DOE OE 2021 Strategy White Papers on Microgrids: Program Vision, Objectives, and R&D Targets in 5 and 10 years–Topic Area #1

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EXECUTIVE SUMMARY

This white paper describes the program vision, objectives, and R&D targets in 5 to 10 years for the Department of Energy (DOE) Office of Electricity (OE) Microgrid R&D Program. The vision is to facilitate the nation's transitions to (1) a more resilient and reliable, (2) more decarbonized electricity infrastructure, in which (3) microgrids have a reduced cost to implement. This strategy is developed in the context that the United States' electricity delivery system is becoming more distributed in nature. The electricity generation capacity in 10 years may be 30-50% distributed energy assets. Therefore, in this vision of the future, microgrids will support three main goals:

Goal 1: Improved resiliency (compared to traditional back-up power options)

Goal 2: Support of decarbonization (by acting as a point of aggregation for large number of distributed energy resources (DERs))

Goal 3: Reduction of cost and promotion of equitable electricity access (compared to a future where carbon emissions have a cost)

To achieve the three primary goals the roadmap for the program includes objectives in three R&D broad categories:

1. Infrastructure and operations,
2. Analysis and tools, and
3. Institutional framework.

This white paper on the overall program strategy is one of seven papers being prepared for the DOE Microgrid R&D program as part of this strategy development. The seven white papers focus on the following areas and fit into one or more the three categories as noted.

1. Program vision, objectives, and R&D targets in 5 and 10 years (Categories 1, 2 and 3)
2. Transmission and distribution co-simulation of microgrid impacts and benefits (Category 2)
3. Building blocks for microgrids (Categories 1 and 2)
4. Microgrids as building blocks for the future grid (Category 1)
5. Advanced microgrid control and protection (Category 1)
6. Integrated models and tools for microgrid planning, designs, and operations (Category 2 and 3)
7. Enabling regulatory and business models for broad microgrid deployment (Category 3)

Following this set of white papers being written in conjunction with a virtual workshop in the spring of 2021, a roadmap will be developed. This roadmap will meet the objectives identified in this strategy document, for performing R&D in the above three categories, covering topics in papers 2-7. The objectives are designed to fulfil the program vision and include enabling near- and long-term safe and secure, reliable and resilient, and decarbonized microgrid adoption that is affordable and equitable.

In the near term, a successfully executed R&D program may primarily benefit single microgrid adoption and operation. In the longer term, approaching 10 years out, the focus is more heavily on adoption and operation of networked microgrids and their role in the wider electricity delivery

system. This can be realized by addressing barriers within the three categories and targeting R&D to address them while being mindful of compatibility to future network architectures and networked microgrid designs.

Integrated models and tools for planning, designs and operations (topic 6) need to standardize microgrid controls and design around blocks (topic 3), to facilitate microgrid deployment in a range of environments. Simultaneously, microgrids as building blocks in grid architectures that are likely to be adopted that can accommodate high penetrations of DERs (topic 4), which in turn should include advanced controls and communications as well as protection functions (topic 5) to enable a paradigm of networked microgrids. This will require a new generation of models/tools (topic 6) to plan and operate systems of microgrids as well as new co-simulation platforms to capture the impacts and interdependencies with the bulk power system and other infrastructures as necessary (topic 2). Finally, it is important to translate this new paradigm into clear policy and regulatory directives to accommodate efficient, safe, secure, and reliable microgrid adoption through clear processes that are not burdensome (topic 7).

A strong forcing function in microgrid adoption or other energy investments comes from the institutional framework. This framework includes market and financing as well as permitting and regulation. This paper envisions a future grid that is heavily penetrated with DER with numerous networked microgrids. It then evaluates the current state of the institutional framework, analysis and tools, and infrastructure and operations around microgrids and identifies gaps and needs to realize this future.

DOE's Office of Electricity (OE) is well positioned to lead this strategic effort and to coordinate core R&D activities to meet these objectives. These objectives support the wider DOE OE objectives to achieve megawatt scale grid storage, revolutionize sensing technology utilization, and address transmission.[1] Resources beyond OE will need to be leveraged to maximize the value of the work, which requires alignment of government and industry efforts, and the mobilization of resources from national labs, universities, industry and other stakeholder groups. The program vision is to enable microgrids to be a fundamental operational element for a future power system where the majority of generation is low to no emissions, and 30%-50% of the generation resources at the distribution level. Additionally, this future power system will have large numbers of DERs, in addition to generation, such as stationary batteries, electric vehicles, responsive loads, and distributed power electronic devices. In this future, microgrids operate in various control architectures to support bulk power system operations, achieve local economic and operational objectives, and support the critical end-use loads where the bulk power system is not available.

R&D efforts should standardize microgrid controls and design around blocks (topic 3), to facilitate broad microgrid deployment. Simultaneously, grid architectures need to be developed that can accommodate high DER and microgrid penetrations (topic 4), which in turn must include advanced controls and communications as well as protection functions (topic 5) to enable a networked microgrid paradigm. This will require a new generation of models/tools (topic 6) to plan and operate microgrid systems as well as new co-simulation platforms to capture the impacts and interdependencies with the bulk power system and other infrastructures as necessary (topic 2). Finally, it is important to translate this new paradigm into clear policy and regulatory directives to

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[1] https://www.energy.gov/oe/mission/oe-priorities

accommodate efficient, safe, secure and reliable microgrid adoption through processes that are not burdensome and are clear (topic 7).

Program activities impacts must be quantified, and technology transfer to the industry achieved to improve the electric delivery system in the United States. Continued and new benchmarking studies are required to quantify the current state and needs in industry, and to measure the program impacts. Demonstration projects and stakeholder engagement avenues must continue to be carried out to ensure activities funded to investigate the R&D barriers in the above three domains will provide solutions that are not currently available, valuable, and realizable, and that the impact to the industry is measurable. Demonstrations must leverage past projects and explore new technical and regulatory challenges. Multi-owner demonstrations, and networked microgrids should be targeted for future demonstrations. Stakeholder engagement must become a larger, more coordinated effort, formalized through consortia, or other venues, in addition to ongoing efforts.

To achieve the microgrid program goals enabling activities are needed. These can be leveraged to achieve the objectives outlined above. The DOE OE Microgrid Program will leverage the advancements made within DOE's complementary offices and initiatives across Office of Energy Efficiency and Renewable Energy, OE, Advanced Manufacturing Office and the GMLC. The current strategies and roadmaps from these programs are important elements to advance the electric delivery system, and DERs in particular. This strategy further complements the specific roadmaps and strategies put forward on grid forming inverters,[2] grid interactive buildings,[3] and photovoltaic cyber security[4].

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[2] Lin, Yashen, et al. *Research Roadmap on Grid-Forming Inverters*. No. NREL/TP-5D00-73476. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2020.

[3] Neukomm, Monica, Valerie Nubbe, and Robert Fares. "Grid-interactive efficient buildings technical report series: Overview of research challenges and gaps." (2019).

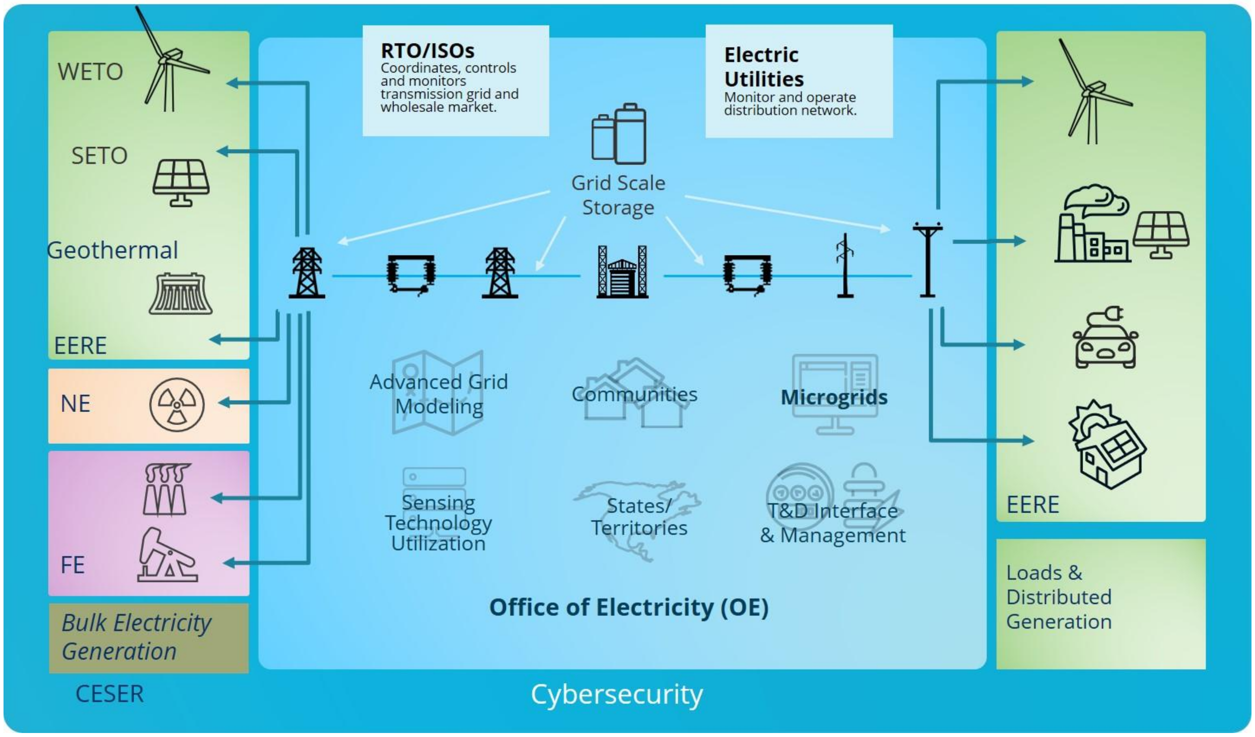
[4] Johnson, Jay. "Roadmap for photovoltaic cyber security." *Sandia National Laboratories* (2017).

