Microgrids Research Assessment – Phase 2

Final Report

May 2006

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Table of Contents

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The objective of this report is to provide input to CEC and DOE for making research investment decisions relative to microgrids.

Are microgrids an attractive area for additional government investment?

- Is there a single definition for microgrids?
- Are there attractive microgrid business cases?
- Is the market attractive?
- Are the public benefits attractive?
- Are there technology or policy challenges that require gov't support?

Phase 1

Define Microgrids and the Business Case

- Review prior R&D activity
- Develop a working definition of a microgrid
- Develop several potential business models that apply microgrid technology

Phase 2

Characterize the Market and R&D Needs

- Solicit feedback on Phase 1: microgrid definitions, customer/owner needs, microgrid business cases
- Estimate the market opportunity and public benefits for the potential business models
- Characterize the technical, market, business and information gaps identified in developing the market opportunity

This document summarizes the results of Phase 2.

This final report summarizes results of the four primary tasks in Phase 2.

Phase 2

Task 1 — Customer / Owner Interviews

- Understand customer needs
- Test value proposition of 3 business cases
- Identify changes to business cases
- Identify potential applications and challenges

Task 2 — Technical & Functional Assessment

- Identify technical and functional requirements of 3 business cases
- Assess ability of current technology to satisfy functional requirements
- Examine approaches to overcome technical gaps

Task 3 — Market & Benefits Assessment

- Estimate the potential size of the microgrid market
- Understand public benefits resulting from microgrids

Task 4 — Workshop

- Solicit feedback & input from microgrid owners, customers, researchers, equipment suppliers
- Develop a consensus vision & roadmap for microgrids

Task 5 — Final Report

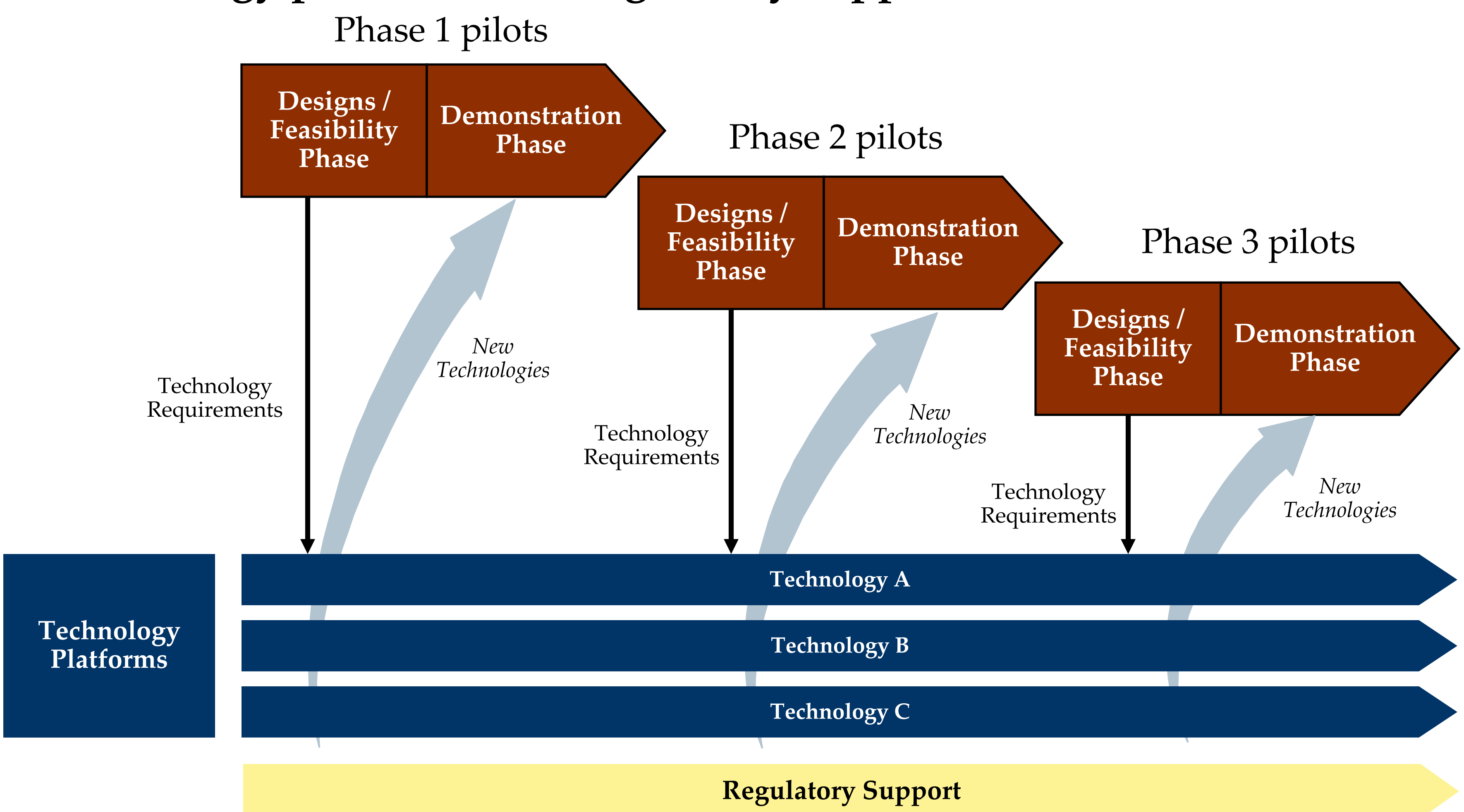
- Final report which clearly answers overall objectives of Phase II and incorporates insights from multiple stakeholders

Phase 2 identified significant opportunities for microgrids, but there are challenges that require government support.

Microgrid Opportunities	Microgrid Challenges
If technology and regulatory challenges are overcome, the microgrid market opportunity is attractive. • Microgrids can deliver several value propositions including reduced cost, increased reliability & security, green power, service differentiation, and power system optimization. • The market opportunity is driven primarily by a microgrid's ability to reduce the cost and manage the volatility of energy. Because microgrids can deliver many different value propositions, the market size and public benefits can be significant under many market conditions and scenarios. • In our base case, microgrids can attain a 5.5GW market in 2020 and deliver approximately $1 Billion in public benefits.	**To capture the most attractive markets, technology and regulatory barriers must be overcome.** • Microgrids could be built with current technology, but the cost and functionality would not meet the 2020 Vision for microgrids. • Technology gaps are primarily driven by system integration issues, but also from standards and individual technology platforms. • Technology challenges are greater for larger microgrids like multi-facility or feeder applications – these are also the largest markets. • Technology challenges are greater when delivering value propositions beyond reduced cost, e.g. power system optimization, service differentiation and green power.. • Regulatory barriers are also important. For example, utilities have a large opportunity to own and operate microgrids, but there are issues with owning generation and cost allocation.

Design/Feasibility assessments (improving design), pilots (testing economics and technology), technology platform research (improving cost and functionality of microgrid technology) , and regulatory support (reducing regulatory barriers) are required to over the challenges to wide scale deployment of microgrids.

NCI recommends an integrated program of microgrid pilots, technology platforms and regulatory support.



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Microgrids are facing business model and technology barriers that could best be addressed by pilot demonstrations.

- Business Model
  - Value Proposition
  - Scope and ownership
  - Regulatory focus
- Technology
  - Control system focus
  - Functional requirements
  - Key technologies

The pilots would test different value propositions, scope and ownership options, and regulatory issues.

Phase 1 Pilots

Value Propositions Tested:
- Reduced Cost – Reducing the cost of energy and managing price volatility
- Reliability - improved reliability

Scope: Single facility and Multi-facility

Ownership: Landlord, Utility, Muni

Regulatory Focus
- Allow competition, while maintaining obligation to serve.
- Fairly compensate utilities for services provided and investments made

Phase 2 Pilots

Value Proposition Tested:
- Security - Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources

Scope: Multi-facilities, Feeder and Substation

Ownership: Utility, Muni

Regulatory Focus:
- Cost recovery of security investments

Phase 3 Pilots

Value Proposition Tested:
- Power System - Optimizing the power delivery system, including the provision of services
- Green Power - Managing the intermittency of renewables and promoting the integration of energy-efficient technologies

Scope: Feeder and Substation

Ownership: Utility, Muni

Regulatory Focus:
- Provide transparent compensation for environmental, system reliability, and homeland security benefits.
- Permit customers to see the real cost of electricity, which include real-time, location, and environmental attributes

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The pilots would also test the technology required to support the microgrid value propositions.

Phase 1 Pilots

Value Propositions Tested:
Reduced Cost
- Reliability

Control System Focus:
- Primary – Internal
- Secondary – External

Technical Functional Reqs Tested:
- Design
  - NEC/NESC code requirements
  - Critical loads
- Performance requirements
- Monitoring and Control
- Protection
- Operations
  - Safety

Technology Platform Focus:
- Fast Switch
- Power Electronics

Phase 2 Pilots

Value Proposition Tested:
- Security

Control System Focus:
- Primary – External

Technical Functional Reqs Tested:
- Design
  - Critical loads
- Protection
  - Black Start Capability

Technology Platform Focus:
- Fast Switch
- Power Electronics
- Energy Storage

Phase 3 Pilots

Value Proposition Tested:
- Power System
- Green Power

Control System Focus:
- Primary – External
- Primary – Asset

Technical Functional Reqs Tested:
- Design
  - Switching (generator/ load isolation)
  - Load transfer
- Monitoring and Control:
  - Control system algorithm
  - Load
  - Generation
  - Communications infrastructure
- Protection
  - Auto synchronization with the grid

Technology Platform Focus:
- Energy Storage
- Demand Response
- Processing/Sensing

- There are three control domains to consider for microgrids (internal, external and asset). The emphasis of these control schemes varies by value proposition.
- The Phase 1 pilots would demonstrate the majority of the functional requirements for all microgrids, regardless of value proposition. Subsequent phase pilots would include additional functional requirements unique to those value propositions.
- Technologies developed on the technology platforms would be incorporated over time to support the pilot value propositions.
- Functional requirements or emphasis on technology platforms may change during the feasibility/design phase of each pilot.

Microgrids could provide greater flexibility and optimization of generation, loads, and the larger (macro-grid) power system.

Microgrid Definition

General Definition

A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources which as an integrated system can operate in parallel with the grid or in an intentional island mode[1].

Key Defining Characteristics

The integrated distributed energy resources are capable of providing sufficient and continuous energy to a significant portion of the internal demand. The microgrid possesses independent controls and can island and reconnect with minimal service disruption.

- **Flexibility** in how the power delivery system is configured and operated
- **Optimization** of a large network of load, local Distributed Energy Resources and the broader power system

What a Microgrid IS NOT

- One microturbine in a commercial building is not a microgrid, but DG
- A group of individual generation sources that are not coordinated, but run optimally for a narrowly defined load
- A load or group of loads that cannot be easily separated from the grid or controlled
- Does not have to have thermal (whereas CHP by definition has thermal)

Notes: 1) Remote power systems that are isolated from larger power distribution systems that are operated as a coordinated system of loads and generation are considered microgrids.

Microgrids could provide six complementary value propositions.

Value Proposition	Description
Reduced Cost	Reducing the cost of energy and managing price volatility
Reliability	Improving reliability and power quality
Security	Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources
Green Power	Helping to manage the intermittency of renewables and promoting the deployment and integration of energy-efficient and environmentally friendly technologies
Power System	Assisting in optimizing the power delivery system, including the provision of services
Service Differentiation	Providing different levels of service quality and value to customers segments at different price points

Note: Remote power systems can primarily provide the Reduced Cost, Reliability and Green Power value propositions.

Microgrids could capture between one and thirteen gigawatts by the year 2020.

Today

2020 Scenario[1]	More Central Power	Base Case	Reliability Constrained	Environmental Push
Microgrid Attributes[2]				
Reduced Cost	1.0	4.5	4.5	8.0
Reliability	0.1	0.4	2.0	1.0
Security	0.2	0.4	2.0	0.4
Green Power	<0.1	0.2	0.2	3.0
Power System	<0.1	<0.1	1.0	<0.1
Service Diff.	<0.1	<0.1	0.5	<0.1
Total	1.3 GW	5.5 GW	10.2 GW	12.6 GW

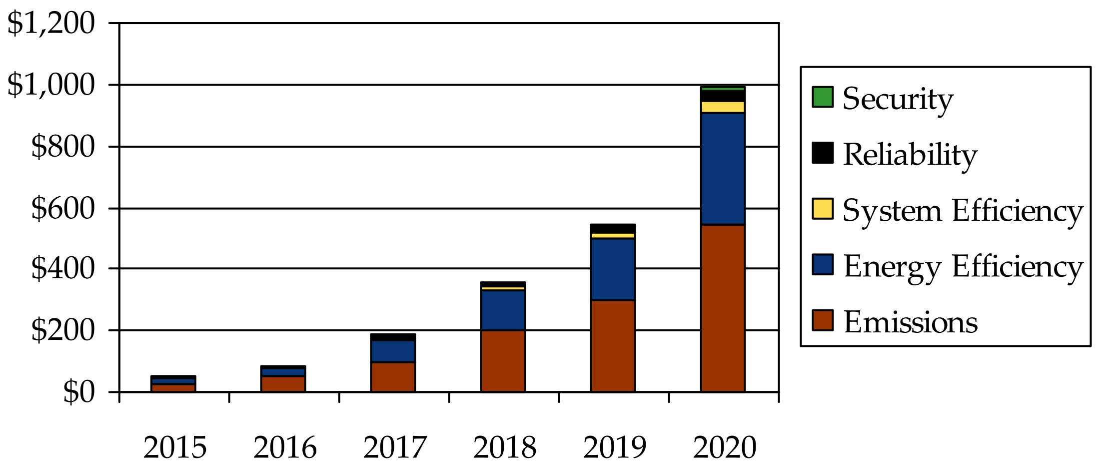
Notes:
- Microgrids must be able to deliver energy at favorable costs. As the Phase 1 analysis determined, the primary drivers behind microgrid economics are the spark spread and the cost of the generation technology.
- The market assessment assumes that regulations and technical challenges identified in the workshop will be overcome

The market opportunity is driven primarily by a microgrid's ability to reduce the cost and manage the volatility of energy. Because microgrids can deliver many different value propositions, the market size and public benefits can be significant under many different market conditions and scenarios.

Notes: (1) Selected scenarios were chosen to illustrate how microgrids could perform given select market conditions, but do not represent "likely" or "desired" scenarios.
(2) The total market size can be attributed to the value created by each value proposition.

Microgrid benefits could total almost $1 billion per year by 2020 under the base case scenario.

Annual Microgrid Benefits – Base Case Scenario ($Million)



Annual Emission Reductions – Base Case Scenario (tons)

Emission	2015	2016	2017	2018	2019	2020
CO_2	793,000	1,590,000	3,170,000	6,340,000	9,510,000	17,400,000
SOx	4,000	9,800	19,700	39,400	59,100	108,000
NOx	821	1,640	3,290	6,570	9,850	18,000
PM-10	90	181	361	723	1,084	1,987

Examples of Benefits in 2020

- $360MM in energy savings due to 10% reduction in energy bills at ~0.5% of U.S. total capacity
- 550 microgrids of an average 10MW serving primarily C&I markets with improved reliability and supporting grid stability.
- Forty or more communities with 10MW of facilities that can have energy during a grid outage.
- 200MW of renewable energy deployed within a microgrid.
- Reduction of 17.4 Million tons of CO2, 108,000 tons of SOx, and 18,000 tons of NOx.

Notes: (1) Assumes emissions emission prices per ton of $25 for CO2, $5,000 for NOx, and $200 for SOx. SOx and NOx prices are based on 2005 prices, and CO2 prices based on low-range estimates of carbon prices from the Massachusetts Institute of Technology's EPPA model.

