reducing part count and/or reducing material requirements that could lower costs. Silicon carbide-based semiconductors allow operation at higher voltages and higher frequencies than silicon insulated gate bipolar transistors, reducing the number of components and cooling requirements, thus decreasing system cost.

3.2.2 Technologies that Enable Continual On-Off Switching of D-DERs

Action #23: Develop new switching or braking capability to replace mechanical switches

The ability of a synchronous power system to return to a stable condition and maintain its synchronism following a relatively large disturbance is referred to as transient stability. When the synchronous generator is fed with a supply from one end and a constant load is applied to the other, the machine at this instance is considered to be running under stable condition. If load is suddenly added or removed from the machine, the rotor decelerates or accelerates accordingly with respect to the stator magnetic field, and the operating condition of the machine becomes unstable. Moreover, the switch contacts of a mechanical relay will wear down rapidly from arcing after many cycles of on and off switching, necessitating costly replacement. Therefore, longer-lasting switching or braking technologies that improve transient stability could allow synchronous D-DERs to continually come on and off the electric grid system. Electronic or hybrid breakers could also be developed to reduce transients and prevent arcing damage.

Action #24: Increase capability to control multiple DERs at a single SME site

Different types of DERs (including renewables as well as D-DERs) operate at varying time-scales. Moreover, each site has a unique mix of these systems and load characteristics. Operators are challenged to ensure

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[32] Delille, Uthier, Bruno Francois, and Gilles Malarange. "Dynamic frequency control support by energy storage to reduce the impact of wind and solar generation on isolated power system's inertia." *Sustainable Energy, IEEE Transactions on* 3, no. 4 (2012): 931-939

these systems work in a coordinated fashion so that the required power level and load demands are met seamlessly. Operators must also optimize DER operation for transient power requirements demanded by the grid. Therefore, new control technologies are needed to better manage the rapid switching on and off of multiple DERs. Potential technological solutions include improved control architectures, algorithms, and forecasting tools. For example, models are needed to provide insight into the best DER operational strategy based on a known or assumed future load profile.

3.2.3 Publications and/or Standards that Reduce D-DER Soft Costs

Action #25: Conduct a public study outlining best practices in distribution system interconnection for D-DERs, including equipment requirements (transfer trip, etc.) and review of interconnection functionality of various equipment installed on the grid and available in the marketplace

The cost for a simple D-DER interconnection to the distribution system can run in the thousands of dollars. More complex hookups can cost much more, decreasing return on investment for D-DERs and deterring manufacturers from deploying additional units. Costs and practices can vary widely across the country, and owners of D-DER assets often lack information to make informed decisions about connecting to the grid. A public study identifying best practices in DER system interconnection and outlining typical interconnection costs (including equipment requirements) could provide these owners with information that would simplify DER business case development and yield more predictable outcomes when connecting D-DERs to the grid.

4. Opportunities Throughout the Rest of the Plant

4.1 Overview of Opportunities and Emerging Applications

Sensors, controls, communications equipment, and forecasting tools are the enabling technologies that can allow an industrial customer or third-party aggregator to provide grid services while concurrently meeting the thermal and electrical requirements of the manufacturing plant. These technologies play important roles such as measuring the amount of electricity consumed, monitoring the state of equipment, allowing for the analysis of performance information, and permitting rapid changes in system operation through automatic controls or operator intervention.

Workshop participants predicted that grid operators will require real-time (e.g. four-second intervals) information on D-DER operation at manufacturing sites that provide grid services. Participants also agreed that simultaneous control of onsite load requirements and generation to provide offsite grid services could be enhanced if control systems had access to additional information about generator systems (such as temperature, speed, pressure, and voltage). However, because sensor and control technologies require investment, SMEs will assess the expected benefits from this equipment and weigh them against the deployment cost.

In particular, the high lifecycle costs for sensors can be a barrier to investment. Secondary communications networks for delivery of sensor data can also add cost, yet these networks are often required when SMEs are working with third-party aggregators to manage energy consumption and D-DER output. Workshop participants mentioned the need for technical advancements to reduce the cost and increase the durability and reliability of sensors and communications technologies. Many participants also believed that more transparent information on equipment costs for telemetry, metering, and communications equipment and best practices for installation could reduce cost, therefore improving the business case for D-DERs at manufacturing sites.

Finally, participants pointed out that forecasting at the micro-grid scale has proven to be difficult, since loads on these systems exhibit high levels of variability relative to their mean. Under-prediction of peak demand in particular is important as it can increase electricity generation costs and block opportunities to provide electricity services to the grid when they are in greatest demand, and therefore most valuable. One suggestion was that AMO fund the development of improved simulation and forecasting tools (including new algorithms) to allow industrial customers to forecast on-site load, retail tariffs, and wholesale market conditions. However, third party aggregators are most likely to provide this service and consider algorithms proprietary.