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
AC	Alternating current
DER	distributed energy resource
DOD	Department of Defense
DOE OE	Department of Energy Office of Electricity
EERE	Office of Energy Efficiency and Renewable Energy
EV	electric vehicle
FEMA	Federal Emergency Management Agency
GMLC	Grid Modernization Lab Consortium
GW	gigawatt
IEEE	Institute of Electrical and Electronics Engineers
MBB	microgrid building block
MDT	Microgrid design tool
PV	photovoltaic
R&D	research and development
T&D	transmission and distribution

1. INTRODUCTION

Technology and policy trends are driving towards a more distributed electric infrastructure. These trends will lead to a future power system that can be expected to be 30%-50% of the generation assets connected at the distribution level in the next 10 years. Woods McKinsey projects 387 GW of installed capacity will be distributed by 2025[5], which is over 30% of capacity in 2021.[6] The Department of Energy Office of Energy Efficiency and Renewable Energy (DOE EERE) as well as DOE Office of Electricity (OE) offices hold responsibility to support the evolving US electric infrastructure while the DOE office of Cybersecurity, Energy Security and Emergency Response (CESER) is responsible for energy security R&D. Within DOE OE, the microgrid program has responsibility to advance microgrid R&D and adoption. This effort is complementary to efforts in other offices to advance the electricity delivery system (EDS). The Department of Defense (DoD) is often an early adopter of microgrid solutions and has invested in research and development in complementary efforts to those of the microgrid program. These offices complement one another in microgrid advancement. Joint efforts resulted in the development of the microgrid design tool (MDT) and the execution of the Smart Power Infrastructure Demonstration for Energy, Reliability, and Security (SPIDERS) program. These efforts have enabled advancement of R&D for microgrid design, installation and operations.



Distributed energy resources (DERs) make up 15% or more of electricity generation in the United States today. That is expected to rise to nearly 30% by 2025, and further still by 20317, when 10 years from now, it is conceivable that in some regions DERs could approach 50% of generation. Stationary and mobile storage along with flexible load will combine with this distributed generation

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[5] https://www.greentechmedia.com/articles/read/coming-wave-of-der-investments-in-us

[6] https://www.publicpower.org/resource/americas-electricity-generating-capacity

[7] https://www.c2es.org/content/microgrids/

to provide increased system flexibility. The DOE microgrid program defines a microgrid as a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity. A microgrid can connect and disconnect from the grid to enable it to operate in grid-connected and island mode or as an isolated off-grid electricity network. The future role of microgrids in the distributed generation assets can provide resilience.

The National Academy of Sciences, Engineering and Medicine in their 2021 *Future of Electric Power in the United States*, "Acknowledg[es] that because there is no way to make power systems completely invulnerable to intentional or accidental physical or cyber disruptions and to the effects of extreme weather events, the nation must move aggressively to create systems that can continue to provide basic services as they recover from disruptions."8 Microgrids currently make up 0.2% of the electricity generation of the national electrical infrastructure. From 2013-2016 the number of microgrids installed in the United States per year was relatively flat at 112-143 per year, with most of those being basic in design. From 2016-2019, installed microgrids saw a yearly increase of 62-68% in numbers of microgrids installed, with a growing fraction being advanced. Navigant expects global microgrid capacity to reach 19,888.8 MW by 2028, up from 3,480.5 MW in 2019. The research firm sees North America and Asia Pacific as the centers of growth.9 Meanwhile the size of installed microgrids decreased with most being under 5MW in 2019.10

The renewable sources that will support a future decarbonized system will operate in coordination with other sources such as modular fossil and natural gas, in addition to other distributed assets such as station battery energy storage, electric vehicles, and responsive end-use loads. The increasingly large number of distributed assets cannot readily be integrated into existing centralized operational system architectures. One option to effectively integrate the increasing number of distributed assets, while simultaneously increasing reliability and resilience, is to use microgrids as a fundamental building block of system planning and operations. Distributed energy resources may be implemented in a microgrid, which can operate in support of the bulk power system, or independently as necessary; in remote applications microgrids may not be committed to any bulk power system. Microgrids will be incorporated in the United States in a hierarchical manner, fitting into the centralized power system of today, though the architecture details are not known and may vary depending on penetration. Independent of the degree of decentralization of the grid, the visibility and control is an important area of R&D for microgrids to manage their energy.[11] The microgrids of the future will be increasingly "advanced" and the needs and benefits of such have been described in the 2014 white paper on their integration and operation.[12] In 2019 86% of installed microgrid generation capacity came from fossil fuel sources[13] while in 2021 the anticipated installed capacity will be 16% fossil fuel.[14] The degree to which distributed assets are aggregated into microgrids depends on access to technical capabilities, available resources, mid and long-term planning considerations, as well as regulatory and policy issues.

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[8] Future of the Electric Grid in the US (complete reference)

[9] https://microgridknowledge.com/microgrid-defined/

[10] https://solarbuildermag.com/news/2019-saw-a-record-number-of-microgrids-installed-in-the-united-states/

[11] Singh, Ravindra, Reilly, Jim, Phan, Albert, Stein, Eric, Kotur, Dimitrije, Petrovic, Mladen, Allen, Will, and Smith, Monica. *Microgrid Energy Management System Integration with Advanced Distribution Management System*. United States: N. p., 2020. Web. doi:10.2172/1706120.

[12] Ward Bower,et. al.The Advanced Microgrid Integration and Interoperability*SAND2014-1535*

[13] https://www.smart-energy.com/industry-sectors/distributed-generation/microgrid-installations-hit-new-record-in-the-united-states/

[14] https://www.eia.gov/todayinenergy/detail.php?id=46416

Understanding these constraints, and identifying where DOE can most effectively reduce barriers, is of strategic importance to the DOE OE microgrid program. To achieve the desired electric grid in the United States, microgrids play a critical part and their adoption depends on their costs coupled with the value and priorities of the relevant stakeholders. For the former, costs of microgrids vary widely due to the unique conditions, needs, and level of complexity. Cost per installed energy capacity show economies of scale, with microgrids above 10MW observing reduced cost. Soft costs for design are reported with wide ranges from 1-74% of project costs. This is done by considering compiled data across over 80 microgrids as well as pulling from a select set of exemplar use cases. Based on a survey of 81 microgrid installations some trends in costs were identified that point to increased cost for more complex and for smaller microgrids. More complex microgrids, with mixed generation, advanced microgrid controller cost over twice that of basic microgrids using standalone backup generators. Additionally, controller costs decline as a percentage of total cost as microgrid generation capacity increases, indicating significant fixed component costs. Soft costs are also greater for microgrids smaller than 1 MW. Together these result in economies of scale, where price per MW increases as capacity drops below 10 MW.[15] For assessing values, tools to assess the value to an avoided outage, and to a blue sky benefit are needed.

The DOE OE Microgrid program has made significant progress in the areas of tool development (green), standards contributions and guide development (blue) and demonstration projects and site assessments (red). The program created the Microgrid Multi-year program plan in 2017, and achievements to date have been in support of that plan.