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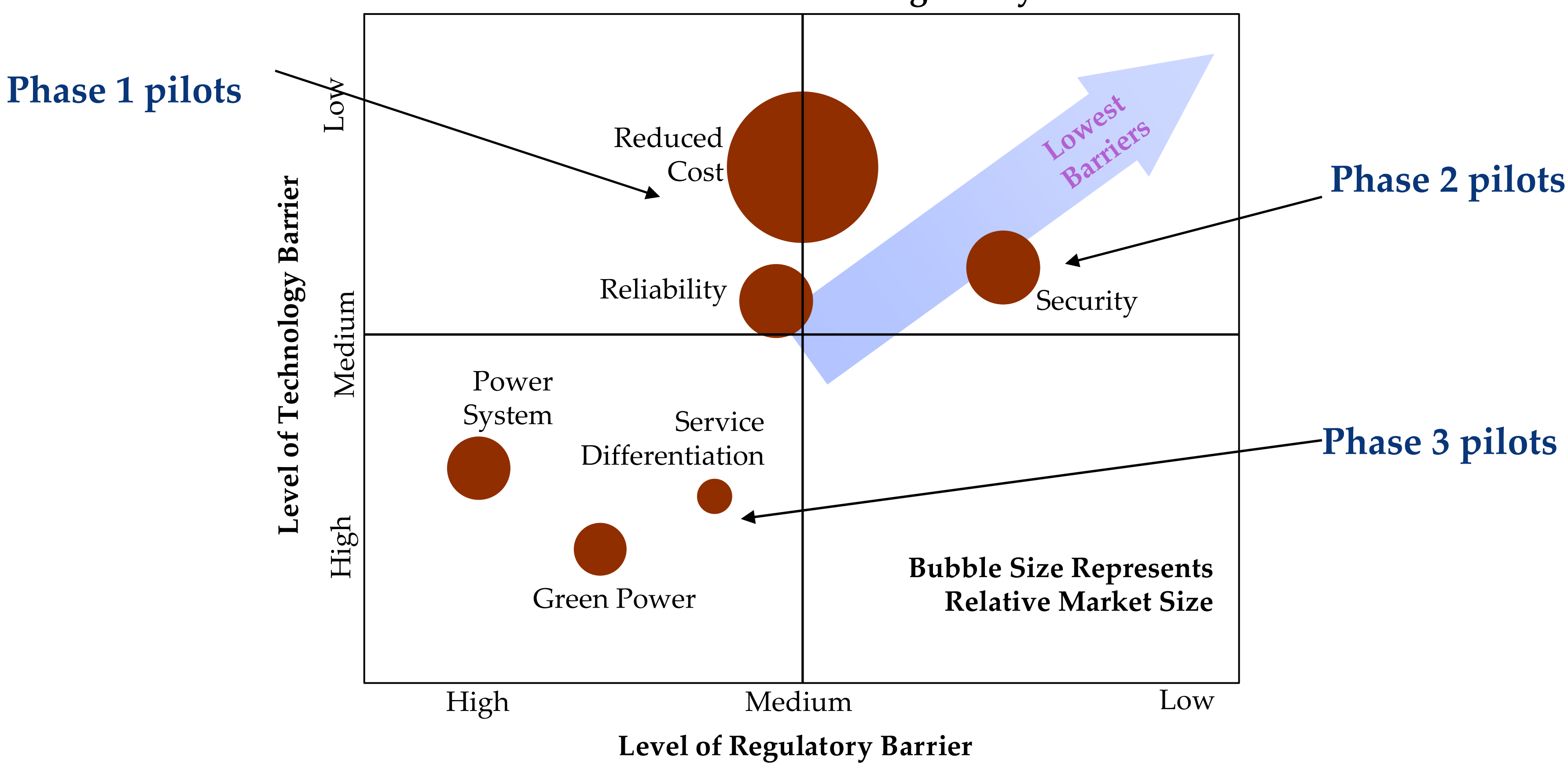
Microgrids support DOE's goals of grid modernization.

Grid Modernization

Attributes	DOE Goals	Microgrid Benefits
Energy Efficiency	Increase efficiency of the electric delivery system through reduced energy losses.	•Lower cost of energy to end users - *estimated 20% - 30% savings vs. CHP based on the business case.* •Improved primary energy efficiency – *> 70% efficient via CHP. Increases the market for CHP by tackling <20MW market.* •Reduced T&D losses – *use of on-site power limits line losses.* •Increased Penetration of Renewables
System Efficiency	Reduce peak price and price volatility of electricity, increased asset utilization and provide accessibility to a variety of fuel sources.	•Power system optimization (reduced volatility, reduced peak prices, fewer constraints) through the provision of services - *microgrids can help manage the intermittency of renewables, provide services, like demand response, system capacity, spinning reserve, T&D relief.* •Increased Penetration of Renewables
Reliability	Strengthen grid stability and reduce the frequency and duration of operational disturbances.	•Improved reliability for microgrid customers - *Microgrids can achieve 99.999% reliability vs. 99.9% for the grid.* •Improved reliability for the entire grid – *provision of services, and integration of renewables can help improve system reliability.*
Security	The energy infrastructure is hardened to detect, prevent and mitigate external disruptions to the energy sector.	•Increased resiliency and security of the power delivery system by promoting the dispersal of power resources. •Provides safe havens – *microgrids provide energy during grid outages.*

There are technical and regulatory barriers that are preventing the deployment of micrograms.

Market Size Relative to Technical and Regulatory Barriers



The pilots should be prioritized based on size of the opportunity and the technical and regulatory barriers.

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Each pilot would address the microgrid regulatory issues that are important to the value propositions demonstrated in that phase.

Phase 1 Pilots

Phase 2 Pilots

Phase 3 Pilots

2020 Regulation Vision	Importance of Regulation: Reduced Cost	Importance of Regulation: Reliability	Importance of Regulation: Security	Importance of Regulation: Green Power	Importance of Regulation: Power System	Importance of Regulation: Service Differentiation	Level of Gap
a) allow competition, while maintaining obligation to serve. b) fairly compensate utilities for services provided and investments made	Med	Med	Low	Med	Med	Med	High
c) provide transparent compensation for environmental, system reliability, and homeland security benefits. d) permit customers to see the real cost of electricity, which include real-time, location, and environmental attributes	Low	Low	Very Low	High	Very High	Med	Med
e) remove barriers to utility deployment of DER	Low	Low	Very Low	Med	High	Low	High
f) adopt nationally recognized interconnection standards	High	High	Med	High	High	High	Low
g) cost recovery of security investments	Very Low	Med	Very High	Very Low	Low	Med	Med

Notes: (1) Level of Regulatory Challenge is defined by combining the importance of the regulatory barrier to delivering the value proposition, and the gap in removing the regulatory barrier.

Microgrids can also be defined by scope of service and ownership.

Microgrid Market Size – Reduced Cost – Base Case Scenario (GW)

Owner	Scope of Service (Size of Microgrid): Single Facility (<2MW)	Multi Facility (2-5MW)	Feeder (5-20MW)	Sub-Station (>20MW)	Total
Utility	0.01	0.7	1.4	0.6	2.7
Muni	0.01	0.4	0.5	0.2	1.2
Landlord	.06	0.5	-	-	0.6
Total	0.09	1.7	1.9	0.8	4.5

Based on analysis for the reduced cost value proposition, 80% of microgrids could be in multi-facility or feeder applications

Scope of Service Definitions and Insights

Scope	Definition and Insights
Single Facility	Smaller individual facilities with multiple loads, e.g. hospitals, schools. Lack of a cost advantage over DG will limit market penetration
Multi Facility	Small to larger traditional CHP facilities plus a few neighboring loads, exclusively C&I. Increased scale provides cost advantages of DG/CHP.
Feeder	Small to larger traditional CHP facilities plus many or large neighboring loads, typically C&I. Increased scale provides further cost advantages.
Sub Station	Traditional CHP plus many neighboring loads. Will include C&I plus residential. Poorer economics due to load factor, decreased thermal loads, and increased infrastructure costs.

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The scope of service demonstrated would increase over the three phases. All ownership types are attractive and should be piloted.

	Scope of Service (Size of Microgrid)			
Owner	**Single Facility (<2MW)**	**Multi Facility (2-5MW)**	**Feeder (5-20MW)**	**Sub-Station (>20MW)**
Utility		Phase 2	Phase 3	
Muni				
Landlord	Phase 1			

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Phase 1 will demonstrate most of the functional requirements, Phases 2&3 will address other high importance functional requirements[1].

Phase 1 Pilots

Phase 2 Pilots

Phase 3 Pilots

Importance of Functional Requirements by Value Proposition

Functional Area	Functional Requirements	Reduced Cost	Reliability	Security	Service Differentiation	Power System	Green Power
Performance Requirements	•Meet IEEE 1547 requirements	high	high	high	high	high	high
	•Power quality	high	high	high	high	high	high
	•Steady-state and dynamic performance	high	high	high	high	high	high
Design	•NEC/NESC code requirements	high	high	high	high	high	high
	•Switching (Generation and Load isolation)	low	low	low	high	high	high
	•Load transfer	low	low	low	high	high	high
	•Line and equipment ratings	med	med	med	med	med	med
	•Regulation (voltage and power factor)	med	med	med	med	med	med
	•Critical loads	low	high	high	high	med	med
Monitoring and Control	•Control system algorithm	low	med	low	high	high	high
	•Frequency (load following)	med	med	med	med	med	high
	•Voltage (load following)	med	med	med	med	med	high
	•Power Factor	low	low	low	low	low	med
	•Load	high	high	high	very high	high	high
	•Generation	high	high	high	high	high	high
	•Communications infrastructure	low	low	low	high	high	high
Protection	•Fault current interruption	low	med	med	med	med	med
	•Coordination (normal vs. reconfigured)	low	med	med	med	med	med
	•Under/Over voltage	low	med	med	med	med	med
	•Fault isolation (voltage and current)	low	med	med	med	med	med
	•Auto synchronization with the grid	low	med	med	high	high	high
	•Black start capability	low	high	high	high	med	low
Operations	•Safety	high	high	high	high	high	high
	•Plan and protocol (O&M plan)	med	med	med	med	med	med
	•Spare parts and inventory	med	med	med	med	med	med
	•labor	med	med	med	med	med	med
Infrastructure	•Utility system and equipment upgrades	low	low	low	low	low	low
	•Interconnection requirements	med	med	med	med	med	med
	•Communication Infrastructure & Controls	low	med	med	med	med	med

1. Phases 2&3 will demonstrate functional requirements that have not been addressed in Phase 1 or are likely to need further emphasis than what could be accomplished in Phase 1.

Gaps in functional requirements could also be closed by focused research on technology platforms.

Functional Area	Functional Requirements	Technology Platforms: Control System – Asset	Control System – Internal	Control System – External	Fast Switch	Energy Storage	Demand Response	Power Electronics	Sensors, processing
Performance Requirements	•Meet IEEE 1547 requirements								
	•Power quality	X	X			X	X		
	•Steady-state and dynamic performance	X	X			X	X		
Design	•NEC/NESC code requirements								
	•Switching (Generation and Load isolation)	X	X		X		X	X	
	•Load transfer	X	X	X	X	X	X		
	•Line and equipment ratings								
	•Regulation (voltage and power factor)	X	X	X	X	X	X	X	X
	•Critical loads								
Monitoring and Control	•Control system algorithm	X	X	X	X	X			X
	•Frequency (load following)	X		X	X	X			
	•Voltage (load following)	X	X	X	X	X		X	
	•Power Factor	X	X	X	X	X		X	
	•Load	X			X	X		X	
	•Generation	X	X		X	X			X
	•Communications infrastructure	X	X	X				X	X
Protection	•Fault current interruption							X	X
	•Coordination (normal vs. reconfigured)		X					X	X
	•Under/Over voltage								X
	•Fault isolation (voltage and current)							X	X
	•Auto synchronization with the grid	X	X	X	X				X
	•Black start capability	X	X	X					
Operations	•Safety								
	•Plan and protocol (O&M plan)								
	•Spare parts and inventory								
	•Labor								
Infrastructure	•Utility system and equipment upgrades								
	•Interconnection requirements								
	•Communication Infrastructure & Controls	X	X	X					

"X" denotes a significant contributor to meeting a requirement

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Each phase would integrate technologies developed on the technology platforms into the pilot demonstrations.

Technology Platforms			Phase 1 Pilots	Phase 2 Pilots	Phase 3 Pilots
Technology Platforms	Control System	Asset			✓
		Internal	✓	✓	
		External		✓	✓
	Fast Switch		✓	✓	
	Energy Storage			✓	✓
	Demand Response				✓
	Power Electronics		✓	✓	
	Sensors, Processing				✓

The proposed approach will allow DOE to achieve the Microgrid Vision.

Microgrid Vision[1] – One GW of Microgrids was installed during the year 2020

Value Proposition

Microgrids are providing added value to society, the grid, and to customers by:
- Improving reliability,
- Reducing the cost of energy and managing price volatility,
- Assisting in optimizing the power delivery system, including the provision of services,
- Providing different levels of service quality and value to customers segments at different price points,
- Helping to manage the intermittency of renewables.
- Promoting the deployment and integration of energy-efficient and environmentally friendly technologies, and
- Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources.

Technology

Technologies exist to support these microgrid value propositions, and can:
- Operate to provide transition between grid-parallel and islanded-operation modes,
- Rely on monitoring, information exchange (including price signals), control technologies, open architecture, and interoperability,
- Fully coordinate financial, physical, and operational elements with the larger power system,
- Integrate demand response, renewables, CHP, storage, power conversion, metering, and other DER, and
- Operate under appropriate interconnection and interoperability standards.

Regulation

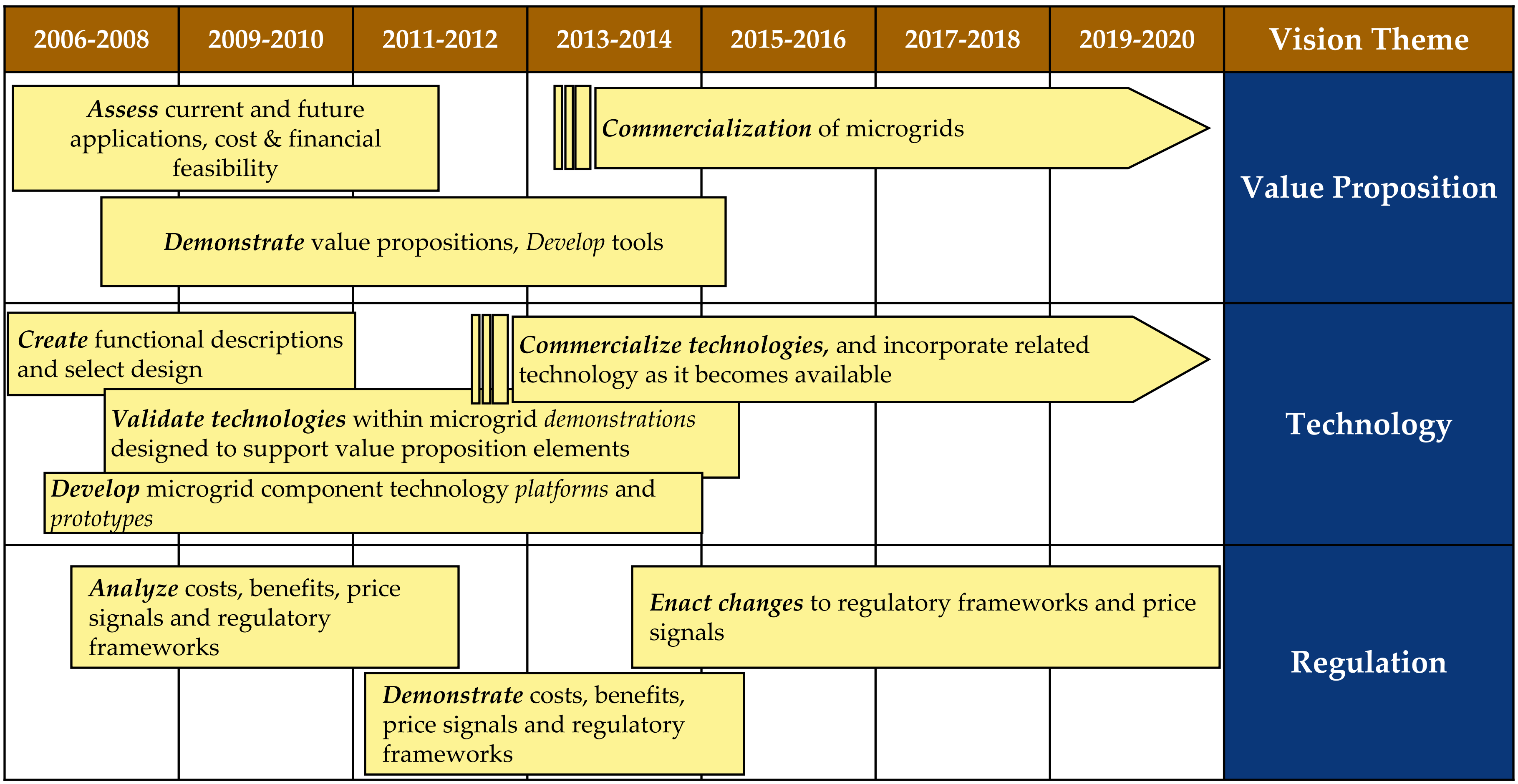
Regulations have changed to:
- Allow competition, while maintaining an obligation to serve,
- Fairly compensate utilities for services provided and investments made,
- Provide transparent compensation for environmental, system reliability, and homeland security benefits,
- Permit customers to see the real cost of electricity, including real-time, locational and environmental attributes
- Remove barriers for utility deployment of DER, and
- Adopt nationally recognized interconnection standards.