4.2 Key R&D Opportunity Areas

As noted earlier, workshop participants discussed a variety of innovations related to sensors, controls, communications equipment and forecasting tools critical to dispatch D-DERs to the grid while meeting onsite power demands. While this section does not capture every idea that was introduced during the breakout discussions, it outlines the main opportunity areas for technology research and development that were identified during the workshop.

4.2.1 Technologies that Allow for Optimization and Control of Loads and Generation by SME or Aggregator

Action #26: Reduce the cost and increase the durability of self-powered sensors that enable an industrial customer or third-party aggregator to provide grid services while simultaneously meeting the thermal and electrical requirements of the manufacturing plant

The ability to sense and monitor multiple electrical characteristics in near real time and feed this information to control systems enables better operation of any power system. Distributed generator systems are poorly controlled for the dual task of supporting onsite demand while simultaneously providing grid services. Control of loads and generation could be enhanced if control systems had access to additional information about D-DERs such as temperature, speed, pressure, and voltage. Collecting data with current sensor technology can be cost-prohibitive, whether data is collected by wired sensors or wireless sensors that cost roughly \$150–\$300 per node.[33] Furthermore, there is an issue of durability and self-powering as many of these sensors would need to be placed in extreme operating environments and at multiple points on the D-DER system.

Action #27: Reduce cost of secondary communications networks (often installed by aggregators) to increase D-DER return on investment

Third-party aggregators often have to build secondary communication networks at client sites. There are significant costs to connect the sensors, controls, and meters in a communications network such as wiring, wireless devices, and sensors which can combine to be too expensive for sufficient return on investment. Research should examine reducing the costs of these components, and also at ways to more seamlessly integrate micro-grid communications networks with current systems already at a site without negatively impacting the functionality and security of these systems.

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[33] Oak Ridge National Laboratory, “Innovative, lower cost sensors and controls yield better energy efficiency,” *Building Technologies Update*, March 2015

4.2.2 Publications and/or Standards that Reduce D-DER Soft Costs

Action #28: Deliver a public study that provides transparency on costs for telemetry, metering, and communications equipment, as well as best practices for installation

Advanced metering, telemetry, and communication equipment can be costly. As the accuracy and interval frequency of the communication requirements increase, the costs also increase.[34] The share of telemetry costs relative to the total costs of capacity will be greater for smaller assets like DERs as compared to traditional centralized generating assets for the same telemetry requirement. Moreover, these costs vary substantially between DER sites. Manufacturers with onsite DER are focused on their core business of fabricating products and are unfamiliar with the functionality, costs and best installation practices of telemetry. A public survey and study providing greater transparency on equipment costs, as well as cost-effective practices to connect this equipment, would be an important resource for SMEs as they consider how and where to deploy new D-DERs.

4.2.3 Forecasting Tools for SMEs and/or Aggregators

Action #29: Develop improved simulation and forecasting tools (including new algorithms) to allow industrial customers to forecast on-site load, retail tariffs, and wholesale market conditions

Well-developed forecasting tools can give an industrial operator the capability to model what the plant will do in a given day, evaluate tradeoffs, and schedule participation in wholesale energy markets and provide other services to the grid in a timely manner (including real-time). Industrial operators will require tools that forecast on-site load in conjunction with wholesale market conditions on the grid. The tools also need to forecast at different time scales (e.g. real-time, day-ahead, etc.) Too often there is a lack of sufficient data as most manufacturing sites do not have sub-metering or enough sensors around the DER system to make accurate predictions. As stated previously, peak under-prediction, in particular, is a critical metric for the effectiveness of a prediction model. Development of improved, open-source algorithms could also improve forecasting accuracy; however it should be noted that third-party aggregators are likely to provide this service and consider algorithms to be proprietary, so the role for US DOE may be limited in this area.

5. Opportunities Outside the Plant Fence

During the workshop, participants provided suggestions regarding R&D needs in technologies that would be employed by distribution utilities, such as communications systems, DER controls, and grid modeling software to maintain system connectivity, reliability, stability, and continuous service. However, given AMO's mandate to focus on the manufacturing sector, technologies "in front of the meter" are unlikely to receive significant R&D funding from AMO. However, other DOE programs (including the Office of Electricity Delivery and Energy Reliability) should consider these suggestions in their future program planning. While no specific actions are proposed for these technology areas, a summary of high-level findings is provided below.