- RDSI (Renewable and Distribution System Integration): nine demonstration projects completed to integrate use of DER to provide at least 15% peak demand reduction on distribution feeder or substation
- SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability and Security): a joint capability technology demonstration sponsored by DoD in collaboration with DOE/DHS to demonstrate a cyber-secure microgrid architecture with integration of smart grid technologies, distributed and renewable generation, and energy storage on military installations for enhanced mission assurance
- DER-CAM+ (Distributed Energy Resources Customer Adoption Model Plus): a decision support tool developed by LBNL that primarily serves the purpose of finding optimal DER investments in the context of either buildings or multi-energy microgrids
- CSEISMIC (Complete System-level Efficient and Interoperable Solution for Microgrid Integrated Controls): a microgrid controller developed by ORNL that performs both real-time controls and energy management, and also provides interface to the power system operator/energy market for the microgrid to participate in system operation and/or energy market activities
- MDT (Microgrid Design Toolkit): a decision support software program developed by Sandia. Provides designers a Pareto frontier of microgrid solutions that meet user-defined objectives, such as performance, reliability and cost.

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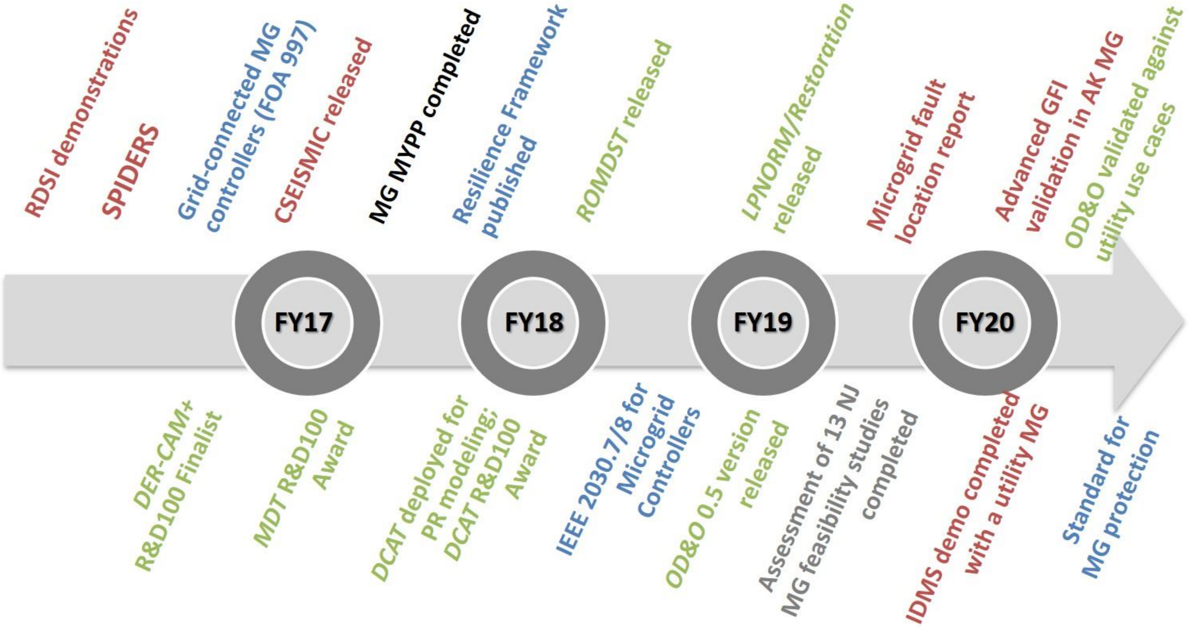
[15] Giraldez Miner, Julieta I., Flores-Espino, Francisco, MacAlpine, Sara, and Asmus, Peter. *Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States*. United States: N. p., 2018. Web. doi:10.2172/1477589.

- DCAT: The Dynamic Contingency Analysis Tool developed by PNNL screens for weak spots on the power grid by analysis of dynamic and steady-state operations in response to extreme events, assesses the potential impact of cascading outages, and helps design proactive corrective actions that improve grid resiliency.
- ROMDST (Design Support Tool for Remote Off-grid Microgrids): a planning tool developed by LBNL that leverages DER-CAM to support designs for remote microgrids including AC/DC MGs and n-1 security constrained designs
- LPNORM (the LANL, PNNL, and NRECA Optimal Resiliency Model): an open-source software for resilient distribution system design, available at www.omf.coop for use by the nation's utilities
- Restoration: a closed-loop distribution system restoration tool developed by ANL to support utilities in performing distribution system restoration after extreme weather events,
- OD&O: an Optimal Design & Operation (OD&O) software tool being developed by a multi-lab team to support development of a preliminary design of a networked microgrid



Microgrids, by design, are largely unique to the location and needs. There are general categories of microgrid use cases that are typically considered as having similar categories of needs or design criteria. Consideration must be made for a use cases primary drivers (economic, resilience, and sustainability mix are the three main goals of support for this strategic effort). Use cases vary in their features based on numerous additional factors, some of which include region (rural, urban, remote, island, mobile/temporary), ownership model (utility owned, private, community, public), and ownership mix (single or multiple owner). Commonly, microgrids are broken down by customer:

1. Institutional/campus microgrids
2. Commercial/industrial microgrids
3. Community/utility microgrids
4. Industrial microgrid
5. Military microgrids

Microgrids can further be categorized by application (district energy microgrids, "premium power, resilience-oriented, loss reduction, etc.)…and the type of voltages and currents adopted in the microgrid (such as ac, dc, and hybrid)."[16] In the set of six topical strategic white papers that accompany this paper there are sections on use cases that describe both use cases and case studies of types of microgrids and specific microgrid examples respectively that illustrate important areas of R&D such as types of controls (topic area 5) and regulatory environment (area 7).

A driver for the future vision of microgrids is making the leap from R&D of individual microgrids, to seeing microgrids as building blocks for a future grid. Significant R&D must be directed simultaneously to both standalone microgrids and a future of networked microgrids across areas of research. Initial research on networked microgrids has been conducted by the Microgrid R&D program.

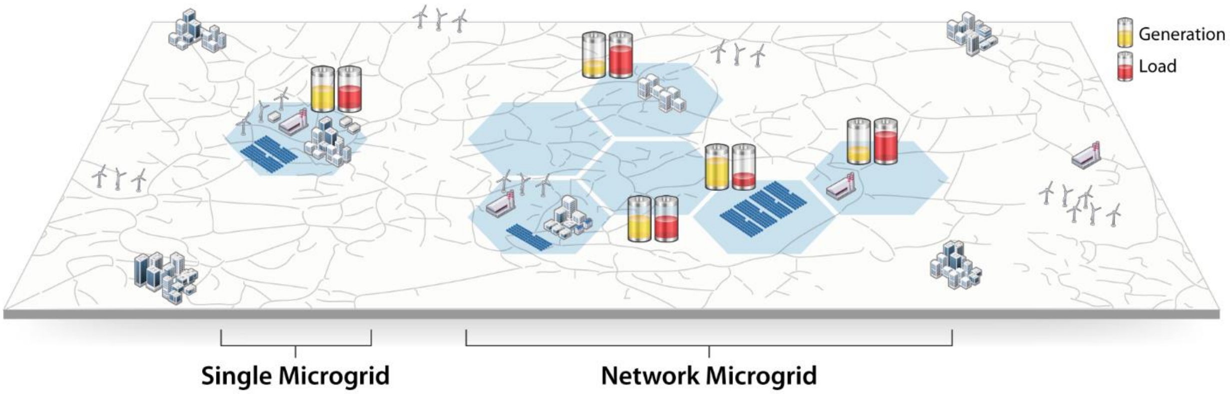


Figure 1. Stand-alone versus Networked Microgrid example

The future state of the United States electric grid will be increasingly distributed and decarbonized, and its architecture increasingly hierarchical, with increased numbers of microgrids. With more active elements, control systems will be more complex and flexible. This paper outlines the vision and goals for the DOE Microgrid Program and provides the context for the six-compendium white papers, each addressing a specific scope. Each of these white papers assesses the gaps and opportunities in the topical areas for different use-cases and explores the opportunities with a 10-year timeframe. Additionally, successful R&D into the most significant barriers to adoption may enable microgrids to play a role in the grid to make it more resilient, enable increased decarbonization, and facilitate equitable energy and services in blue sky and grey sky scenarios. An increased penetration of microgrids will require increased attention to advancing modular components and designs, simpler planning for microgrid designs, and enable optimal coordination

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[16] IEEE Std 2030.7™-2017

among networked microgrids. Foresight is necessary to plan for multiple potential grid architectures and electric delivery system impacts as distributed assets increase in prevalence. Planning must accommodate a range of possible future grids, from actively controlled to passively monitored. The future of microgrids is certain to have asset mixes, microgrid numbers, and microgrid sizes that vary widely across diverse geographical areas with widely different institutional constraints. Integrated models and transmission and distribution (T&D) co-simulation are critical areas of development and R&D to consider this future. Cross cutting the technical challenges are the needs to consider equity, security, resilience, sustainability, and cost.