Utilities, new investors, and customers own and operate microgrids, under arrangements which allow:
- Utility-owned generation and wires,
- Privately owned generation and wires,
- Hybrid ownership and operational structures.

1. Vision was developed at the Microgrids Visioning Workshop (June 22-24, 2005)

The proposed approach is consistent with the roadmap developed with industry and the research community.

Microgrids Roadmap[1]



1. Roadmap was developed at the Microgrids Visioning Workshop (June 22-24, 2005)

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Are microgrids an attractive area for additional government investment?

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- Are the public benefits attractive?
- Are there technology or policy challenges that require gov't support?

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Based on the interviews, more emphasis should be placed on single and multi-facility microgrids with cost reduction as the primary value.

- Although the working definition provided was generally clear, there was some confusion on the following on
  - How a microgrid is different from DG/CHP
  - What the value of a microgrid is
  - How we created our microgrid working definition
- Stakeholders believed that customers and owners are primarily concerned about cost
  - Reducing costs, improving reliability, and improving price certainty are all seen as very important, but customers are not believed to want to pay for added reliability
  - There could also be a few niche segments who would look at microgrids for security/independence or green power, but these are believed to be limited
  - From an owner perspective, microgrids could potentially fit into existing plans as a cost-effective means to offer premium power or upgrade the distribution system.
- Stakeholders valued reduced cost higher than other value propositions
  - Extra reliability is always valued, but customers are not expected to pay for it
  - Offering differing service levels was seen as contractually difficult and more easily accomplished with back-up DG
- Interviewees thought the business cases should be altered to focus more on single- and multi-facility applications
  - Expansion to an entire feeder or substation is seen as prudent after the microgrid concept has been proven on a smaller scale
  - Microgrids might not offer a significant advantage over DG for single-facilities, but familiarity drives significant interest in single-facility applications

Based on our interviews, the following changes to the microgrid definition and business case taxonomy are recommended.

Microgrid Working Definition

General Definition

A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources which as an integrated system can operate in parallel with the grid or in an intentional island mode[1].

Key Defining Characteristics

The integrated distributed energy resources are capable of providing sufficient and continuous energy to a significant portion of the internal demand. The microgrid possesses independent controls and can island and reconnect with minimal service disruption.

Business Case Taxonomy

Business cases should focus on two key attributes, owner and scope of service:

	Scope of Service			
Owner	Single Facility <2MW	Multi Facility <5MW	Feeder 5-20MW	Sub-Station 20+MW
Utility				
Municipal				
Landlord[2]				

Other attributes can be adjusted as needed to suit customer/owner needs:

- Generation Technology (e.g. natural gas turbines, recip engines, solar)
- Services (e.g. reliability, independece/security, green power)

Notes: 1) Remote power systems that are isolated from larger power distribution systems that are operated as a coordinated system of loads and generation are considered microgrids. 2) A Landlord is a non-utility or non-municipal owner, e.g. university campus, military, airport.

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The purpose of these interviews was to solicit stakeholder feedback about our microgrid definition and business cases.

- Is the *definition* of microgrids clear?
- What are the *customer and owner needs*?
- What is the customer and owner *evaluation of the business cases*?
  - What is the perceived *value* in the microgrid business cases?
  - What other permutations might work better for *potential applications*?

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The interviews followed an interview guide that followed the following topics:

- Part 1: Microgrids Primer (~15 minutes)
  - Review of the Microgrid definition, business cases, value propositions, and DOE and CEC background
- Part 2: Interview
  - A: Customer and owner needs
  - B: Customer and owner perceptions of microgrids / value propositions
  - C: Evaluation of the business cases / suggested changes
  - D: Likely candidates for application, biggest drivers / barriers

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Utilities, municipalities, facility owners, developers, and OEMs were interviewed.

Group	Number of Organizations Interviewed
Utility	4
Municipality	2
Facility Manager	3
Developer	6
OEM	2
Total	17

In Phase 1, a definition was developed that was consistent with other definitions, yet broad enough to focus on business cases.

Technical Attributes / Source of Characterization	Capable of islanded operation	Capable of operating parallel to the grid	Seamless transition from grid-connected to islanded operation if able to operate parallel to grid	Protection within the microgrid for inverter-based sources	Local autonomous control systems	Single point of connection to the grid, if interconnected	Non-interconnected systems can be microgrids
DTE Energy Energy|now Microgrid	●	◑	●			◑	●
CERTS Microgrid Concept	●	●	●	●	●		○
EPRI	●	◑	●			○	◑
European Research Project Cluster	●	◑	●		●	◑	●
Northern Power (Jonathan Lynch)	●	◑	●		●	◑	●
ENCORP (Randy West)	●	●	●				○
NREL (Ben Kroposki)	●	●	●			●	○
GE R&D (Keith White)	●	●	●		●		●

Necessity ● Preferred, but optional ◑ Not required ○ No comment was made – blank cell

In Phase 1, a definition was developed that was consistent with other definitions, yet broad enough to focus on business cases (continued).

Technical Attributes / Source of Characterization	Ability to meet full load requirement	Utility two-way power flow capable	>1 Generation source	> 1 End user facility/ building	Employs CHP	Employs storage devices
DTE Energy Energy|now Microgrid		●	●	●	◑	●
CERTS Microgrid Concept		◑	●		●	●
EPRI	◑		◑	○	◑	
European Research Project Cluster						
Northern Power (Jonathan Lynch)	○		●	◑	◑	◑
ENCORP (Randy West)	○		○	○	◑	
NREL (Ben Kroposki)			◑	◑		
GE R&D (Keith White)		◑	●	●	◑	◑

Necessity ● Preferred, but optional ◑ Not required ○ No comment was made – blank cell

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The interviewees were provided with the Phase 1 microgrid working definition.

Working Definition[1]

- Microgrids are electricity and thermal energy delivery systems that include a collection of loads and Distributed Energy Resources that operate in parallel with a larger power delivery system but possesses independent local control.

This working definition is:

- Consistent with the other definitions
- Broad enough to allow us to transcend technology and focus on the business cases.

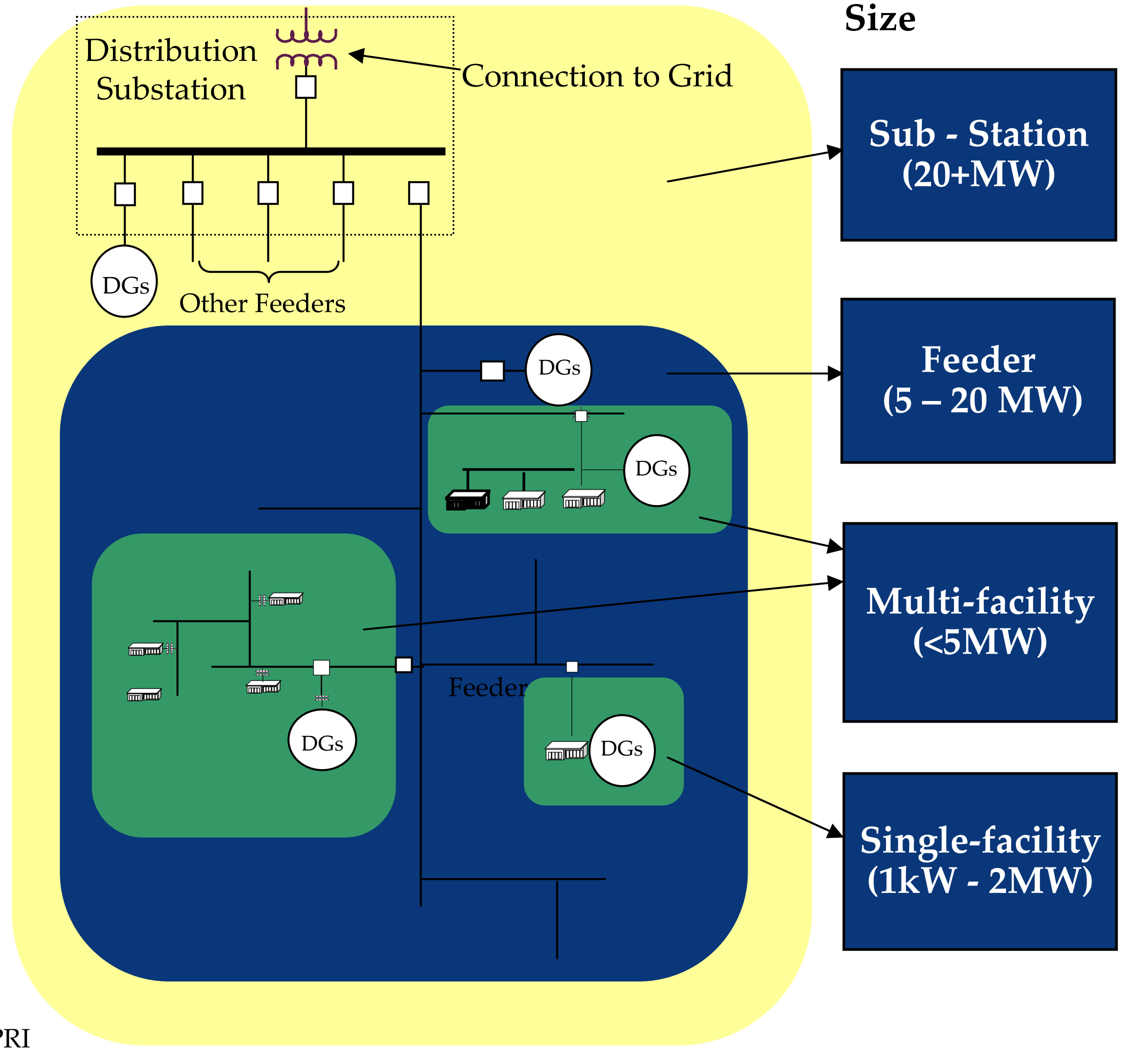
Attributes that can be configured:

- **Size / Customer Base** – change number, type, and size of customers served
  - *Individual customer*, e.g. Industrial facility, commercial park, housing complex (<1MW)
  - *Multi-facility*, e.g. housing sub-division, partial-feeder micro-grid (<2MW)
  - *Feeder*, e.g. custom power for a town + industrial facilities + commercial facilities (2 – 10MW)
  - *Sub-Station*, e.g. municipal power for a larger community (10 – 40MW)
- **Ownership** – utility, landlord, or a muni could own the system
- **Services –** change level of reliability, security, "green energy"
- **Generation Type** – modify type, e.g. gas turbines, photovoltaics, wind power, diesel, oil

1. Developed to facilitate DOE and CEC analysis. Several definitions exist, but differ on the technology requirements. This definition is broad enough to allow us to transcend technology and focus on the business cases.

Microgrids vary in size, ownership, generation and value proposition.

Microgrid Schematic



Note: Adapted from EPRI

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Interviewees generally thought that the working definition was clear, but there were some common questions.

Typical Question	Sample Interview Quotes
How is a microgrid different from DG or CHP?	•"New name on an old concept, but still a good idea." •"I guess you could say that we have microgrids. We have done some CHP installations at hospitals."
What is the value of a microgrid?	•"I'm not sure what value microgrids would offer beyond what a typical DG application offers." •"I'm not sure why I would expand beyond a single-facility application."
How did you get your definition?	•"How does your definition relate to other definitions." •"Our definition is slightly different." •"To me a microgrid must operate fully isolated from the grid."

Examples of what a microgrid is and is not helped clarify the microgrid definition.

What a Microgrid IS	What a Microgrid IS NOT
• A system that includes electricity **and/or** thermal	• Does not have to have thermal (whereas CHP by definition has thermal)
• Multiple loads and multiple generation sources	• One microturbine in a commercial building is not a microgrid, but DG
• Multiple generation sources coordinated to optimize the performance of the loads (a micro-version of the grid)	• A group of individual generation sources that are not coordinated, but run optimally for a narrowly defined load
• The Microgrid is connected to the grid with a "smart switch" that allows control over power flow to the microgrid	• A load or group of loads that cannot be easily separated from the grid or controlled
• The microgrid can be fully isolated or operate in parallel with the grid	

Providing more detail about the value of microgrids also helped interviewees understand microgrids and evaluate the business cases.

Advantages of Microgrids	Disadvantages of Microgrids

• Larger scale allows the choice of larger, cheaper, more robust, more efficient generation technology
• Controls and smart switch could make storage unnecessary
• Aggregation of loads improves the aggregate load factor, and thus the economics of the generation technology
• Increased ability to aggregate loads expands the market of loads able to be served by DG/CHP
• Proximity of the generation to the loads enables CHP where appropriate, but not necessary for economics to be favorable
• Helps utilities defer T&D, increase system reliability, meet capacity needs, meet RPS
• Easier interconnection, lower power electronics costs, improved economics for DG/renewables
	• Regulations may prohibit utilities from using microgrids to avoid making for T&D upgrades
	• In some areas, utility ownership of generation may be prohibited
	• Non-utilities are limited in their ability to generate electricity for multiple paying end-users
	• Higher relative infrastructure costs
	  • Upgrade T&D
	  • Power electronics, e.g. "Smart Switch" to interface with grid
	• Technology not fully available/affordable
	• Visible service level offerings may be unacceptable

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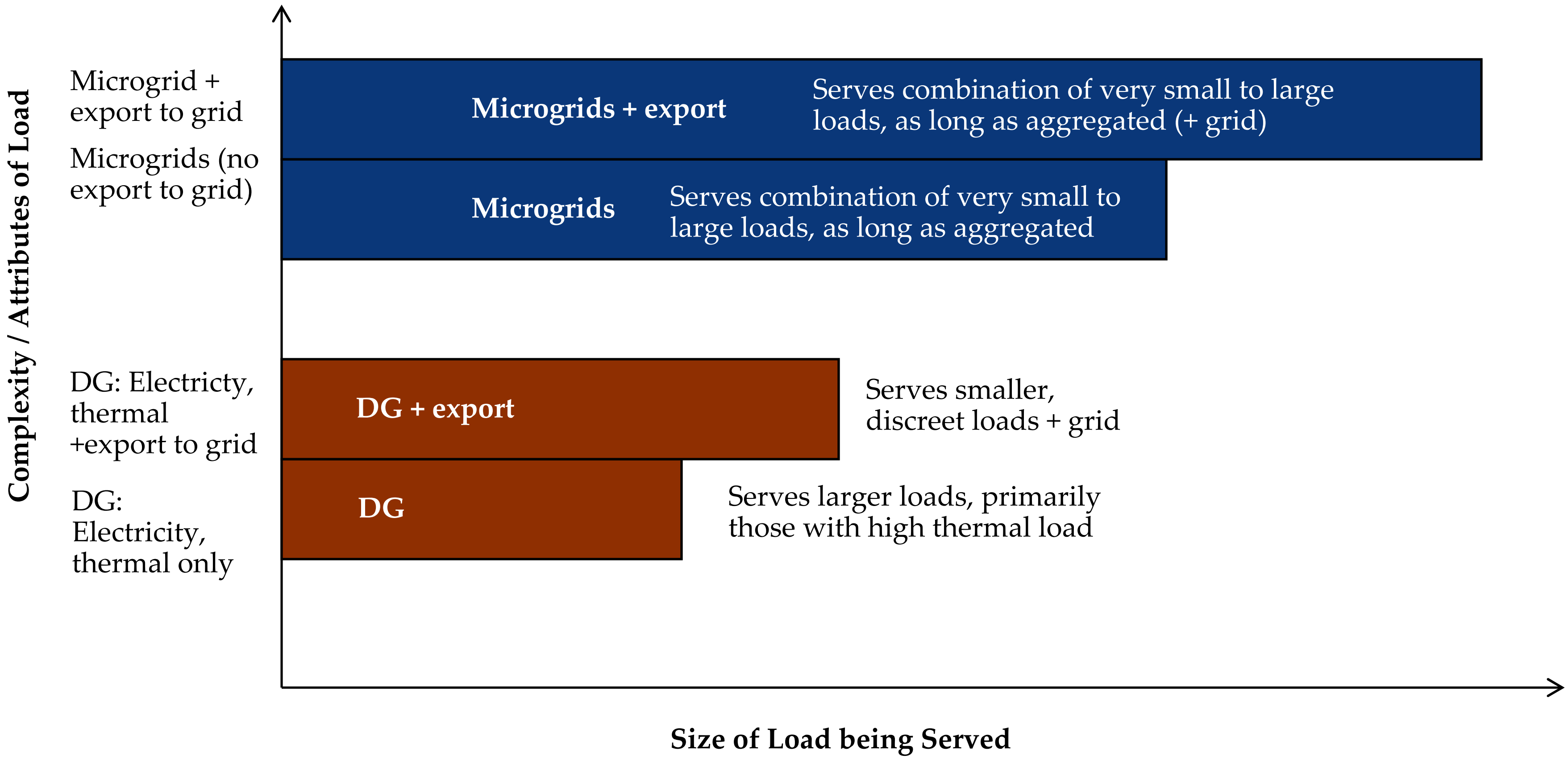
Another explanation that helped was that microgrids could act as an enabler of DG by helping DG serve larger, more complex loads.