5.1 Overview of R&D Opportunities and Emerging Applications

Electric grid system operators monitor the state of the power system and control assets on that system to balance generation and load. The main tool of these operators is the Supervisory Control and Data Acquisition (SCADA) system made up of a centrally located master computer, multiple remote terminal units

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[34] DNV GL, *A Review of Distributed Energy Resources*, report for NYISO, September 2014

(RTUs), telecommunications equipment, sensors, and controls throughout the system. Distribution management systems (DMS), an expansion of SCADA capabilities, monitor grid system conditions to ramp up and down generators based on best economics and system reliability factors. Planning software that incorporates elements such as load forecasting, generation schedules, and unit outage situations provides the data on which the DMS controls the dispatch of generation.

Workshop participants pointed out that as system operators increase interaction with small and mid-sized (~0.5 to 20 MW) D-DERs connected to the distribution grid—and particularly as these generators sell an increasing amount of ancillary services and energy into wholesale markets—the system operator will require real-time information into the operating status of D-DERs. Currently, distribution management systems update relatively infrequently (often every hour) while future systems will require information on the state of D-DERs in real-time (every 1-4 seconds). Furthermore, it was mentioned during the workshop that although all large power plants are currently monitored, the status of most D-DERs is not monitored because presently the telemetry equipment required for this type of monitoring is cost-prohibitive for smaller generators. These factors point to the need for technological advancements that will lower the cost and increase the durability of communication and control technology used by grid system operators.

The need for improved grid modeling programs also was discussed at the workshop. As more DERs are connected to the grid, improved software tools will be required to profile and forecast loads, analyze current system operating conditions in real-time, assess system reliability and security, and other analyses to ensure stable system operation. In particular, participants explored the need for predictive behavioral models that would allow a distribution utility or system operator to forecast grid impact before a new DER unit is interconnected. The model would utilize all available measurements and other relevant information to calculate the best possible estimate of the future status of the power system after a proposed DER unit is brought online. Processing, simulation, and validation of the model at a local level could allow for expansion to a national level so “what if” scenarios of higher penetration levels of DERs could be performed. Such a tool could be useful for making better investments in the grid system. For a model of this type to provide the accuracy a grid operator requires, better sub-meter data than is generally available would be needed.

6. Non-Technical Challenges to D-DER at Manufacturing Sites

In addition to exploring technical barriers and R&D opportunities, workshop participants briefly identified and discussed some of the key policy, regulatory, and business issues they thought were important to future diffusion of D-DERs in the market. While to goal of the workshop was to identify promising areas for technology R&D rather than to develop solutions for market and policy challenges, AMO recognizes that technology development alone will not be sufficient to increase D-DER penetration. Key non-technical challenges were captured during a brief facilitated session and are presented below.

1. Small and midsized enterprises (SMEs) often avoid investing in D-DER because it is not their core business
    a. The decision to make necessary investments and deploy D-DER are mainly based on expected return of investment, but SMEs lack experience assessing this
    b. SMEs also lack experience in making broader cost-benefit analysis; e.g. risks to core business operations vs. additional benefits like improved power quality and ability to self-generate during grid outages

2. The lack of wholesale electricity market rules for D-DERs means D-DERs cannot monetize provision of many potential grid services

    a. There is a disincentive for both utilities and SMEs to develop and/or adopt new D-DER technologies if market framework does not exist, or if there is substantial uncertainty in how market rules will be structured in the future

3. A patchwork of policies, regulations, and electricity prices in different states and markets leads to uneven D-DER adoption
    a. Renewable energy targets and carbon regulations may reduce ROI for D-DER since these units are mainly fueled by fossil energy. However, opportunities exist for D-DER in states like Texas where environmental regulations are less stringent
    b. Policies in states that provide better tax incentives to larger capital investments de-incentivize investment in D-DER
    c. Decoupling tariff rates eliminates the tie between utility sales volume and profitability making measures like D-DER profitable to utilities, and reduces fear of losing business to DERs
    d. Low electricity prices, such as those generally found in Texas, reduce the ROI of D-DER
4. Grid interconnection issues continue to be a hindrance for DERs
    a. Technical barriers exist, such as costly requirements for protective equipment, and safety measures intended to avoid hazards to utility property and personnel, substantially increase the cost and time needed for interconnection
    b. Business practice barriers also exist, including contractual and procedural requirements with utilities, procedures for approving interconnection, application and interconnection fees, insurance requirements, and operational requirements
    c. Regulatory barriers exist, such as prohibitive backup or standby charges, T&D demand charges, net metering uncertainty, and unevenly applied environmental permitting