2. VISION FOR THE FUTURE

The electric delivery system in the United States is becoming increasingly distributed in both design and operation, and decarbonized. Estimates put the fraction of generation that is distributed at 30-50% by 2030 [17]. With renewable generation expected to be the predominant source of generation by 2030 [18] The next decade represents a critical scale-up period for microgrids. Cumulative deployment of microgrids in the US is projected to double over the next five years, approaching 10 GW by 2025 [19]. However, this represents less than 1% of the electric grid [[20]]. The potential for a significantly larger representation of microgrids would contribute to a more clean, efficient, resilient, reliable, robust, and secure grid, if barriers are addressed holistically.

Microgrids will play a significant role in the future electric power system where there are large numbers of distributed devices. While microgrids have traditionally been used in a limited number of applications, the current drivers in the industry will transition microgrids from high-cost "novelties" to a "staple" solution that utilities commonly make use of. The reason for this transition is the unique ability for microgrids to aggregate DERs at the control level and to integrate with centralized controls systems. The opportunity for the DOE Microgrid R&D Program is to accelerate the deployment of microgrid technologies through the development of new planning and operating concepts. Coupled with field demonstrations of these new technologies, the work from the program will be transitioned to industry. To support this transition, the Microgrids R&D Program will focus on three key "pillars" of work. These pillars are common themes that must be equally supported to ensure the maximum benefit from microgrids. They are:

- Resilience
- Decarbonization
- Cost reduction

For resilience, microgrids will support the bulk power system during normal and abnormal conditions. Additionally, microgrids, and networks for microgrids, can support the critical end-use loads when the bulk power system is not available. For decarbonization, microgrids can act as points of aggregation in control systems with distributed elements to support the effective integration, and utilization, of distributed resources with no emissions. This includes, but is not limited to, solar photovoltaics (PV), wind generation, fuel cells, and biofuels. For cost, microgrids will leverage their operational flexibility to be more cost effective as compared to a highly distributed future where controls are all centralized. Finally, cutting across all three pillars is equitable access to the benefits of microgrids. As microgrids become a more "common" solution to the optional challenges of a highly distributed and decarbonized power system, the cost will decrease and become available to a large portion of the nation.

The DOE OE Microgrid Program objective is to accelerate the modernization of the nation's electrical infrastructure using microgrids as a core operational element. To accomplish this, the most significant barriers must be identified and addressed in a comprehensive R&D program portfolio and in collaboration with stakeholders. This white paper gives the high-level program goals, and provides a basis for the coordination of the other six white-papers This includes standardizing

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[17] https://www.greentechmedia.com/articles/read/5-takeaways-on-the-future-of-the-u.s-distributed-energy-resources-market

[18] https://www.eia.gov/todayinenergy/detail.php?id=46676

[19] https://microgridknowledge.com/microgrid-market-navigant/

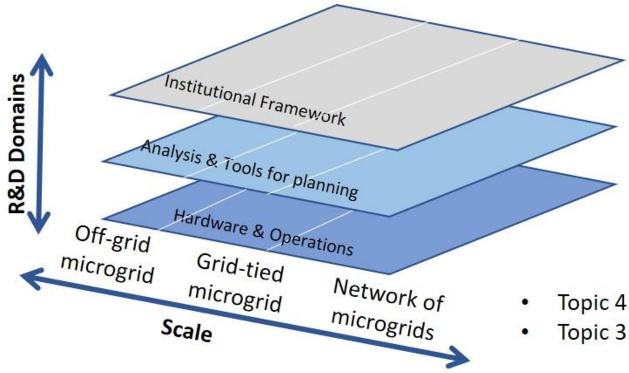
[20] https://www.c2es.org/content/microgrids/

microgrid controls and design around blocks (topic 3), to facilitate microgrid deployment in a diversity of environments. Simultaneously, grid architectures should be developed that can accommodate high penetrations of DERs and microgrids (topic 4), which in turn should include advanced controls and communications as well as protection functions (topic 5) to enable a paradigm of networked microgrids. This will require a new generation of models/tools (topic 6) to plan and operate systems of microgrids as well as new co-simulation platforms to capture the impacts and interdependencies with the bulk power system (topic 2). Finally, it is important to translate this new paradigm into clear policy and regulatory directives to guarantee equity and transparency in the process (topic 7).

The microgrid R&D program can accelerate the nation toward the vision of the future power system, resilient, decarbonized, and cost-effective. Additionally, it can do this equitably for all citizens of the nation. This document, and the six compendium documents, outline the research and development plan to achieve these goals.

3. TECHNOLOGY DEVELOPMENT

The research topics relevant to microgrids are as diverse and challenging as those related to interconnected power systems; however, the microgrid application space provides unique opportunities for differentiated high-impact R&D. The framework depicted below organizes the R&D topics into three domains: *Hardware & Operations*, *Analysis & Tools for planning* and *Institutional Framework*. Each of these domains is applicable to microgrids of all sizes and complexities. The simplest microgrid is an off-grid system that may be found in islands or remote communities. These are standalone energy systems that always operate independent of a wider electric system. A grid-tied microgrid operates as part of a wider often centralized bulk electric grid, but has the capability of operating independently, usually in the event of an electric grid outage that may occur due to a grey sky, or resilience event to provide continuity of operations. These microgrids are usually affiliated with a critical infrastructure. The third category of microgrid listed here is a network of microgrids, which is multiple microgrids that are connected through communications and/or control enabling coordinated action and may include power sharing across their boundaries. Topics 3 and 4 address this progression of microgrid designs by first considering the building blocks that make up a microgrid (topic 3) and then considering using individual microgrids as building blocks for the future grid's electricity delivery system (EDS). Topic 5 deals with hardware and operations by assessing the control and protection of microgrids. Topics 6 and 2 provide analysis and tools for planning. Topic 6 reviews models and tools for planning through operation of microgrids and Topic 2 discusses how microgrids can impact and benefit the EDS at the T&D scale. Finally, Topic 7 assesses the current regulatory and business models for microgrids which are important parts of the institutional framework that influences microgrid adoption.



- Topic 7: Enabling regulatory and business models for broad microgrid deployment
- Topic 2: T&D co-simulation of microgrid impacts and benefits
- Topic 6: Integrated models and tools for microgrid planning, designs, and operations
- Topic 5: Advanced microgrid control and protection

- Topic 4: Microgrids as a building block for the future grid
- Topic 3: Building blocks for microgrids

Figure 2. Depiction of R&D space of strategic importance to the Microgrid Program

3.1. Develop and Execute a Comprehensive R&D Plan Focused on Future High-Penetration Scenarios

A Microgrid R&D Roadmap will be developed based on this set of papers, to serve as a reference to OE, other DOE program offices, DOE crosscut initiatives such as Grid Modernization Lab Consortium (GMLC) and Research and Technology Investment Committee, and related initiatives led by other federal agencies. Future efforts will leverage past successes that provide a set of tools, algorithms, studies and research findings as described in the introduction. Targets for individual topic areas are further enabled by continued R&D advances in the other topical areas, where many goals are complementary as discussed further in the topical papers.