Interviewees were asked about assumptions regarding what customers' and owners' needs and willingness to pay.

Market Drivers

Customer's want:

- More product differentiation, e.g. improved reliability, environmental benefits (economics based purely on cost comparison, and did not make assumptions on ability to monetize reliability or other benefits)
- Lower costs, e.g. lower price, reduced volatility

Utilities want:

- Cost effective distribution planning
- To be able to offer products that meet customer needs
- Efficient compliance to public regulations

Public / Governments want:

- Increased reliability / security – driven by 2002 Blackout, Sept. 11th, Increased focus on Homeland Security
- Improved environmental quality
- Less resource dependence
- Reduced siting issues

Value Propositions

Reduced Cost

Independence / Security

Service Differentiation (reliability, power quality, green power)

Potential Answer

Micrographs

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Interviewees believe that customers are most concerned with cost, and will not likely pay for reliability, even though it is very important.

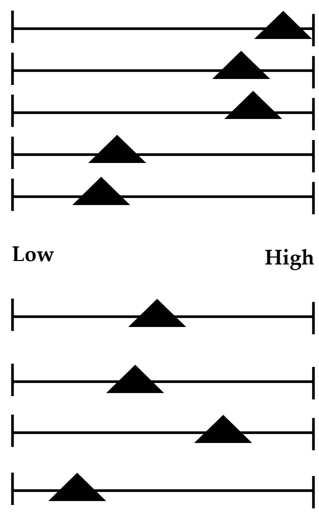
Ranking of Customer and Owner Needs

Market Drivers

Relative Importance[1]

Customer Needs
- Cost
- Price Certainty
- Reliability
- Security / Independence
- Green Power

Owner Needs
- Cost effective distribution planning
- Offer different products
- Offer lower cost products
- Efficient compliance to public regulations



Key Insights

- Customers value cost, price certainty, and reliability very highly
- Customers are unlikely to pay a premium for improved reliability
- Utilities and Municipalities may see some benefits in using microgrids as they upgrade distribution, seek to offer premium power to customers, and lower the cost of service.
- There may be niche markets that need/value "green power", e.g. customer-focused commercial customers like Starbucks, Borders, Whole Foods, REITs
- There may also be niche "safe haven" areas for enhanced security / independence
- Public / Government needs, e.g. improved security, improved efficiency, reduced resource dependence, are not highly visible needs for customers or owners

Note: (1) Interviews asked to comment on relative performance either by ranking needs or scoring each need on a scale of 1-10.

Source: Navigant Consulting interviews with customer and owner stakeholders. See appendix for interview outline and list of interviewees.

The Interviewees were consistent in their views of customer and owner needs.

Key Insight	Sample Interview Quotes
Customers value cost, price certainty, and reliability very highly	•"On a scale of one to ten, I would rank cost a 9, and reliability and price certainty both an 8." •"In our area, volatility has made price certainty the most important factor."
Customers are unlikely to pay a premium for improved reliability	•"Customers are not willing to pay for extra reliability, but demand it." •"I've seen customers see audits proving how much they lost due to poor reliability, and they still refuse to pay for additional reliability."
Utilities and Municipalities see benefits in dist. upgrade, offer premium power, and lower cost of service.	•"We are working on updating our infrastructure – building a 'grid of the future.' A microgrid might help us in that endeavor." •"This could fit into our 3rd generation distribution design as well as plans to provide premium power to customers."
Niche markets may exist for green power	•"REITs sometimes push for better environmental quality for their buildings" •"Certain consumer-oriented commercial customers may pay more for green power, e.g. Starbucks"
Niche markets may exist for independence / security	•"For national security reasons, I would imagine there could be some need for a few 'sanctuary locations'." •"The biggest driver for microgrids could come from another big blackout."
There may be a misalignment of public/ government needs with those of customers/ owners	•"I can see why government is concerned about independence and security, but I don't think it is a big need of customers or owners." •"I don't see a big pull from customers or owners on green power or independence/security."

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Interviewees were asked to comment on the permutations of a microgrid selected for the business cases and the value propositions addressed.

Microgrid Business Case	Microgrid Owner / Operator	Customer	Value Proposition Addressed: Custom Energy	Value Proposition Addressed: Independence / Security	Value Proposition Addressed: Reduced Cost
Custom Power	Electric Utility (IOU or REC)	End users that want custom energy solutions	✓		
Municipal Energy	Municipal Utility	Municipality	✓	✓	✓
Renewables	Municipal Utility, IOU or REC	End users that want 100% "green energy"	✓		
Landlord / Aggregator	"Landlord"	Multi-Facility Tenants			✓
		Single-Facility Tenant			✓

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Interviewees valued reduced cost higher than other value proposition proposed for the business cases.

Microgrid Business Case	Value Proposition Addressed				
	Custom Energy			Independence / Security	Reduced Cost
	Differentiated Reliability	Increased Reliability	Green Power		
Custom Power	○	◐			●
Municipal Energy	○		○	◐	●
Renewables	○		○		
Landlord / Aggregator		◐	◐		●
		◐	◐		●

● High Value ◐ Medium Value ○ Low Value

Value propositions other than reduced cost were not valued as high, but are important for the success of micrograds.

Key Insight	Sample Interview Quotes
Cost is the primary value	•"Cannot justify microgrids on one value proposition alone. Need to have lower cost plus some other compelling need." •"Cost is most important."
Custom Power, i.e. differentiated serve levels, not valued	•"I don't think we could commercialize differing service levels, and I don't think customers would accept different service levels." •"may not be possible to offer different service levels, and customers will not accept lower service levels than others."
Independence / Security	•"For national security reasons, I would imagine there could be some need for a few 'sanctuary locations'." •"I don't think customers differentiate much between independence/security and reliability." •"I can see why government is concerned about independence and security, but I don't think it is a big need of customers or owners."
Increased Reliability	•"Most of our customers are looking for increased reliability." •"Reliability is a key driver for people wanting a microgrid, but they will not pay extra for it."
Green Power / Renewables not valued components	•"I'm not sure why you included renewables. I guess I don't see the link to microgrids." •"The 'green' segment may be the only segment willing to pay a premium." •"I am not sure how much customers see in the value of renewables, but there are customers who want them. Microgrids could help reduce the engineering and permitting costs of renewables."

Landlords expressed more interest for microgrids, primarily because they see more economic value, but are constrained by regulations.

Evaluation of Business Cases

Owner	Overall Interest
Utility	low-med
Municipal	med-low
Landlord	med

Scale

Low	Low-Med	Med-Low	Med

→ Increasing Interest

Sample Interview Quotes

•"I don't think there would be much interest because I think the costs will be prohibitive outside a few niche situations." •"Utilities will be cautious." •"Microgrids would be a good idea if we could solve the regulatory issues, technical issues, and economic issues. The technical and economic issues are probably easier than the regulatory issues." •"We are definitely interested in microgrids."
•"I do believe we will see more microgrids." •"We are currently doing microgrids, and we just had a call from a new prospective customer." •"I think municipalities will be fairly receptive to microgrids."
•"The Landlord models would rank about an 8 on a scale of 1-10, whereas the Custom Power, and Municipal would all be at a 5." •"Customers are really open to microgrids in the right applications." •"I don't think it is possible from a regulatory perspective for a developer to go beyond a multi-facility applications - they would become a utility." •"I would like to be able to aggregate more loads from an economic perspective, but that can be difficult from a contractual and business process standpoint."

Source: Navigant Consulting interviews with customer and owner stakeholders.

Interviewees saw more opportunity for single facilities now, but predicted greater promise for multi-facilities in the long-term.

Custom Power

Scope of Service			
Single Facility (<2MW)	Multi-Facility (<5MW)	Feeder (5-20MW)	Substation (20+MW)
low	low-med	low	low

Utilities will want to start with smaller applications

Sample Interview Quotes

- "There are many applications where we could test a microgrid, but we would want to prove the concept at a smaller scale first, then maybe we would want to expand."
- "The costs could be very high, thus making applications beyond a few select applications very difficult."
- "Very unique situations can run – can be cost effective."

Municipal

Scope of Service			
Single Facility (<2MW)	Multi-Facility (<5MW)	Feeder (5-20MW)	Substation (20+MW)
low-med	med-low	low	low

Municipalities will want to start with smaller applications

Sample Interview Quotes

- "I can see potential applications at hospitals, and others who need increased reliability. I can't imagine expanding beyond a few facilities, especially into residential."
- "Applications will likely be in niche applications like hospitals, airports, universities, data centers, casinos, military bases. I don't see expanding beyond these type of applications in the short term."

Landlord

Scope of Service			
Single Facility (<2MW)	Multi-Facility (<5MW)	Feeder (5-20MW)	Substation (20+MW)
med	med	n/a	n/a

Landlords have interest in both single and multi-facilities

Sample Interview Quotes

- "Despite the [legal] difficulty, the multi-facility business model is much more attractive. How would the single facility landlord model differ significantly from plain DG?"
- "I would really like to be able to aggregate more loads like in the multi-facility model."
- "I am more familiar with the single-facility model."
- "Less financial risk and easier exit strategy with the single facility."

Scale

Low	Low-Med	Med-Low	Med

Increasing Interest →

Source: Navigant Consulting interviews with customer and owner stakeholders.

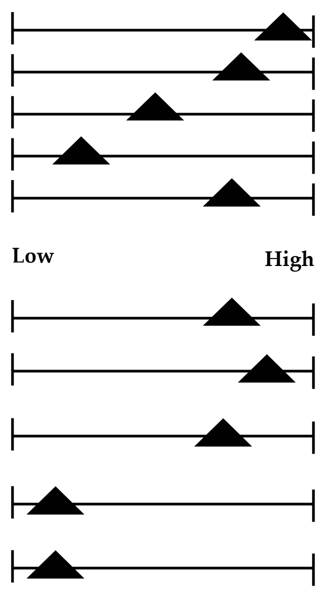
Interviewees also signaled preferences for single and multi-facility applications when naming candidates for potential applications.

Most Likely Near-Term Microgrid Applications

Application | **Frequency[1]**

Multi-facility
- School campus
- Military Facility
- Airports
- Remote villages
- Medical campuses

Single-Facility
- Hospitals
- Industrial Facilities with high steam loads
- Commercial Facilities with high steam loads
- Commercial Facilities wanting Green Power
- Agriculture, e.g. chicken farms



Key Insights

- Strong overlap with CHP market
- Applications chosen because of high reliability needs as well as steam needs
- Applications are most suitable for a multi-facility or a single-facility business model
- Applications at the feeder or substation level, were not top of mind or did not receive as much support
- Aggregating load at the feeder or substation level was seen as difficult and potentially uneconomical

Note: (1) Interviews asked to comment on relative performance either by ranking needs or scoring each need on a scale of 1-10.

Source: Navigant Consulting interviews with customer and owner stakeholders. See appendix for interview outline and list of interviewees.

Overall, the primary interest lies in single or multi-facility applications until some key barriers are overcome

Level of Interest in Microgrid Business Cases

	Scope of Service			
Owner	**Single Facility**	**Multi Facility**	**Feeder**	**Sub-Station**
Utility	low	low-med	low	low
Municipal	low-med	med-low	low	low
Landlord	med	med	n/a	n/a

Scale

Low	Low-Med	Med-Low	Med

→ Increasing Interest

Key Barriers

Utility	•Economics - • Will microgrids be cost competitive? • Will there be a good business model for utilities? •Regulatory - Can utilities own generation? Cost-allocation? •Technical - Can the technology be proven such that utilities are comfortable expanding to a larger scale?
Municipal	•Economics • Will microgrids be cost competitive? • Will there be a solid business model for municipalities? •Technical - Can the technology be proven such that municipalities are comfortable expanding to a larger scale?
Landlord	•Economics • Can landlords be successful in the business of aggregating load / advance past traditional applications? • Will microgrids offer a significant value proposition at the single facility? •Regulatory • How much load can landlords aggregate?

Source: Navigant Consulting interviews with customer and owner stakeholders.

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The objective of the market & benefits assessment was to understand the size of the market opportunity and the resulting benefits.

Phase 2

Task 1 — Customer / Owner Interviews

- Understand customer needs
- Test value proposition of 3 business cases
- Identify changes to business cases
- Identify potential applications and challenges

Task 2 — Technical & Functional Assessment

- Identify technical and functional requirements of 3 business cases
- Assess ability of current technology to satisfy functional requirements
- Examine approaches to overcome technical gaps

Task 3 — Market & Benefits Assessment

- Estimate the potential size of the microgrid market
- Understand public benefits resulting from microgrids

Task 4 — Workshop

- Solicit feedback & input from microgrid owners, customers, researchers, equipment suppliers
- Develop a consensus vision & roadmap for microgrids

Task 5 — Final Report

- Final report which clearly answers overall objectives of Phase II and incorporates insights from multiple stakeholders

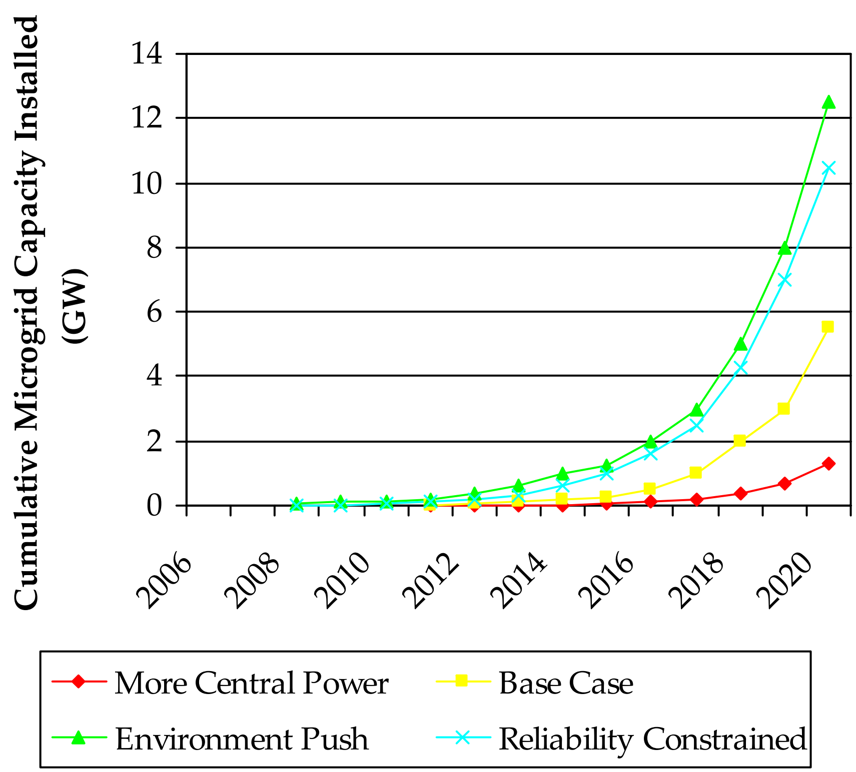
The potential microgrid market is attractive and will be driven by the ability of microgrids to provide energy at a reduced cost.