5. Volt-VAR management and other services for the distribution network could be a good stream of revenue, but there are various barriers to D-DERs
    a. Utilities struggle to deliver power within appropriate voltage limits so that consumers' equipment operates properly, and to deliver power at an optimal power factor to minimize losses
    b. Rules to compensate D-DERs for better power factors are not well developed
    c. D-DERs competes with utility-owned equipment, such as capacitor banks, voltage regulators, and power transformers with on-load tap changers
    d. Aggregation could help overcome some of these barriers but the aggregator model has not worked well in many ISO markets such as ERCOT

6. There is substantial uncertainty about the need for certain energy and ancillary services in the future, which increases SMEs' investment risk in D-DERs
    a. It is unclear exactly how the electric grid system in any given region will change in the future, which raises uncertainty about which grid services will be required
    b. Increased integration of intermittent renewables can create substantial ramping needs in the shoulder hours (the hours that precede and follow peak usage) when PV or wind output can change relatively rapidly (i.e. California ISO's "duck chart). However, a combination of larger, more flexible gas units coming on line and improved demand response with smart grid technologies may enable the system to adequately respond to the need for ramping services for some time to come.
    c. Owners of D-DERs need to ask the question: "what investments do I make today to ensure I have a revenue stream not just tomorrow but 5-10 years in the future?"

7. Meter installation costs and requirements can substantially increase the cost of interconnected D-DER systems
    a. In ERCOT, for example, the local utility is needed for installation of meters that can cost $50K - $200K or more
    b. Two bi-directional meters would be required for a D-DER to participate in ERCOT ancillary markets and/or as a dispatchable resource, which increases costs and complexity of meter installation requirements
    c. Contractual requirements with utility, procedures for approving interconnection, application and interconnection fees, and insurance requirements can all be potential additional barriers

Appendix A: Workshop Participants

First Name	Last Name	Title	Company
John	Adams	Principal Engineer	Electric Reliability Council of Texas
Veronica	Adetola	Staff Research Engineer	United Technologies Research Center
Art	Anderson	Grid Integration Laboratory Program Manager	National Renewable Energy Laboratory
Munidhar	Biruduganti	Principal Research Engineer	Argonne National Laboratory
Jordan	Blackman	Lead Associate	Booz Allen Hamilton
Anime	Bose	Associate Professor	University of Houston
Leo	Casey	Electrical Lead	Google, Inc
Isaac	Chan	Program Manager	DOE Advanced Manufacturing Office
Charles	Chen	Chief Strategy Officer	Energetics
James	Faletti	Senior Technical Steward	Caterpillar
Kathey	Ferland	Project Manager	The University of Texas, Texas Industries of the Future
Joel	Fetter	Lead Associate	Booz Allen Hamilton
Robert	Gemmer	Technology Manager	US Department of Energy
Julieta	Giraldez	Research Engineer	NREL
Alison	Gotkin	Business Development Manager	UTRC
Mark	Harral	CEO	Group NIRE
Kevin	Harrison	Research Engineer	National Renewable Energy Laboratory
Bruce	Hedman	Technical Director	Institute for Industrial Productivity
Rusty	Heffner	Senior Lead Technologist	Booz Allen Hamilton
Allen	Hefner	(not provided)	NIST
Mark	Johnson	Office Director	DOE-AMO
Rajendra Prasad	Kandula	Research Engineer	Georgia Institute of Technology
Paul	Lemar	President	Resource Dynamics Corporation
Anne Marie	Lewis	Associate	Booz Allen Hamilton
Ron	Melton	Team Lead, Electricity Infrastructure Integration	Pacific Northwest National Laboratory
Sainath	Moorty	Principal, Market Design and Development	ERCOT
Martin	Narendorf	Sr. Director	CenterPoint Energy
Kim	Nguyen	Research Engineer	Southern Company
Pinakin	Patel	Director	FuelCell Energy, Inc
Ziaur	Rahman	Support Contractor to AMO	Advanced Manufacturing Office
Doug	Rephlo	Senior Originator	Shell Energy North America
Ethan	Rogers	Senior Program Manager - Industry	ACEEE

First Name	Last Name	Title	Company
Benjamin	Ross	Program Manager	GE Distributed Power
Marc	Rouse	Director of Sales	Capstone Turbine Corp.
Uwe	Schmiemann	PG Marketing & Product Strategy Manager	Solar Turbines Incorporated
Ingmar	Sterzing	VP, Power Supply and Energy Services	Pedernales Electric Cooperative
John	Storey	Distinguished R&D Staff Member	Oak Ridge National Laboratory
Le	Tang	VP & Head of US Corporate Research Center	ABB Inc.
Gregory	Thurnher	Chairman of ERCOT DREAM Task Force	Shell
Eddy	Trevino	Program Specialist	State Energy Conservation Office
Gokul	Vishwanathan	Lead Technologist	Booz Allen Hamilton
Bryon	Washom	Director of Strategic Energy Initiatives	University of California San Diego
Michael	Weedon	Executive Director	BC Bioenergy Network
Brian	Weeks	Director, Houston Office	Gas Technology Institute
Parker	Wells	Graduate Student	University of California - Los Angeles
Herman	Wiegman	(not provided)	GE Global Research
Mike	Yohe	Product Line Manager	Caterpillar