It is also important to identify promising opportunities for enhanced US leadership in technology development, commercialization, and applications. Specific topic areas that have the potential to enable the Microgrid 2035 Vision make up the topics #2-7 in this strategic effort and the corresponding strategic white papers for each of these topics. Participants of the 2022 DOE Microgrid Strategy Symposium identified area (c) Microgrid planning, design, and operations tools and (d) Modular microgrid architectures below as being of high importance for focus. The conclusions are summarized below:

a. Systems-level analyses impacts and benefits of microgrids. This analysis should cover a variety of systems performance aspects, from dynamic stability to system planning. The analysis will likely need to proceed in phases, with later phases addressing more detailed aspects as better models and methods become available. Increased penetration of DER should be modeled with the bulk system to identify impacts to bulk system operations.

b. Advanced power electronics technologies for microgrids. Power electronics represent a transformative technology for microgrids and power systems in general; however, advanced concepts are likely to be first adopted in microgrid applications. Additional development and validation of grid control is needed to demonstrate system stability across a wide range of system conditions. Distribution-class full-power electronic interfaces (generally called solid state transformers) can greatly simplify the interconnection of microgrids to the grid and to other microgrids by decoupling voltage, frequency and phase topology, and by integrating advanced protection and control functions in one package, and actively control the direction of power and reactive power flow. Advancements in power electronics can also enable DC and mixed DC/AC microgrid topologies, which can reduce integration complexity and increase efficiency.

c. Microgrid planning, design, and operations tools. Utilities and stakeholders make decisions on whether to introduce or adopt microgrid technologies for a variety of reasons, often centered on improving the resilience, efficiency, sustainability, reliability, security, and flexibility of power delivery. To assess the potential benefits of a microgrid or a collection of microgrids, stakeholders need design and planning tools to help them answer: whether or not they need a microgrid, if so, where the microgrid(s) needs to be placed and, once placed, what technologies must be included in the microgrid. Providing comprehensive answers to each of these questions motivate the need for integrated models and tools for microgrid planning design, and operations that can handle including capabilities below, with the topic of recommending ideal locations for microgrids being if great importance.

- Evaluate and assess the benefits the introduction of a microgrid will have.
- Incorporate models of increasingly complex microgrid technologies and the constraints these technologies place on operating the microgrid and the systems they are integrated with, be it a distribution feeder, a thermal heating system, or a communication system,
- Recommend the ideal location(s) for microgrids, their configuration, and technology adoptions, to achieve maximum potential benefits (bullet 1) considering operational (bullet 2) constraints of a designed or planned microgrids
- Develop a microgrid design tool that models the interdependencies of the microgrid with its connected power utility, thermal systems, communication systems, and natural gas system
- Develop a microgrid modeling and simulation tool that captures the as-yet-undiscovered impacts of climate-related hazards (e.g., wildfires and hurricanes) accompanied with uncertainty critical for short-term operational and long-term resiliency planning

d. Modular microgrid architectures: As a new technology, the Microgrid Building Block (MBB) concept offers modularity and flexibility to the microgrids by systemizing control architecture and creating a universal microgrid controller and building block approach that can serve diverse technologies such as PVs, batteries, electrical vehicles (EVs), low-voltage direct current/medium-voltage direct current. The building block and a universal controller will simplify integration of these devices in a tightly interconnected environment, generalizing the main functions of power conversion, switching with the utility grid (and/or other microgrids), and microgrid control and communication. Thus, a building block is the fundamental unit for microgrid standardization and can be defined as a common interface that allows for the interoperable integration of sources (generators) and sinks (loads) into a microgrid.

Moving towards an MBB concept entails important R&D challenges to achieve generalized power and communication interfaces and standardized control functions, to support the diversity of microgrid applications. Particularly, to support interoperability, scalability, and plug and play capability, MBB design should be multi-dimensional, comprising communication, control, intelligence, advanced algorithms, and protection. An additional challenge is related to the technology transition and the identification of MBB commercialization pathways that are agnostic to specific technologies and respect interoperability in energy management, communications and optimization and control functions. To accelerate this transition, it is important to develop use cases that are able to demonstrate the economic benefits of MBB in terms of modularity, flexibility, resilience, and transactive market integration.

e. **Grid of the future having microgrids as a building block:** Today's power grid largely uses a centralized control architecture. As penetration level of the distributed assets increase, their integration into the existing centralized system operations poses a challenge due to limitations in the scalability of control and computations. A number of control frameworks have been proposed and discussed during the past few years, ranging from decentralized, meshed, hierarchical to fully distributed control architectures. It is envisioned that a more distributed framework with hierarchical control and communication structure would provide greater benefits toward scalability of monitoring, control and communications, system resilience and the underlying computations for grid operation. The future grid that combines the vision of using microgrids as a building block while leveraging R&D in modeling, sensing, control and protection, will provide a streamlined path toward systematic integration of large scale DERs and transition toward a distributed control framework. Paper on Topic 4 touches upon the various architectures while highlighting the hierarchical architecture in particular, and the case study scenarios how the vision of the future grid having microgrids as a building block can be leveraged in large-scale system simulation, operation and control, during normal and emergency operation for the power grid. Realization of this vision will require various foundational technologies in modeling/simulation, algorithms/analytics, sensors/communications, protection/control, and advances in hardware.

f. Controls, protection and communication to enable networked microgrids: In the area of controls, hierarchical, distributed, and hybrid control strategies for devices, microgrids, and networked microgrids are necessary. Including the inverter transient response characteristics and operational capabilities/limits. Control systems must be able to provide dynamic stability region calculation and state estimation for robust off-grid controls, including imbalanced system controls. Bulk system interactions and grid service provisioning along with grid-forming inverter control and off-grid behavioral characteristics will enable interactions that support the grid. For resilience scenarios, microgrid controls must support black-start capabilities of DERs and microgrids even at the bulk scale. Along with network reconfiguration of microgrids and multi-microgrid systems, microgrids with advanced controls can support the grid and support critical loads in resilience events.

Protection of microgrids needs further development to model and estimate inverter faults. Inverter controls for protection systems, including zero-sequence contributions of inverters along with protection schemes with low fault currents are areas of needed development. Re-coordination of devices in a dynamic environment is critical to resilience events and networked microgrids. DC microgrid protection and fault extinguishing devices must be available. Finally, advanced sensing for protection systems is crucial to protect the microgrids of the future.

In the area of communication, cyber security of hardware and communications to secure a large number of endpoints, abstraction of behaviors to standardize controller/controlee interactions, identification of critical device information for control and modelling, and data aggregation and filtering methods to extract only necessary data are all areas of needed R&D.

g. Regulatory and institutional barriers to multi-user microgrids: To realize a future in which microgrids are treated as critical grid modernization assets that serve as networked grid resources, integrators of DER, enablers of energy localization, and providers of resilience, fundamental changes in state regulatory frameworks governing utility planning, procurement, operations, ratemaking, and investment will be required. Given DOE's focus on moving toward a future of networked microgrids, efforts to address key barriers to microgrid market development should be focused on multi-user microgrid applications. This is because multi-user microgrids are in the very beginning stages of market development and are a clear stepping-stone to a networked microgrid future. Furthermore, there are an immense number of highly formidable regulatory and institutional barriers to multi-user microgrids, whether they are developed by utilities or third-party entities. Surmounting these barriers will not be trivial, as ultimately, it is challenging for state and local governments, regulators and self-governed utilities to keep up with the technological capabilities and business model innovations offered by microgrids. DOE can support development and widespread utilization of key information resources and tools that will enable decision makers to move forward confidently with the development of regulatory and investment frameworks for multi-user microgrids. Furthermore, DOE-funded institutional support programs can help to accelerate progress in key jurisdictions and create demonstrable case studies for microgrid institutional and regulatory frameworks that build confidence among key stakeholders and inspire new efforts by key institutions. Further investment by DOE in stakeholder-oriented analytical capabilities and tools for valuing and justifying microgrid investments could fill a critical and much-needed gap in the regulatory space that accelerates deployment.

4. ENABLING EFFORTS AND R&D

1

Develop and execute a comprehensive R&D plan focused on future high-penetration scenarios

- Systems integration study, white paper series, workshops
- Microgrid R&D roadmap to inform R&D investment
- DOE/OE MGRD program to lead

2

Engage stakeholders to improve alignment, coordination and collaboration

- Sustained through workshops, CoP, inter-agency coordination.
- Better integration of R&D infrastructure at national labs
- Industry microgrid consortium, regional hub.

3

Accelerate technical and institutional innovation through targeted pilots

- Leverage external partnerships and investment (FEMA, DoD, etc.)
- Target technical/institutional innovation, high impact and replicability potential.
- Facilitate technology transition

Figure 3: Thrust 1 R&D plan (section 3.1), Thrust 2 and 3 are covered in section 4.1 and 4.2.