- Depending on the market conditions for 2020, microgrids could capture between 1 and 13 GW by the year 2020.
- Each microgrid value proposition will increase the attractiveness and the size of the microgrid market, and the additional penetration caused by each value proposition will depend on how favorable 2020 market conditions are to the value propositions.
- Although microgrids will provide numerous benefits and different sources of value to customers, reduced cost will be the primary driver of microgrid market penetration.
- Significant benefits would accrue to society, totaling almost half a billion dollars in annual benefit by the year 2020 in the base case.
- The largest market applications will be for groups of commercial and industrial customers between 2 and 20MW of total demand.

Note: The market assessment assumes that regulations and technical challenges identified in the workshop will be overcome

Microgrids could capture a market size in 2020 between 1 GW and 13 GW, depending on market conditions.

Microgrids could capture a market size in 2020 between 1 GW and 13 GW



Actual deployment in 2020 is highly dependent on market conditions

- If conditions are similar to today, deployment could be 5.5 GW as represented in the Base Case scenario
- If conditions are less favorable for microgrids (e.g. spark spreads deteriorate, there are minimal advances in DG technologies), microgrids could capture approximately 1 GW.
- If conditions for microgrids improve either, for example through higher environmental constraints or though higher reliability needs, the market could be 10 GW to 13GW as represented in the Environmental Push and Reliability Constrained scenarios

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Microgrids are well positioned to help address some of the key challenges facing the grid.

Microgrid Value Propositions

- **Reduced Cost** – Reducing the cost of energy and managing price volatility
- **Reliability** – Improving reliability
- **Security** – Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources
- **Green Power** – Helping to manage the intermittency of renewables, Promoting the deployment and integration of energy-efficient and environmentally friendly technologies
- **Power system** – Assisting in optimizing the power delivery system, including the provision of services
- **Service differentiation** – Providing different levels of service quality and value to customers segments at different price points

Challenges Facing the Grid

- Power quality
- Reliability
- Lack of new investment in the grid
- Greater demand on the grid
- Vulnerability to natural disasters and terrorist attacks
- DG required to shut down during a disturbance on the grid
- Intermittency of renewable sources
- Environmental constraints
  - Emissions
  - Siting of generators and transmission lines

The total microgrid market in each scenario is driven by individual microgrid value propositions.

Today

2020 Scenario

Microgrid Attributes	More Central Power	Base Case	Reliability Constrained	Environmental Push
Reduced Cost	1.0	4.5	4.5	8.0
Reliability	0.1	0.4	2.0	1.0
Security	0.2	0.4	2.0	0.4
Green Power	<0.1	0.2	0.2	3.0
Power System	<0.1	<0.1	1.0	<0.1
Service Diff.	<0.1	<0.1	0.5	<0.1
Total	1.3 GW	5.5 GW	10.2 GW	12.6 GW

Notes:

- Microgrids must be able to deliver energy at favorable costs. As the Phase 1 analysis determined, the primary drivers behind microgrid economics are the spark spread and the cost of the generation technology.
- The market assessment assumes that regulations and technical challenges identified in the workshop will be overcome

Selected scenarios were chosen to illustrate how microgrids could perform given select market conditions, but do not represent "likely" or "desired" scenarios.

Each value proposition will incrementally increase the size of the market; the range of penetration will depend on market conditions.

Microgrid Market Penetration Estimates in 2020 – (GW)

Value Proposition	Main Sensitivity Driver	Favorability of Market Conditions: Less Favorable (Very Low)	Base Case (Low)	More Favorable (Medium)	Most Favorable (High)	
Reduced Cost	Size of CHP Market	1	4.5	8	12.5	NCI Market Assessment(1)
Reliability	Value of Reliability / Size of Stand-by Power Market	0.1	0.4	1	2	
Security	Government Policies for Safe Havens	0.2	0.4	2	5	NCI Estimates(2)
Green Power	Size of Renewables Market / Need to Manage Intermittency of Renewables	<0.1	0.2	1	3	
Power System	Power System Constraints	0	<0.1	0.5	1	
Service Differentiation	Market Size of Customers Seeking Premium Power / Service Differentiation	0	<0.1	0.25	0.5	

Although microgrids will provide different benefits and sources of value to customers, reduced cost will be the primary driver of microgrid market penetration.

Source: (1) Based on NCI Market Assessment including the technical market potential, microgrid relative market economics, market penetration rate, and market expansion potential. Details provided in Market Assessment.
(2) Based on the relative market size to the Reduced Cost market and supporting calculations..

Microgrid benefits could total approximately $1 billion per year by 2020 under the base case scenario.

Annual Microgrid Benefits – Base Case Scenario ($Billion)

Category	2015	2016	2017	2018	2019	2020
Energy Efficiency	$0.02	$0.03	$0.07	$0.13	$0.2	$0.36
System Efficiency	$0.00	$0.00	$0.01	$0.01	$0.02	$0.04
Reliability	$0.00	$0.00	$0.01	$0.01	$0.02	$0.04
Security	$0.00	$0.00	$0.00	$0.01	$0.01	$0.01
Emissions[(1)]	$0.02	$0.05	$0.10	$0.20	$0.29	$0.55
Total	$0.04	$0.09	$0.18	$0.36	$0.54	$1.0

Annual Emission Reductions – Base Case Scenario (tons)

Emission	2015	2016	2017	2018	2019	2020
CO_2	793,000	1,590,000	3,170,000	6,340,000	9,510,000	17,400,000
SOx	4,000	9,800	19,700	39,400	59,100	108,000
NOx	821	1,640	3,290	6,570	9,850	18,000

Examples of Benefits in 2020

- $360MM in energy savings due to 10% reduction in energy bills at ~0.5% of U.S. total capacity
- 550 microgrids of an average 10MW serving primarily C&I markets with improved reliability and supporting grid stability.
- Forty or more communities with 10MW of facilities that can have energy during a grid outage.
- 200MW of renewable energy deployed within a microgrid.
- Reduction of 17.4 Million tons of CO2, 108,000 tons of SOx, and 18,000 tons of NOx.

Notes: (1) Assumes emissions emission prices per ton of $25 for CO2, $5,000 for NOx, and $200 for SOx. SOx and NOx prices are based on 2005 prices, and CO2 prices based on low-range estimates of carbon prices from the Massachusetts Institute of Technology's EPPA model.

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The largest applications will be for clusters of commercial and industrial customers ranging between 2-20MW in total size.

Microgrid Market Size – Reduced Cost – Base Case Scenario (GW)

	Scope of Service (Size of Microgrid)				
Owner	**Single Facility (<2MW)**	**Multi Facility (2-5MW)**	**Feeder (5-20MW)**	**Sub-Station (>20MW)**	**Total**
Utility	0.01	0.7	1.4	0.6	2.7
Muni	0.01	0.4	0.5	0.2	1.2
Landlord	.06	0.5	-	-	0.6
Total	0.09	1.7	1.9	0.8	4.5

Based on analysis for the reduced cost value proposition, 80% of microgrids could be in multi-facility or feeder applications

Scope of Service Definitions and Insights

Single Facility	Smaller individual facilities with multiple loads, e.g. hospitals, schools. Lack of a cost advantage over DG will limit market penetration
Multi Facility	Small to larger traditional CHP facilities plus a few neighboring loads, exclusively C&I. Increased scale provides cost advantages of DG/CHP.
Feeder	Small to larger traditional CHP facilities plus many or large neighboring loads, typically C&I. Increased scale provides further cost advantages.
Sub Station	Traditional CHP plus many neighboring loads. Will include C&I plus residential. Poorer economics due to load factor, decreased thermal loads, and increased infrastructure costs.

Future research needs to be tailored to enable the development of the most attractive markets.

Microgrid Penetration – Reduced Cost – Base Case Scenario (GW)

	Scope of Service (Size of Microgrid)				
Owner	**Single Facility (<2MW)**	**Multi Facility (2-5MW)**	**Feeder (5-20MW)**	**Sub-Station (>20MW)**	**Total**
Utility	0.01	0.7	1.4	0.6	2.7
Muni	0.01	0.4	0.5	0.2	1.2
Landlord	.06	0.5	-	-	0.6
Total	0.09	1.7	1.9	0.8	4.5

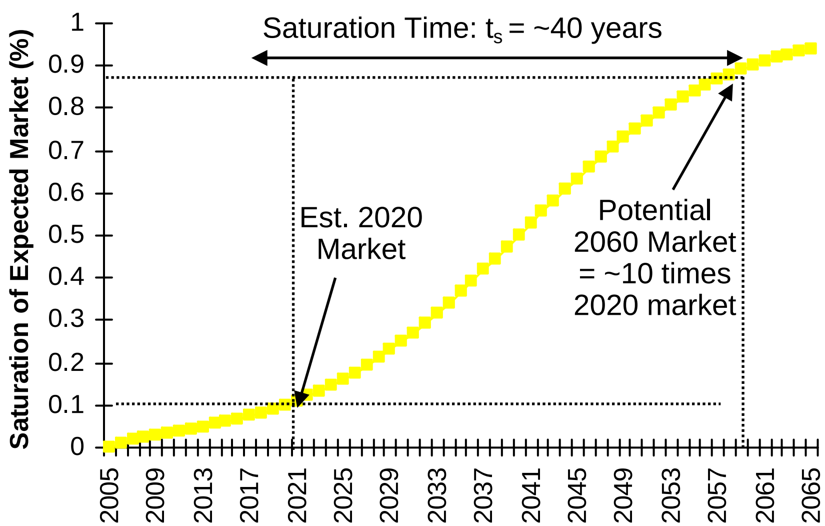
80% of microgrids (particularly for reduced cost) could be in multi-facility or feeder applications

Key Insights

- Single facility applications do not provide significant benefits over pure CHP/DG applications; therefore, the market for single facilities is low
- Multi facility and Feeder applications offer significant value from reduced cost arising from the increased scale and improved reliability.
- The economics for Sub-station applications deteriorates due to the increased need for electric distribution infrastructure and deteriorated load profiles of customers.

Microgrids, if proven viable, are likely to expand significantly after 2020.

Fisher-Pry S-Curve adapted to Microgrid



Explanation and Implications

- Projections are based on S-Curve analysis performed by Fisher and Pry in 1971 that showed that market penetration of technologies follows S-Curves
- The analysis showed that different classes of technologies penetrate at differing rates
- Microgrids are likely to fall into a class of technologies that adopts slowly (~40 years to saturate expected market) unless some of its characteristics change
- Because microgrids are likely to adopt slowly, the estimated market in 2020 is likely to be only a small portion of the long-term potential

Previous research suggests that the basis for microgrid markets will be around the value propositions, owner, and scope of service.

Insights from Previous Research

- Phase 1 developed the hypothesis that microgrids deliver a few key value propositions: custom energy, independence/security, and reduced cost
- Phase 1 showed that microgrids have the potential to be economically competitive in certain business cases
- Interviews with customers and owners revealed that the attractiveness of the business cases depends primarily on the owner and scope of service
- Customers and owners also stated that reduced cost would be the primary value proposition to drive market penetration. Other value propositions would increase the microgrid market, and could grow as market conditions change.
- The workshop clearly defined the value propositions and provided insights into how the total market size could grow as market conditions change.

Value Propositions

- **Reduced Cost** – Reducing the cost of energy and managing price volatility
- **Reliability** – Improving reliability
- **Security** – Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources
- **Green Power** – Helping to manage the intermittency of renewables, Promoting the deployment and integration of energy-efficient and environmentally friendly technologies
- **Power system** – Assisting in optimizing the power delivery system, including the provision of services
- **Service differentiation** – Providing different levels of service quality and value to customers segments at different price points

Business Cases

	Scope of Service			
Owner	**Single Facility**	**Multi Facility**	**Feeder**	**Sub-Station**
Utility				
Municipal				
Landlord				

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Reduced cost is the primary value to customers/owners; microgrids are relatively well positioned to deliver this value propostition.

Value Proposition	Value to Customers/ Owners[1]	Ability of Microgrids to Deliver Value vs. Alternate Technologies[2]	
		Near term	Longer term considerations
Reduced Cost	High	Medium	By aggregating loads, microgrids can reduce costs and manage price volatility. The ability to reduce costs depends on the spark spread, generation technology, infrastructure of the microgrid – similar to CHP.
Reliability	High	Low	For most customers it is currently cheaper to provide improved reliability with back-up power. If the overall reliability of the grid deteriorates, microgrids may become a more attractive option to improve reliability.
Security	Medium	Medium	Microgrids are likely to be well positioned to provide grid resiliency and safe havens in both the near and long-term
Green Power	Medium	Low	As renewable energy sources become more prevalent, the value of microgrids could increase as a tool for managing intermittency and interconnection with the macrogrid.
Power System	Low	Low	Where siting issues are prevalent for transmission, distribution, and generation, microgrids could become more attractive means of optimizing the power system.
Service Differentiation	Low	Medium	Although service differentiation is not believed to be a high priority for customers or owners, microgrids might be the best option to provide differentiated service in the niche applications where it is desired. As energy consumption trends change, customers may demand increased reliability in their electricity service.