Appendix B: Workshop Agenda

February 10, 2016

Time	Topics	Speakers/Facilitators
0800	**Registration**	
0830	**Welcome, Introductions and Workshop Overview**	Dr. Bob Gemmer, DOE
0845	**Introduction to Advanced Manufacturing Office** *Overview of AMO, its past activities, and its current interest in distributed generation as a grid asset.*	Dr. Mark Johnson Office Director DOE-AMO
0915	**Vision of Distributed Generation as a Grid Asset** *Discussion of future operating models and key challenges as distributed generation more fully participates in wholesale markets.*	Gregory Thurnher, Shell (Chairman of ERCOT DREAM Task Force)
0945	**Break**	
1000	**Panel 1: Opportunities & Challenges for DG as a Grid Asset** *Discussion of the benefits of DG to industrial customers and the grid as a whole, as well as identification of key challenges and constraints.* John Adams – ERCOT Byron Washom – University of California San Diego Mark Harral – Group NIRE Ingmar Sterzing – Pedernales Electric Cooperative	Moderator Dr. Reid Heffner Booz Allen Hamilton
1100	**Panel 2: Capabilities of Dispatchable DG Technology** *Discussion of the capabilities of dispatchable DG technologies and identification of future R&D challenges.* Uwe Schmiemann – Solar Turbines Incorporated Herman Wiegman – General Electric Pinakin Patel – FuelCell Energy Art Anderson – National Renewable Energy Laboratory	Moderator Dr. Bruce Hedman Technical Director Institute for Industrial Productivity
1200	**Divide into Breakout Groups and Lunch (in Breakout Rooms)**	Bob Gemmer
1300	**Breakout Rooms A & B** **Topic 1. Key Non-technical Challenges** *Brain-storming aimed at identifying non-technical challenges to greater utilization of dispatchable DG from manufacturing sites to support the grid such as cybersecurity, impacts on plant operations, grid interconnection, etc.*	Facilitators

February 10, 2016

Time	Topics	Speakers/Facilitators
1330	**Topic 2: Innovation in Generation Technology** *1. Identifying the key technical barriers for dispatchable distributed generation to play a larger role in providing services to the grid. Relative priority of barriers.* *2. Advances needed for potential avenues of R&D in technologies such as microturbines, gensets and fuel cells.*	Facilitators
1430	**Break** **Time May Vary Between Breakout Groups**	
1500	**Topic 3: Innovation in Other Technology Behind the Meter** *1. Identifying the key technical barriers for dispatchable distributed generation to play a larger role in providing services to the grid. Relative priority of barriers.* *2. Advances needed for potential avenues of R&D in technologies such as power conditioning systems, forecasting tools and load optimization tools, and the need for "Smart Manufacturing."*	Facilitators
1600	**Topic 4: Innovation in Technology at the Grid Edge** *1. Identifying the key technical barriers for dispatchable distributed generation to play a larger role in providing services to the grid. Relative priority of barriers.* *2. Advances needed for potential avenues of R&D in telemetry, communications and other technologies at the industry and T&D interface.*	Facilitators
1700	**Adjourn** *Sign-up lists for dinner groups.*	

February 11, 2016

Time	Topics	Speakers/Facilitators
0830	**Reconvene in Breakout Rooms** **Preparation of Findings from Day 1 Breakouts** *Advances needed, prioritized R&D needs for AMO to address, DOE role, and potential collaborative arrangements.*	Facilitators
1000	**Break** **Reconvene in Main Room**	
1015	**Report Outs of Findings of Breakout Groups and Stakeholder Discussion** *Report outs of advances needed, prioritized R&D needs and overview of collaborative arrangements required.*	Facilitators, Volunteers from Each Group and Bob Gemmer

February 11, 2016

Time	Topics	Speakers/Facilitators
	Moderated session for stakeholders to react to findings and report outs.	
1145	**Stakeholder Closing Reaction and Closing Remarks** *Moderated session for stakeholders to voice general comments, concerns, etc.*	Bob Gemmer with Facilitators
1200	**Adjourn**	