4.1. Engage Stakeholders to Improve Alignment, Coordination, and Collaboration

The goal of this activity is to increase alignment of R&D investment specifically related to microgrids by enhancing collaboration and coordination among key government and industry stakeholders. Coordination efforts must first involve DOE agency components and extend to national labs, universities, industry, and institutional partners. The following actions are suggested:

a. Improve programmatic coordination at the federal level, principally DOE. This could be accomplished through the establishment of a DOE microgrid community of practice or informal consultation platform in addition to the existing GMLC effort. Initially, this group could provide additional context and feedback for the strategy and increase awareness of microgrid-related initiatives across the department. It could also be used obtain early feedback on and support for this strategy. Engagement could continue through focused technical discussions via a series of seminars or workshops. A similar coordination effort beyond DOE could be through inter-agency coordination mechanisms.

b. Improve R&D coordination by federating microgrid R&D infrastructure. National labs, universities and industry maintain R&D infrastructure and testbeds relevant to microgrid R&D, but additional capabilities can be obtained by more closely linking these capabilities by, for example, working with common baseline scenarios, sharing of validated models and testing protocols, linking hardware-in-the-loop testbeds to enable high-fidelity simulations or greater complexity and scale, and simplifying mechanisms for industry to access resources available at multiple labs. Such linkages can accelerate new technology solutions development and validation. An effort to federate microgrid-related national lab capabilities could be initiated under the GMLC *grid*PULSE platform.

c. Engage with stakeholders to address regulatory objectives that rely on partnered efforts as identified in topic 7, including Microgrid Modeling Tools Usability and Usefulness Improvements, Improved Dissemination Efforts on Energy Resilience for Local Governments, development of a Handbook on Integrating Microgrids into Utility Planning, Direct Technical Assistance to Regulators on Multi-Property Microgrid Regulatory Framework Development, Support for “Regulatory Sandbox” Microgrid Pilots, Multi-Property Microgrid Regulation “Boot Camp”, Quantifying the Value of Resilience of Microgrids in Regulatory Proceedings, and Model Interconnection Procedures for Multi-Property Microgrids.

4.2. Accelerate Technical and Institutional Innovation

A key goal of the DOE OE Microgrid R&D program is to validate new technologies technically and financially while also increasing resilience of critical infrastructure. Another key goal is to inform R&D efforts by providing realistic context and use cases, and to expand partnership opportunities to engage in applied R&D activities. Use cases presented in the set of strategic papers that supplement this strategy paper are demonstrative but far from exhaustive. A methodology and framework for consistent assessment of benefits, technical and institutional challenges across a representative range of applications, regions and regulatory environments is required. The technology validation program should target critical infrastructure and community microgrids that (a) involve significant technology or institutional innovation, (b) have a high replicability potential, and (c) have commitment for lifecycle monitoring to identify and disseminate lessons learned. The framework should include a robust mechanism for data access and protection. This strategic thrust can be jump-started via existing DOE OE partnerships and interagency agreements such as the Defense Critical Electric Infrastructure program and the Federal Emergency Management Agency (FEMA) inter-agency agreement related to recovery technical assistance. It must be tailored to align with established Federal initiatives such as the DoD Environmental Security Technology Certification Program and the FEMA Building Resilient Infrastructure and Communities program.

The microgrid program must develop and house a stable microgrid database. This can be coordinated with new efforts by the DOE Combined Heat and Power and Microgrid Installation Databases[21] Such a database is critical for benchmarking and improving in areas of greatest need, and identifying areas of need for DOE funded research. This should include a point of contact, relevant details of the project, location, regulatory environment, status and be vetted for accuracy.

Surveys of microgrid owners/operators/approvers must be conducted to understand the perspectives and barriers to cost effective efficient design, development, construction, and maintenance of microgrids. Assessment of maintenance realities and needs is missing. Understanding long term maintenance of microgrids is an important aspect of these systems and not well covered by industry.

Comprehensive state energy storage policy overviews and analysis should be facilitated and maintained to educate potential microgrid developers.

Standards gap analysis, R&D for technical gap areas, and standards development activities must be funded.

A significant, deliberative, and concerted effort must be undertaken to assess the resilience benefit and value of microgrids, this is discussed over and over without significant movement to actualize value with consensus. Standardization of assessing costs as a function of attributes like design process, A&E firm type, microgrid size, asset composition, load, location/regulatory environment, control system, architecture, interaction with the bulk system and/or networked microgrid architecture, protection and cyber/physical security, load, owner, maintenance. This relies on a comprehensive and broad effort to develop, maintain, disseminate, and educate users on tools.

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[21] https://doe.icfwebservices.com/microgrid

The microgrid program should be an information discrimination, sharing and educating source to include aspects such as a series of monthly public webinars featuring laboratory funded R&D, as well as industry leaders, other DOE offices and programs, organization etc.

4.3. Impact to the Community, Economy and the Workforce

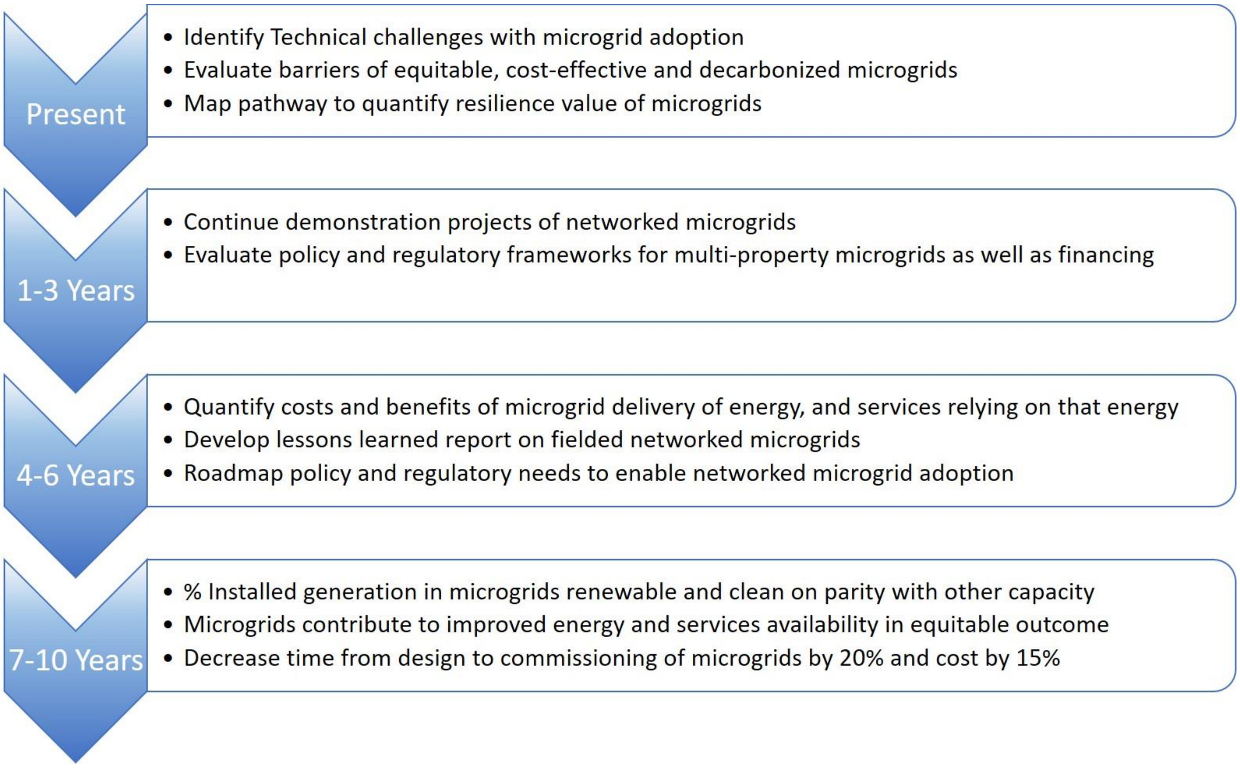
Electrical Engineering graduates in the United States must be equipped with capstone projects in focus areas of need for microgrid R&D. Pipeline development from K-12 through graduate level course work and tutorials for university adoption of tools and research platforms of interest to the microgrid program must also be developed and adopted to ensure the next generation of staff to serve as stakeholders for microgrids.

Green technology offers workforce development. To get at cost effective and efficient microgrid implementation, community college technologist programs in key states must be equipped to prepare a workforce that can implement microgrids. Bringing toolsets to a level of usability and user friendly enough to be useful is a cornerstone of success for the program.

Equity considerations must be made now, to plan for overlooked and unintended consequences of grid designs, especially regarding institutional framework and planning tools, and to build in equitable access to microgrids and the benefits of networked microgrids and DER in the future grid.