Source: (1) Customer / Owner Interviews, Microgrids Visioning Workshop (June 22-24 2006), NCI analysis

● High ◑ Medium ○ Low

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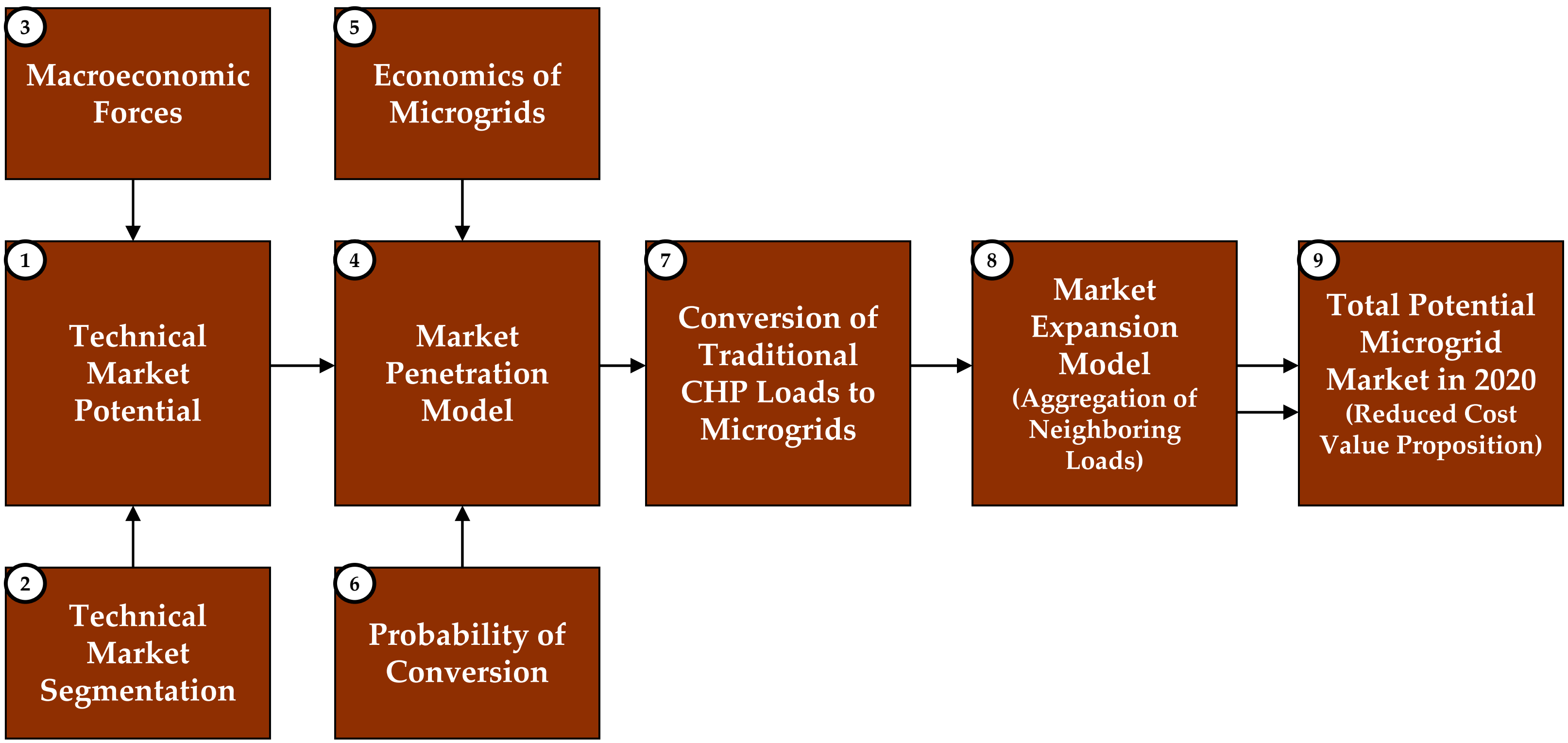
The reduced cost market is determined by estimating the ability of microgrids to penetrate the CHP market and expand by aggregating neighboring loads.

Market Sizing Methodology – Reduced Cost



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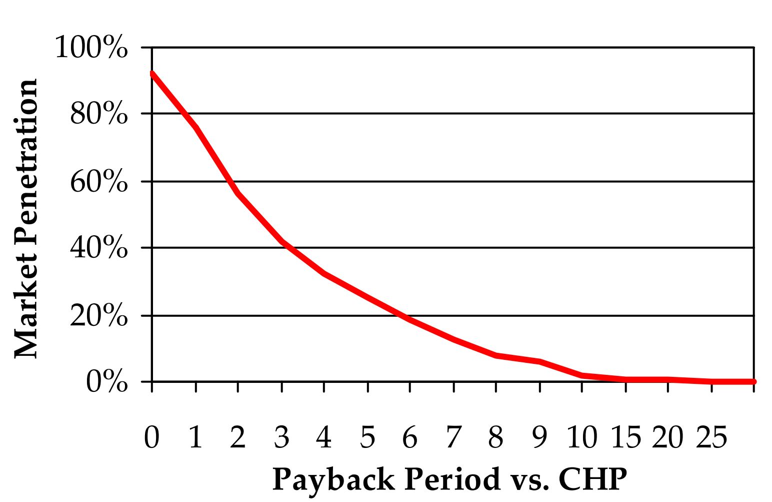
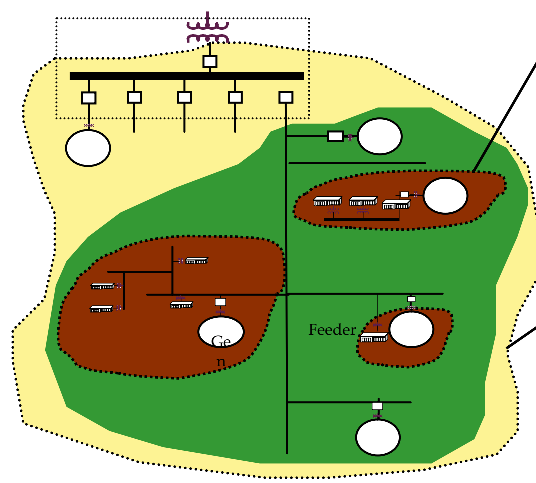
At the core of the reduced cost model are market penetration models and a market expansion model.

Based on the payback vs. CHP, what level of market penetration will microgrids realize?



- Relies on previous analysis that estimate actual market penetration based on payback
- Each business case/scope of service will have different penetration rates because 1) economics are different and 2) likelihood of business case occurring is different, e.g. single-facility is more likely to occur than a substation

Based on the size of the microgrid, how much neighboring load will a microgrid aggregate?



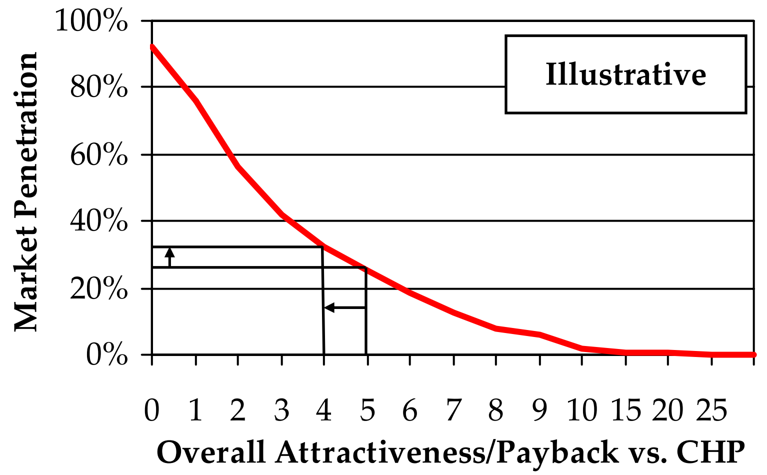
Multi-Facility: More likely to occur, limited aggregation of load

Substation: Less likely to occur, large opportunity to aggregate load

- Amount of aggregated load is based on a typical size of a microgrid application and a typical size of a single facility application

The market sizes for other values are based on their potential impact on overall microgrid market penetration.

Other values can improve the overall attractiveness of microgrids vs. CHP



• Customers and Owners will choose microgrids primarily based on reduced costs, but other values could improve the overall attractiveness of a microgrid and increase market penetration

Supporting Calculations

Reliability	% of projected market for back-up generators that uses microgrids instead of back-up power
Security	Number of communities using microgrids to provide energy for critical facilities or safe havens
Green Power	% of green power market that is deployed within a microgrid
Power System	Number of feeders upgraded using a microgrid
Service Differentiation	Number of residential and commercial customers served by a microgrid for premium power

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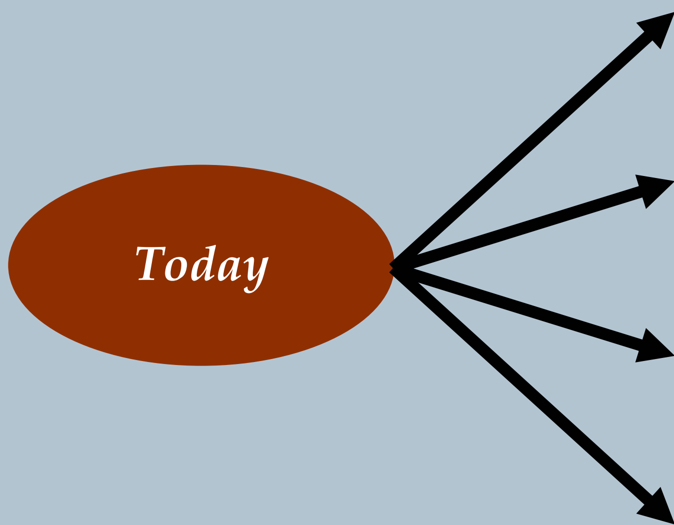
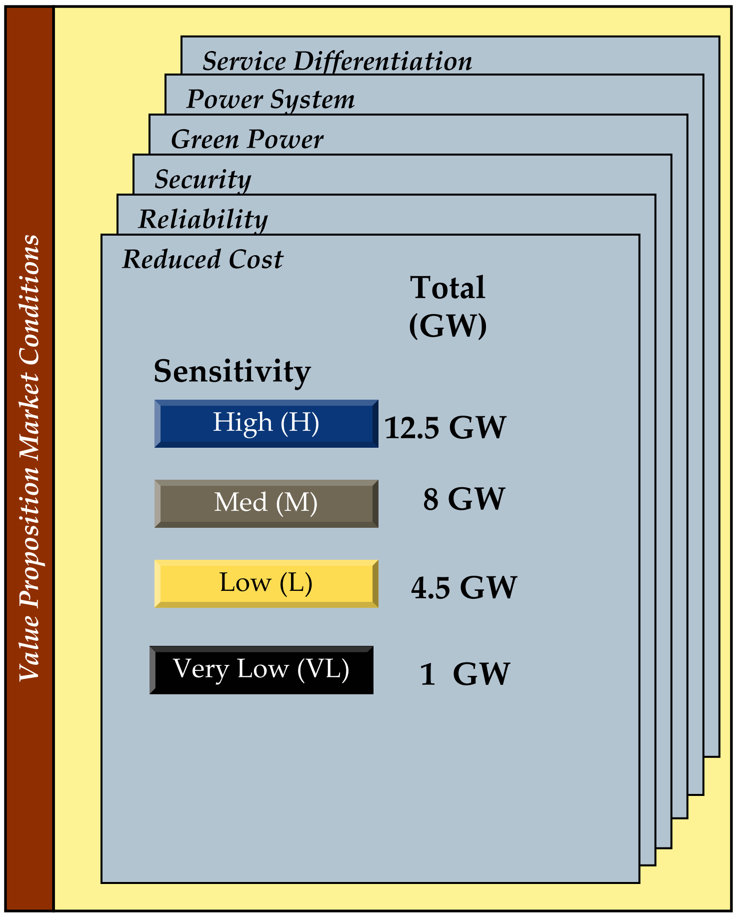
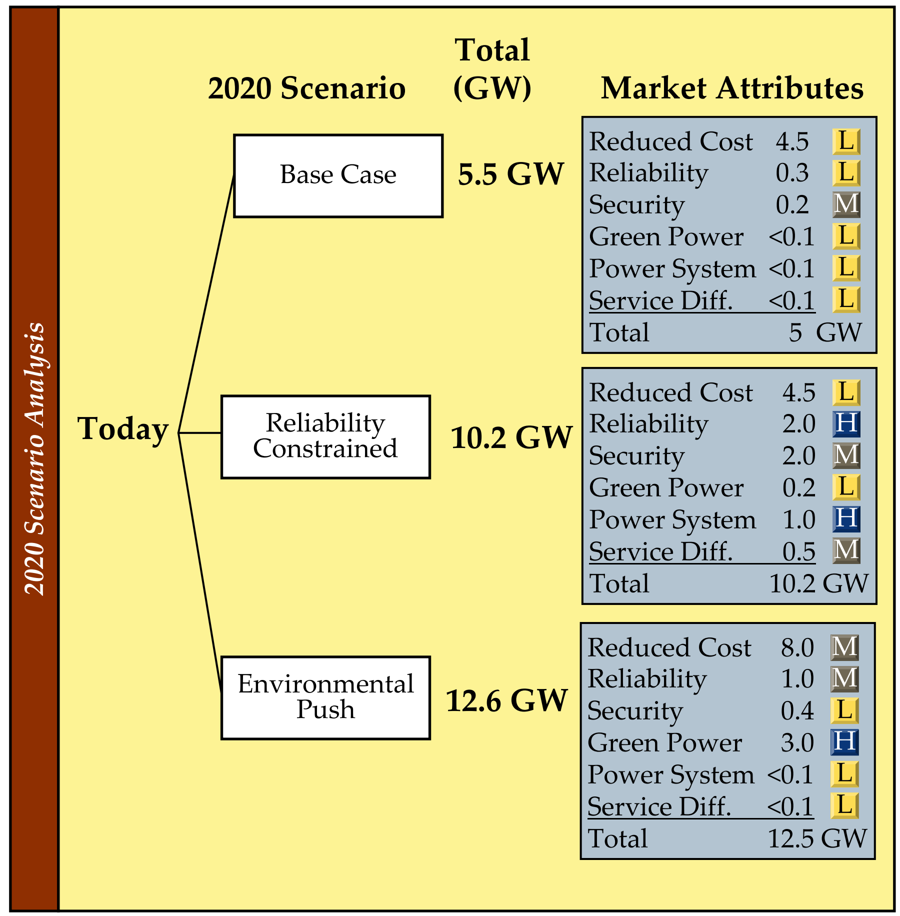
For each value proposition, the market contribution is estimated for different market conditions in 2020.



Market Conditions	Favorability Towards Microgrids
High (H)	Most favorable market conditions for microgrids exist.
Med (M)	Market conditions are more favorable for microgrids than in 2005, but conditions not ideal.
Low (L)	Similar conditions exist as in 2005.
Very Low (VL)	Market conditions have changed so that microgrids are less favorable than in 2005.

Composite scenarios are shown to illustrate how the total microgrid market could change.





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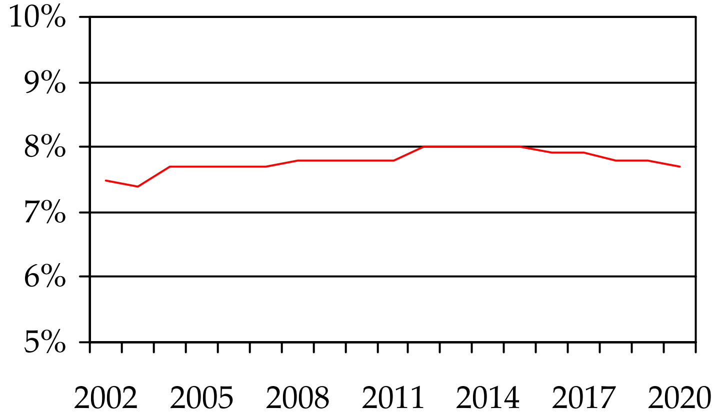
The technical market potential for microgrids for the purpose of this analysis is the estimated new CHP additions through 2020.

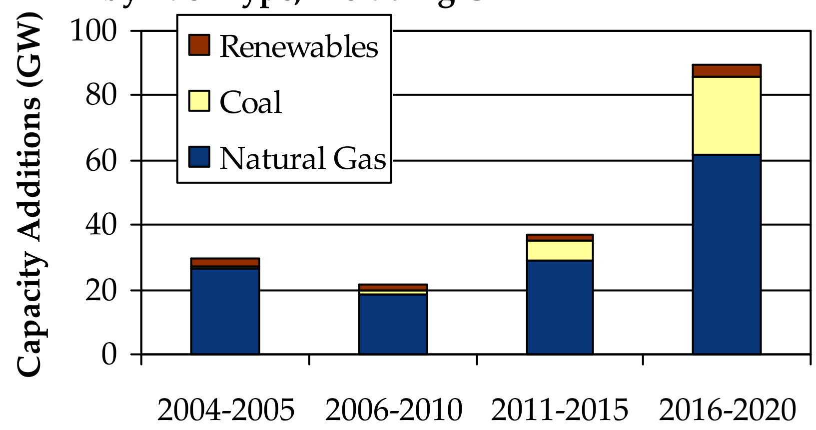
- Phase 2 interviews revealed that stakeholders believe that potential applications for microgrids would be similar to those of CHP, e.g. hospitals, university campuses, airports and other facilities with high thermal load and reliability needs.
- The Phase 1 economic analyses showed that microgrids should be economical in similar buildings and applications as CHP because they have very similar cost drivers, e.g. spark spread, capital costs of the generation technology, load shape of the customers.
- Phase 2 interviews indicated that cost was a key concern for microgrid deployment, and Phase 1 analysis showed the importance of CHP in reducing the costs of microgrids.
- Given our approach, the estimates of new CHP additions should provide a good basis for the technical market potential for microgrids.

For the microgrid technical market potential, EIA estimates of 8.5 GW of new CHP additions through 2020 was used.