5. RESEARCH TARGETS AND GOALS FOR 5 TO 10 YEARS

Despite the substantial body of research and field experience, there are fundamental gaps that would, if not addressed, challenge the future deployment of microgrids. For example, there is a need for next-generation packaged controllers and protection systems with flexible configuration options for different operating modes and transitions. Fast-acting power-electronics interfaces are needed to ensure stability though system disturbances that are proportionally more severe in islanded microgrids compared to interconnected systems. More sophisticated models and analysis methods need to be further developed to address high-penetration scenarios across a variety of deployment scenarios. On the institutional side, new technical standards, interconnection requirements, and regulatory mechanisms are needed. Solutions to these gaps, listed in the table below, provide an indication of the future state of gaps. Objectives over the next ten years include studies, R&D, analysis, and work on policy and regulations, as well as demonstration projects and other engagement with stakeholders.



Present
- Identify Technical challenges with microgrid adoption
- Evaluate barriers of equitable, cost-effective and decarbonized microgrids
- Map pathway to quantify resilience value of microgrids

1-3 Years
- Continue demonstration projects of networked microgrids
- Evaluate policy and regulatory frameworks for multi-property microgrids as well as financing

4-6 Years
- Quantify costs and benefits of microgrid delivery of energy, and services relying on that energy
- Develop lessons learned report on fielded networked microgrids
- Roadmap policy and regulatory needs to enable networked microgrid adoption

7-10 Years
- % Installed generation in microgrids renewable and clean on parity with other capacity
- Microgrids contribute to improved energy and services availability in equitable outcome
- Decrease time from design to commissioning of microgrids by 20% and cost by 15%

The future state of the microgrid program will enable key advances. These are described here.

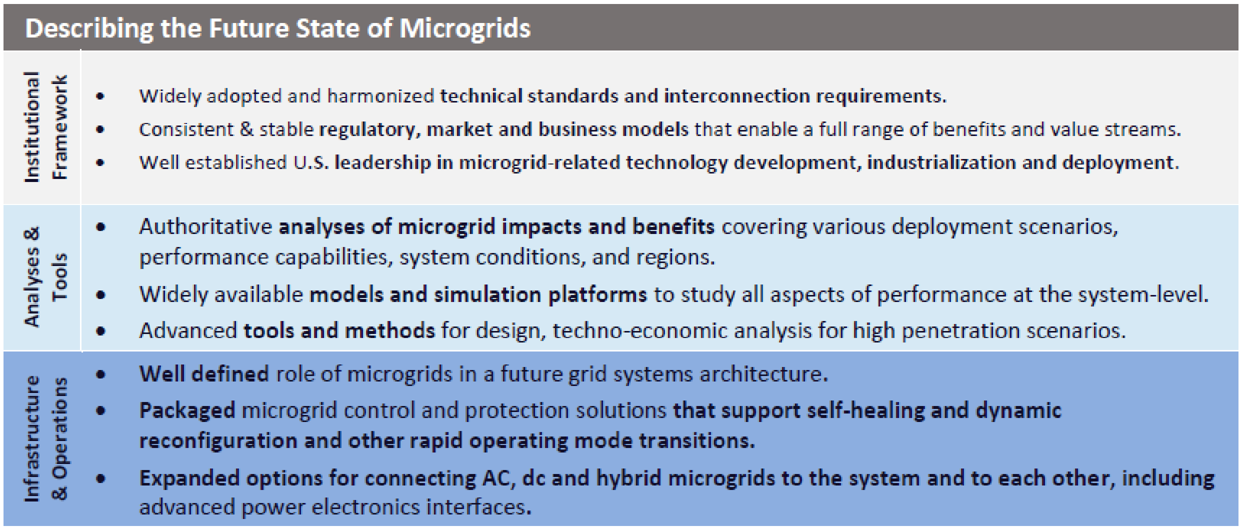
Facilitate and Enhance DER Integration and Aggregation – Microgrids will greatly simplify the interconnection, aggregation and optimal operation of DER and flexible demand and enable their full participation in system operations and energy markets. Today, the deployment of individual DERs is subject to complex interconnection procedures and requirements, and it is difficult for individual DERs to cost-effectively participate in energy markets.

Increase Decentralized Intelligent Control and Automation – Microgrids will provide a way to deploy decentralized control and automation at scale, which will enable functionality such as intentional islanding, dynamic feeder reconfiguration and support for system frequency and voltage, in coordination with utility T&D controls. This capability will result in wider adoption of microgrids as a mainstream non-wires option, replacing the need for transmission upgrades, to provide for system adequacy and a means to reduce transmission congestion.

Provide Resilience and Continuity of Operations – Microgrids will provide enhanced resilience with respect to sustained local grid outages for customers and communities. Microgrids will provide energy assurance to a significant portion of the nation's critical infrastructure such as ports, emergency services, evacuation routes, water treatment plants, defense facilities, and telecommunication nodes.

Enable Electrification of Transportation and Thermal Loads– Microgrids will enable the orderly transition of transportation and space/process heating loads, which today rely on fuels, onto the electric grid. Microgrids will provide a means to reduce the impact on the delivery system by providing local generation resources and control capabilities.

Enable Equitable, Decarbonized Electricity – Load control directly pairs with microgrids and decarbonization because it promotes local usage of renewable energy. This is the idea of virtual microgrids where power balance is managed locally to minimize the power transfer (and therefore impact) with the rest of the grid.



Describing the Future State of Microgrids	
Institutional Framework	• Widely adopted and harmonized **technical standards and interconnection requirements.** • Consistent & stable **regulatory, market and business models** that enable a full range of benefits and value streams. • Well established U.S. **leadership in microgrid-related technology development, industrialization and deployment.**
Analyses & Tools	• Authoritative **analyses of microgrid impacts and benefits** covering various deployment scenarios, performance capabilities, system conditions, and regions. • Widely available **models and simulation platforms** to study all aspects of performance at the system-level. • Advanced **tools and methods** for design, techno-economic analysis for high penetration scenarios.
Infrastructure & Operations	• **Well defined** role of microgrids in a future grid systems architecture. • **Packaged** microgrid control and protection solutions **that support self-healing and dynamic reconfiguration and other rapid operating mode transitions.** • **Expanded options for connecting AC, dc and hybrid microgrids to the system and to each other, including** advanced power electronics interfaces.

6. WHY DOE SHOULD FUND THESE GOALS AND VISIONS

In 2021, the National Academies of Sciences, Engineering, and Medicine released a report on the future of the electric grid containing recommendations to:

- "A much larger political and economic commitment to the support of research and development across all elements of the energy system so that there is at least a tripling of the level of private and public investment in electricity and other energy research.
- The development of regulations, business models, and incentives that encourage innovation, and unleash the creative energies of many different parties.
- Finding ways to do improved holistic planning in a system in which many changes occur incrementally and are implemented by a wide variety of governmental and private actors across many different parts of the country.
- Finding ways to use the states as laboratories to experiment with, and learn how to improve, public regulation and policy, especially at the level of distribution systems. In parallel with doing this, developing strategies to extract, share, adapt, and implement the lessons learned in many other jurisdictions.[22]"

DOE needs to enable microgrid advancement by funding research and development activities that tackle the objectives identified in the topical areas as described in this paper. Private industry will not implement these R&D initiatives on their own. The public dissemination of R&D results from these DOE-funded efforts will allow practical lessons learned to be shared, consensus goals, and advancements that will enable microgrids to reach their full potential. The increase in electric outages is accelerating. In the 1990s there were 13 major power outages, while in the 2010s there were 93. The last decade saw the largest and longest power outages on record[23] and while the average US customer has 2 hours of power outage per year excluding major events, the contribution of power outages from major events has more than doubled from 2015 to 2018.[24] Reliance on stable power is increasing at the same time reliability and resilience of the grid is dropping. The threat to the US economy, and security, and the wellbeing of its citizens dictate that investment in R&D, especially in applied areas grow to have impact to the electric system's quality. The value of maintaining reliable electricity, enabling resilience electric nodes for grey sky situation that best serve the US interests, military, and civilian can have tremendous return on investment. The recent draft document from the National Academies of Sciences, Engineering and Medicine, *The Future of Electric Power in the United States,* posits that a three-fold increase in investment in all electric power system research is necessary. The DOE-OE Microgrid R&D Program is a key aspect in enabling improved resilience and decarbonization of the grid, bridging the bulk system power supply with the distributed energy and load side.

There is growing recognition that significant increased investment in the electric grid is critically important to the nation. The R&D in topics 2-7 are best addressed currently and in the future through DOE funded research, and importantly through increased program support to expand and accelerate the areas of development, building on a program and areas of research that have proven successful to date.

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[22] Future of the electric grid in the US

[23] https://en.wikipedia.org/wiki/List_of_major_power_outages#Longest

[24] https://www.eia.gov/todayinenergy/detail.php?id=43915

- Co-simulation is ideally suited for DOE funding because it is building the foundation for future power system planning and operations that are currently not being explored by industry. Traditional tools are still examining either distribution or transmission with the other treated as a boundary condition.
- The topic of microgrids as a building block for future grids is ideally suited for DOE funding because it is developing the architectural foundation for a future grid. Networked microgrids, which is a first step to using microgrids as a building block, is still in an early R&D phase with some pilots coming online through DOE-funded projects in the next couple of years. Different microgrid installations likely will use different technologies and vendors, and interoperability among the microgrids is a topic that will need to be addressed and DOE can play a strong convening and enabling role in such an effort.
- In controls and protection, the DOE can play a crucial role in spurring research to push beyond the industry standard. Working with vendors and utilities, the labs can demonstrate technologies in simulation, hardware-in-the-loop, co-simulation, and field deployments, potentially reducing apprehension for adoption of the technology. While industry can produce dependable controls and protections to individual devices, to build a grid environment which is more interoperable, controllable, and reliable requires partnering with many utilities and vendors across the country and having them work together towards this vision.
- Microgrid design and planning investment from DOE will produce tools and capabilities for microgrid stakeholders. Built in collaboration and consultation with industry, they will enable assessment of the potential benefits of a microgrid or a network of microgrids in their system.
- In policy and regulation, DOE's role is to ensure that all stakeholders have access to the best information available to support informed and balanced decisions. The DOE supports this by being guided by several principles: transparency, equality of opportunity, inclusiveness, accountability, and leverage. DOE plays an important role in inspiring ideas and lending credibility to novel microgrid applications and business models, while also staying apprised of current market developments. DOE also plays an important role in providing critical information resources, education, and also in supporting direct institutional engagement with public utility commissions and other entities.

Continued institutional support must extend to data collection and dissemination for information sharing including microgrid costs, real timelines to implementation, and guides to the process of microgrid conception through commissioning. Open information can reap benefits to the performance and cost of future microgrids. Collecting data on fielded microgrids and maintaining an open database of them would be beneficial to future developers, and operators as well as researchers. Development and sharing of lessons learned is likewise of value to the advancement of future microgrid development. These have been done in the past and must continue through demonstration project support. These and other supplementary activities are activities the DOE can support to advance the program and industry can benefit from quantitative baselining and improvement evaluations.

These areas of research, development and support are therefore ideally suited to DOE investment. In the microgrid program, projects involve partnerships with academia, national lab, and industry to further the state of the art. This has long provided success through the DOE's Microgrid R&D

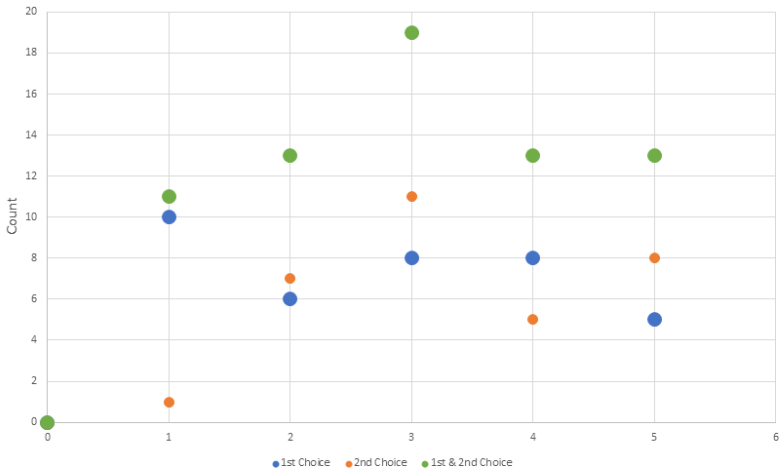
program as evidenced by past achievements. Continued and expanded support will help ensure a cleaner, more resilient, and more equitable critical infrastructure with better affordability.

Appendix 1: DOE Microgrid Strategy Symposium July 27-28, Golden CO surveyed input to strategy.

Aspects of this written strategy were conveyed, and in-person and virtual participants provided rankings and written input to priorities in a draft version of the strategy. These results are provided below in full and they have informed the strategy document. Participants ranked top priority areas in each of five categories. The results were binned to identify topics of high priority (high counts) and low priority (low counts). The text corresponding to the numbers in the horizontal axis of the plots is shown on the left of each plot. Items with high priority are shown in green and low priority in red.

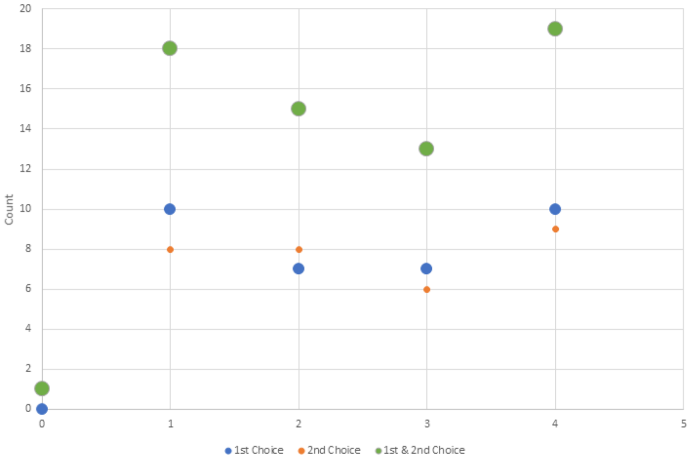
Microgrid planning, design, and operations tools

1. Evaluate and assess the benefits the introduction of a microgrid will have.
2. Incorporate models of increasingly complex microgrid technologies and the constraints these technologies place on operating the microgrid
3. Recommend the ideal location(s) for microgrids, their configuration, and technology adoptions.
4. Develop a microgrid design tool that models the interdependencies of the microgrid with its connected power utility, thermal systems, communication systems, and natural gas system.
5. Develop a microgrid modeling and simulation tool that captures the as-yet-undiscovered impacts of climate-related hazards (e.g., wildfires and hurricanes)



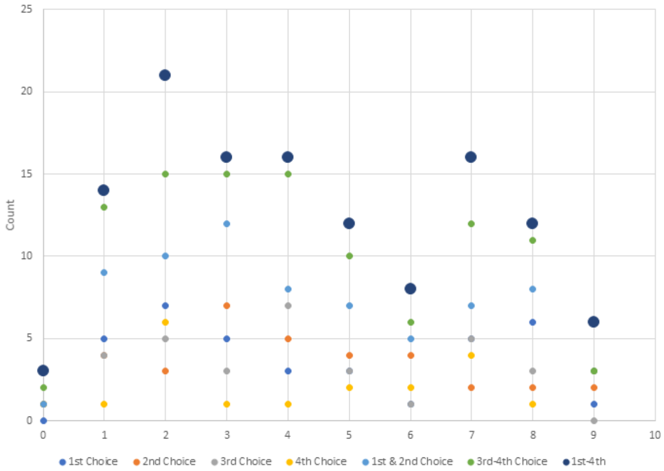
Engage Stakeholders to Improve Alignment, Coordination, and Collaboration

1. Improve programmatic coordination at the federal level, principally DOE
2. Improve R&D coordination by federating microgrid R&D infrastructure
3. Create a microgrid consortium or a regional hubs initiative
4. Engage with stakeholders to address regulatory objectives



Accelerate Technical and Institutional Innovation

1. A methodology and framework for consistent assessment of benefits, technical and institutional challenges
2. A technology validation program should target critical infrastructure and community microgrids
3. Create a robust mechanism for data access and protection
4. Develop and house a stable microgrid database
5. Surveys of microgrid owners/operators/ approvers must be conducted
6. Understanding long term maintenance of microgrids
7. Standards gap analysis, R&D for technical gap areas, and standards development activities
8. Assess the resilience benefit and value of microgrids
9. Information dicimination, sharing and educating source



Impact to the Community, Economy and the Workforce

1. Electrical Engineering masters graduates in the United States must be equipped with capstone projects in focus areas of need for microgrid R&D
2. Pipeline development and graduate level course work and tutorials for university adoption of tools and research platforms
3. Community college technologist programs in key states must be equipped to prepare a workforce that can implement microgrids
4. Bringing toolsets to a level of usability and user friendly enough to be useful is a cornerstone of success for the program
5. Equity considerations must be made now, to plan for overlooked and unintended consequences of grid designs