CHP Share of Electricity Capacity, EIA Annual Energy Outlook Projections(1)



Electricity Generation Capacity Additions by Fuel Type, Including CHP(2)



Estimate of New CHP Capacity Additions

	Time Period			
	2006-2010	**2011-2015**	**2016-2020**	**Total**
Natural Gas Capacity Additions (GW)(2)	19	28.7	62	109
CHP Market Share (%)(1),(3)	7.7%	8.0%	7.8%	7.8%
CHP Additions (GW)(3)	1.4	2.3	4.8	8.5

Notes: (1)Annual Energy Outlook 2005, Energy Information Administration, Table 9 – Electricity Generating Capacity. Includes CHP plus C&I generators.

(2) Annual Energy Outlook 2005, Energy Information Administration, Figure 67 - Electricity generation capacity additions by fuel type, including combined heat and power, 2004-2025

(3) NCI Analysis

To help facilitate the market penetration analysis, the technical market available was broken down by owner.

U.S. Retail Sales by Owner[1] (%)

Location	Market Size
Utility	72%
Municipal	28%
Landlord	0%
Total	100%

X **Technical Microgrid Market** 8.5GW

Technical Market by Location (GW)

Location	Market Size
Utility	6.1
Municipal	2.4
Landlord	0
Total	8.5

Technical Market Available by Owner – (GW)

Owner		Market Available
Utility		6.1
Municipal		2.4
Landlord	Utility	6.1
	Muni	2.4
Total		8.5

Notes: (1) Based on the % of retail sales by owner in 2002 as provided by the EIA. Utilities (Investor Owned) and Municipal (Federally owned, Cooperative owned, and publicly owned)

Source: Energy Information Administration

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The breakdown by owner is based on 2002 retail sales by owner type.

U.S. Total Retail Sales by Owner Type

Owner	Total ($ Billion)	Total (%)
Investor Owned	$226	72%
Federally Owned (e.g. BPA, TVA)	$12	4%
Coop Owned , Publicly Owned (e.g. LADWP, SMUD)	$75	24%
Total	$314	100%

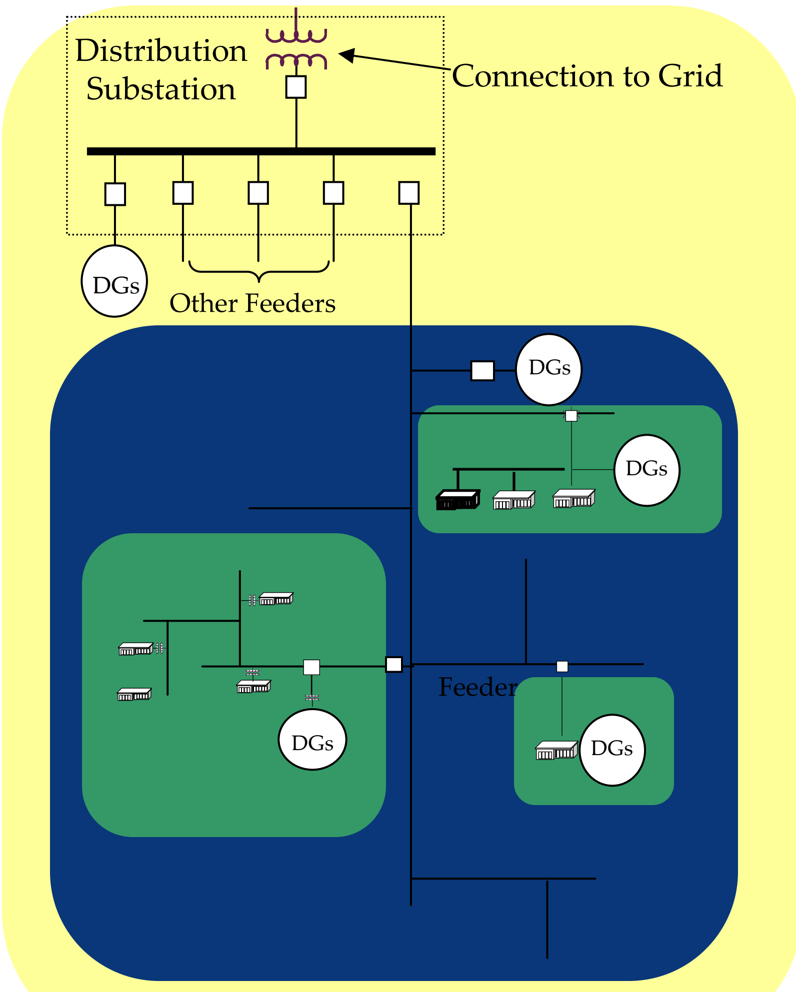
Technical Market by Location (%)

Owner	Single Facility
Utility	72%
Municipal	28%
Landlord	n/a
Total	100%

Source: Energy Information Administration

The market penetration is based on the economics as well as the probability that the CHP facility could be converted to a microgrid.

Microgrid Schematic



Note: Adapted from EPRI

Market Penetration

Economic Penetration Potential

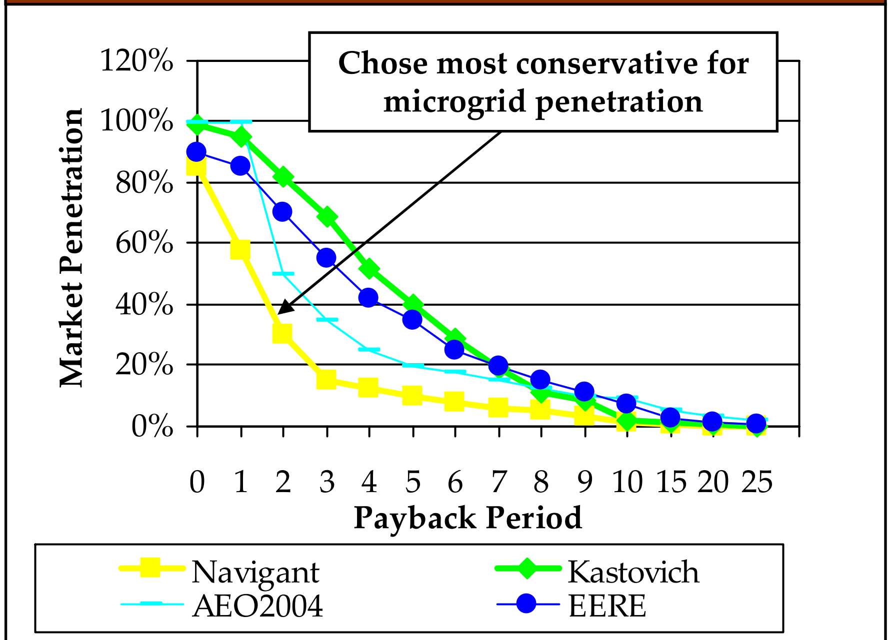
Based on the economics of the microgrid vs CHP, a certain % of CHP facilities could be converted to microgrids

Probability of Conversion

Not all of the CHP facilities could be converted to a microgrid, e.g. loads are not nearby, the right mix of loads are not present, the application does not fit the owner's business model

Based on the economics of the business cases and a conservative estimate of the economic penetration potential, microgrids could achieve up to a 12% share of the CHP market.

Technology Market Penetration Curves(1),(2),(3)



Microgrid Economics vs. CHP and Expected Market Penetration

Scope of Servie	% Annual Savings vs. CHP	Payback vs. CHP	Penetration Potential
Single Facility	n/a	>20 yrs	1%
Multi Facility	23%	6 years	8%
Feeder	33%	4 years	12%
Substation	20%	9 years	2%

Notes: (1) Kastovich, J.C., Lawrence, R.R., Hoffman, R.R., and Pavlak, C., 1982, "Advanced Electric Heat Pump Market and Business Analysis.".
(2) Proprietary data belonging to Navigant Consulting. Developed, based on HVAC penetration experience for the Building Equipment Division, Office of Building Technologies, U.S. Department of Energy (DoE) in 1995.
(3) EERE is based on: Market Trends in the U.S. ESCO Industry: Results from the NAESCO Database Project. Goldman, C., J. Osborn and N. Hopper, LBNL, and T. Singer, NAESCO, May 2002.
(4) AEO2004 based on Annual Energy Outlook 2004 as referenced in U.S. Department of Energy and National Renewable Energy Laboratory, May 2005, "Projected Benefits of Federal Energy Efficiency and Renewable Energy Programs."

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The assumptions in the economic analysis of prototypical microgrids are the same as used during Phase 1 analysis.

Capital Carrying Costs	All in costs [1] ($/kW)	Amortization (years)	Discount Rate	Annual $ / kW
Gas Turbine with cogeneration	$ 1,000	10	15%	$199.25
Recip Engines with cogeneration	$ 1,500	10	15%	$298.88
Gas Turbine without cogeneration	$ 600	10	15%	$119.55
Recip Engines without cogeneration	$ 800	10	15%	$159.40
Microturbines with cogeneration	$ 2,600	10	15%	$518.06
Microturbines without cogeneration	$ 2,200	10	15%	$438.35
Fuel Cells	$ 5,500	10	15%	$1,095.89
Wind Turbines (stand-alone)	$ 4,500	10	15%	$896.63
Wind Turbines (multi-MW aggregated)	$ 1,000	10	15%	$199.25
PV (stand-alone)	$ 8,500	10	15%	$1,693.64
PV (multi-MW aggregated)	$ 6,000	10	15%	$1,195.51

Distribution Costs [2]	Capital Carrying Cost ($/mile/year)	O&M Cost ($/mile/year)
Underground Distribution Line	$ 8,000.00	$ 8,000.00
Overhead Distribution Lines	$ 4,000.00	$ 4,000.00

Average Retail Electricity Rates ($/kWh)[3]	
Industrial	$ 0.102
Commercial	$ 0.137
Residential	$ 0.123

1. All-in costs based on information from the following sources:
- Lasseter, Robert, Abbas Akhil, Chris Marnay, John Stevens, Jeff Dagle, Ross Guttromson, A. Sakis Meliopoulous, Robert Yinger, and Joe Eto. *White Paper on Integration of Distributed Energy Resources: The CERTS MicroGrid Concept*. Lawrence Berkeley National Lab, October 2003.
- *E2I DER Analysis Tool of DG Costs and Benefits*; MS Excel spreadsheet; E2I, 2003.
- Navigant Consulting, Inc. subject matter expert(s)
2. Constructed with the guidance of Navigant Consulting, Inc. subject matter expert(s)
3. 2003 CA retail electricity rates used to calculate cost of grid-supplied electricity <http://www.energy.ca.gov/electricity/current_electricity_rates.html>

The payback of microgrids vs. CHP used for the economic penetration potential is based on an economic analysis of prototypical microgrids.

Results of Economic Analysis for Prototypical Microgrids[1]

		CHP	Prototypical Microgrids			
Owner		**Base Case**	**Single Facility**	**Multi Facility**	**Feeder**	**Sub- Station**
Size		1 MW	1 MW	3 MW	10 MW	25 MW
Load	Industrial	0.5 MW[2]	0.5 MW	1 MW	4 MW	5 MW
	Commercial	0.5 MW[2]	0.5 MW	2 MW	6 MW	7.5 MW
	Residential	0 MW	0 MW	0 MW	0 MW	12.5 MW
Load with Thermal (%)		100%	100%	60%	40%	20%
Generation		1- 500kW Recip for Ind, 1- 500kW Recip for Com	2- 250kW Recip for Ind, 2- 250kW Recip for Com	1- 1.8 MW gas turbine w/ cogen, 1- 1.2MW turbine w/out cogen	2- 2 MW gas turbine w/ cogen, 2- 3MW turbine w/out cogen	2- 3.1MW gas turbine w/ cogen, 2- 9.3MW turbine w/out cogen
Cost (cents/kWh)		9.2 – 13.8	11.9 – 14.3	8.7 – 10.3	8.3 – 9.0	8.6 – 9.9
Annual Cost Reduction vs. CHP		-	n/a	23%	33%	20%
Payback Period vs. CHP (years)		-	>20 years	6 years	4 years	9 years

Notes: (1) Analysis is same as the Phase 1 analysis with the size of loads changed to reflect the modifications to the business cases suggested as a result of the Phase 2 customer and owner interviews.
(2) Separate facilities

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The probability of converting CHP applications to micrograds becomes less likely as the scope of the business case increases.

Insights from Interviews

- "I would like to be able to aggregate more loads from an economic perspective, but that can be difficult from a contractual and business process standpoint."
- "I can see potential applications at hospitals, and others who need reliability. I can't imagine expanding beyond a few facilities, especially into residential."
- "When expanding microgrids, it will be challenging to find the right mix of loads nearby."
- "I don't think it is possible from a regulatory perspective for a developer to go beyond a multi-facility applications - they would become a utility."

Probability of Conversion(1)

	Probability of Converting Economic Microgrids			
Owner	Single Facility	Multi Facility	Feeder	Substation
Utility	20%	50%	20%	20%
Municipal	50%	70%	20%	20%
Landlord	90%	90%	n/a	n/a

Not all of the CHP facilities will be able to be converted to a microgrid, e.g. loads are not nearby, the right mix of loads are not present, the application does not fit the owner's business model

Notes: (1) Probabilities determined by NCI based on interviews with stakeholders and their views on business cases.

Microgrids could capture up to 6% of the technical market potential for individual business cases.

Economic Penetration Potential → **Probability of Conversion** →

Overall Microgrid Market Penetration

Owner	Single Facility	Multi Facility	Feeder	Sub station
Utility	0.2%	4%	2.4%	0.4%
Muni	0.5%	5.6%	2.4%	0.4%
Landlord	0.9%	3.6%(1)	0%(2)	0%(2)

Notes: (1) The penetration depends on the economics, and the economics depends on the size of the facility, e.g. single facility, multi-facility. Because we assume the landlord cannot aggregate as much load, the economics will be worse, and penetration rate is less.

(2) This analysis assumes Landlords will not be able to serve feeders or substations

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Microgrids could capture approximately 1 GW of the estimated 8.5 GW CHP market.

Technical Market Potential – 8.5GW X **Overall Microgrid Market Penetration** =

Market Penetration by Business Case – not including Aggregated Loads (GW)

	Scope of Service				
Owner	**Single Facility**	**Multi Facility**	**Feeder**	**Sub-Station**	**Total**
Utility	0.01	0.24	0.14	0.2	0.42
Muni	0.01	0.13	0.05	0.01	0.21
Landlord(1)	0.07	0.28	-	-	0.35
Total	0.09	0.66	0.19	0.03	**0.98**

Notes: (1) The analysis assumes that Landlords get access to the original technical market potential less the markets pentrated by the Utilities and Munis.

By aggregating neighboring loads, the total market could expand to 4.5 GW.

Technical Market Potential x Market Penetration + (8) Market Expansion = (9) Total Potential Microgrid Market

Market Expansion / Aggregated Loads (GW)

	Scope of Service (Typical Size)			
Owner	Single Facility (1MW)	Multi Facility (3MW)	Feeder (10 MW)	Sub-Station (25 MW)
Utility	-	2x	9x	24x
Muni	-	2x	9x	24x
Landlord	-	1x(1)	-(2)	-(2)
Total				

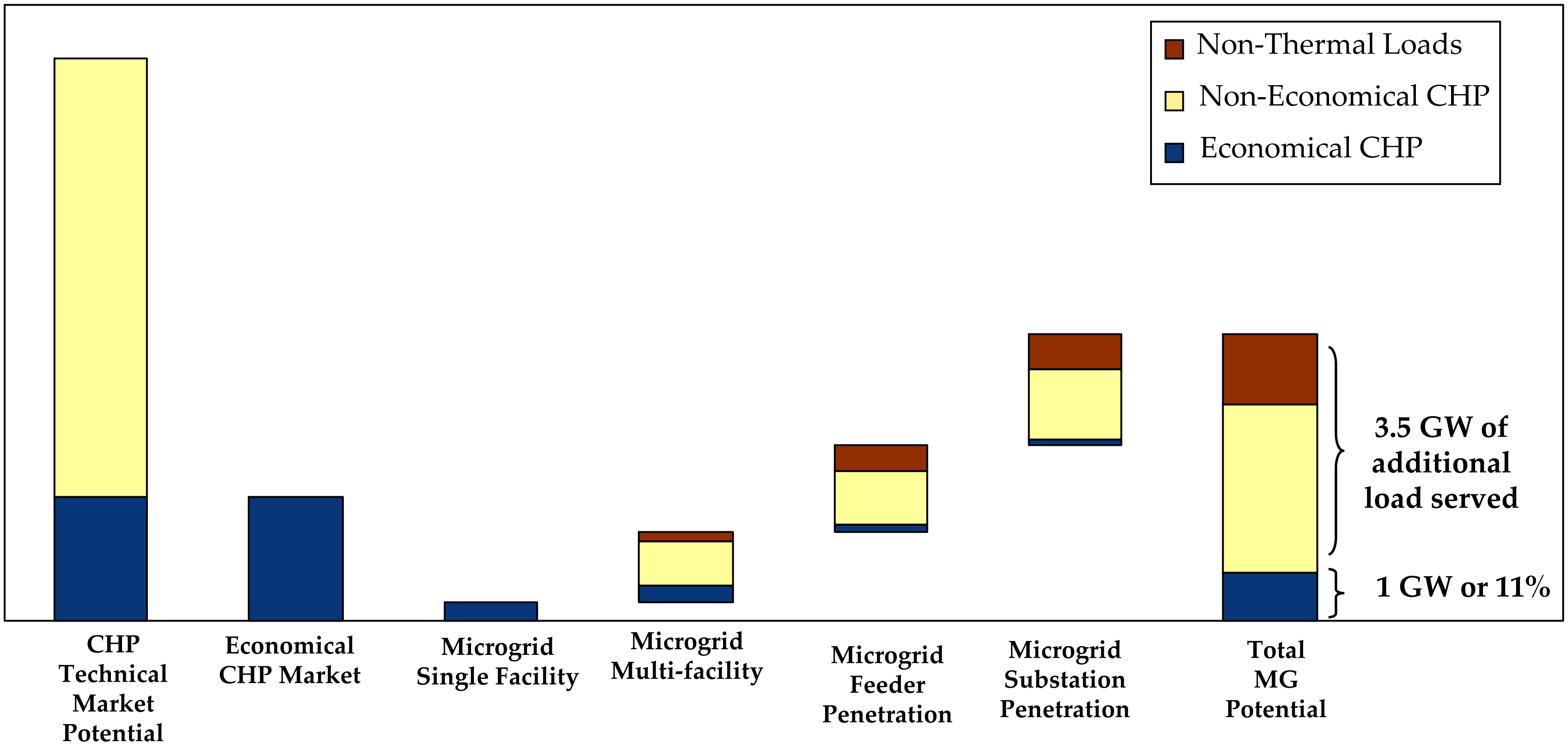
Total Microgrid Market Size (GW)

	Scope of Service				
Owner	Single Facility	Multi Facility	Feeder	Sub-Station	Total
Utility	0.01	0.7	1.4	0.6	2.7
Muni	0.01	0.4	0.5	0.2	1.2
Landlord	.06	0.5	-	-	0.6
Total	0.09	1.7	1.9	0.8	4.5

Notes: (1) The landlord multi-facility would be limited in the amount of load that a landlord could aggregate as compared to a utility or muni.
(2) This analysis assumes Landlords will not be able to serve feeders or substations

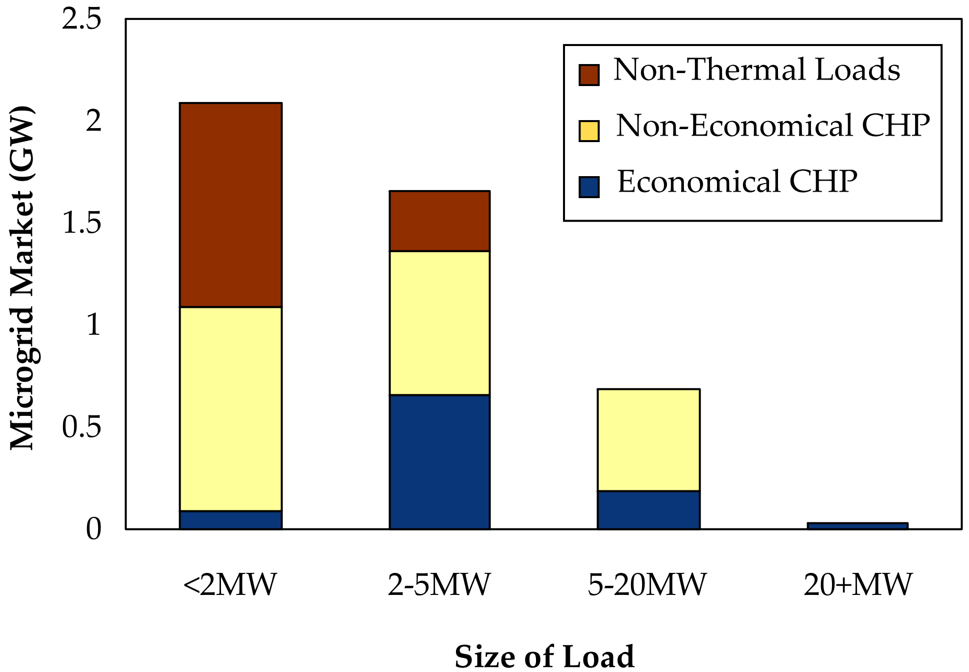
Microgrids could capture 11%, or 1 GW of the CHP market, and expand the microgrid market to 4.5 GW by aggregating loads.

Microgrid Market Size



Most of the aggregated loads would likely be under 5 MW in size.

Microgrid Market by Size of Load (GW)



Key Insights

- Existing CHP applications are almost exclusively at sites over 20MW
- Microgrids can foster the service of smaller loads with cleaner, more efficient, more reliable, more secure technology

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Although Reduced Cost is expected to be the largest market driver, other values will increase the microgrid market.

Market Penetration Estimates – Base Case

Value	2020 Market Penetration (Base Case Scenario)	Supporting Calculation
Reduced Cost	4.5 GW	11% of 8.5 GW CHP market converted to microgrids + 3.5 GW of neighboring loads
Reliability	0.4 GW	~1% of 30 GW Stand-by market converted to microgrids + neighboring loads
Security	0.4 GW	40 communities providing safe havens with microgrids averaging 10 MW
Green Power	0.2 GW	~1% of the 3 GW of solar and wind capacity additions estimated by the EIA will deployed within microgrids
Power System	<0.1 GW	Approximately 10 or fewer feeders with an average size of 10 MW will be upgraded using a microgrid
Service Differentiation	<0.1 GW	Approximately 10 residential communities or commercial parks of 10MW or less will use a microgrid to gain differentiated service

<u>Methodology</u>

Calculated CHP market potential, and microgrids ability to penetrate the CHP market and expand by aggregating neighboring loads (see previous section).

Calculated increased penetration of CHP market due to the improved economic attractiveness of a microgrid (see details in this section).

Calculated by relative size to Reduced Cost and Reliability. Supported by bottom-up calculations (see details in this section).

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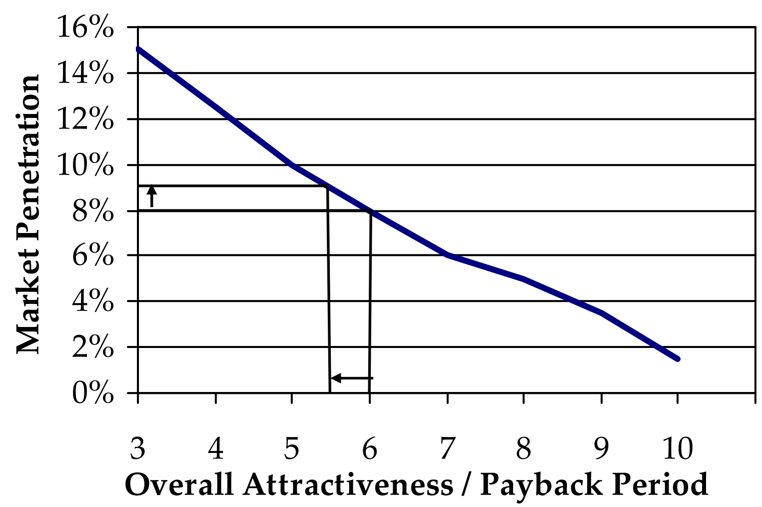
Microgrids are unlikely to be deployed only for increased reliability, but the added value could improve penetration of microgrids by ~1%.

Microgrid and Back-Up Power Economics(1)

	CHP + Back-up Generator	Microgrid (Multi-Facility Example)
Customer Size (MW)	3 MW	3 MW
Back-up power required	1 MW	None required
Cost of electricity	11.8 cent/kWh	9.6 cents / kWh
Cost of Back-up Generator	\$25/kw/year(2) = \$25,000/year or 0.1 cents/kWh	n/a
Savings / Payback vs. CHP		23% / 6 years
Savings / Payback vs. CHP + Back-up Generator		24% / 5.5 years

The improved payback increases the penetration of the microgrids by 1%



In addition, microgrids could help reduce emissions for several key pollutants compared to the average grid emissions

Noes: (1) Same methodology and assumptions as used for Phase 1 and Phase 2 economic analysis.
(2) Assumes back-up generator at \$250/kW and straight-line amortization for 10 years.

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An 1% increase in market penetration would result in an extra 0.4 GW of microgrid capacity.

Microgrid Market Penetration Estimation - Reliability

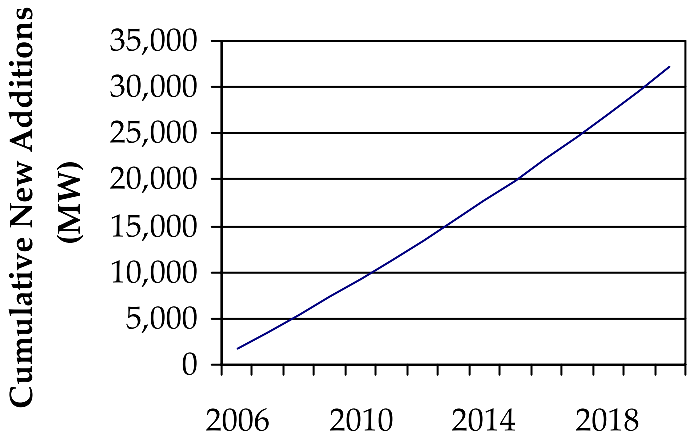
	Reduced Cost	Reliability	Reduced Cost + Reliability
Technical Market Potential	8.5 GW	8.5 GW	8.5 GW
Market Penetration	11%	extra 1%	12%
Traditional CHP penetration	1 GW	0.1 GW	1.1 GW
Market Expansion / Neighboring Loads	3.5 GW	.3 GW	3.8 GW
Total Microgrid Market	4.5 GW	.4 GW	4.9 GW

The Reduced Cost market is getting Reliability for "free"

- Although the driver to do a microgrid is reduced cost for the 4.5 GW Reduced Cost market, these customers get the added benefit of increased reliability and do not need to have back-up power generation.
- Other benefits are accrued to both the Reduced Cost and Reliability markets – improved security, improved optimization of the power system, etc.

An extra 0.4 GW of microgrid capacity is equivalent to an extra 1% of the stand-by power generators being converted to a microgrid.

Cumulative New Stand-by Generators Added[1] (MW)



The extra 0.4GW is reasonable given the low rate of return for displacing a back-up generator with a microgrid

- The extra 0.4GW of microgrid capacity is equal to ~1% of the 30 GW stand-by generator market being converted to a microgrid
- Based on the NCI penetration curves, a 1% penetration rate equates to approximately a 10 year payback on the investment.
- Microgrids deployed for reduced cost are likely to displace an additional portion of the projected generators for stand-by power.

Source: (1) NCI Stand-by Power Generation Estimates. Stand-by for applications of >500kW.

Other values are estimated to be smaller than the reduced cost or reliability markets if overall market conditions do not change.

Microgrid Market Penetration Estimation – Base Case Scenario

Value Proposition	Value to Customer/ Owners[1]	Near Term Ability of Microgrids to Deliver Value vs. Alternate Technologies[2]	Relative Size to Reduced Cost (%)[3]	Market Penetration – Base Case (GW)	Supporting Calculation	
Reduced Cost	High	Medium	1	4.5	11% of 8.5 GW CHP market converted to microgrids + 3.5 GW of neighboring loads	NCI Market Assessment
Reliability	High	Low	0.1	.4	~1% of 30 GW Stand-by market converted + neighboring loads	NCI Market Assessment
Security	Medium	Medium	0.1	0.4	40 communities providing safe havens with microgrids avg. 10 MW	NCI Estimates
Green Power	Medium	Low	0.05	0.2	~1% of the 3 GW of solar and wind new capacity estimated by the EIA will deployed within microgrids	NCI Estimates
Power System	Low	Low	0.01	<0.1	Approximately 10 or fewer feeders with an average size of 10 MW will be upgraded using a microgrid	NCI Estimates
Service Differentiation	Low	Medium	0.01	<0.1	Approximately 10 residential communities or commercial parks of ~10MW will use a microgrid to gain differentiated service	NCI Estimates

Source: (1) Customer / Owner Interviews
(2) Microgrids Visioning Workshop, NCI analysis
(3) Based on relative importance to customers and ability to deliver value vs. alternate technologies

● High ◑ Medium ○ Low

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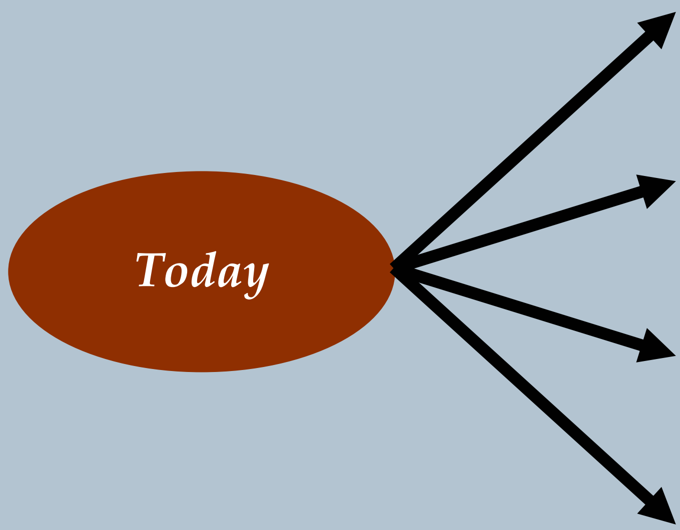
For each value proposition, the market contribution is estimated for different market conditions in 2020.



Market Conditions	Favorability Towards Microgrids
High (H)	Most favorable market conditions for microgrids exist.
Med (M)	Market conditions are more favorable for microgrids than in 2005, but conditions not ideal.
Low (L)	Similar conditions exist as in 2005.
Very Low (VL)	Market conditions have changed so that microgrids are less favorable than in 2005.

As conditions change according to the scenarios, then the potential microgrid market for each value proposition changes significantly.

Microgrid Market Penetration Estimates – (GW)

Value Proposition	Main Sensitivity Driver	Favorability of Market Conditions: Less Favorable (Very Low)	Base Case (Low)	More Favorable (Medium)	Most Favorable (High)	
Reduced Cost	Size of CHP Market	1	4.5	8	12.5	NCI Market Assessment[1]
Reliability	Value of Reliability / Size of Stand-by Power Market	0.1	0.4	1	2	
Security	Government Policies for Safe Havens	0.2	0.4	2	5	NCI Estimates[2]
Green Power	Size of Renewables Market / Need to Manage Intermittency of Renewables	<0.1	0.2	1	3	
Power System	Power System Constraints	0	<0.1	0.5	1	
Service Differentiation	Market Size of Customers Seeking Premium Power / Service Differentiation	0	<0.1	0.25	0.5	

Market estimates for values other than reduced cost are based on relative size estimates compared to reduced cost.

Source: (1) Based on NCI Market Assessment including the technical market potential, microgrid relative market economics, market penetration rate, and market expansion potential. Details provided in Market Assessment.
(2) Based on relative market size to the Reduce Cost and Reliability markets.

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For example, reduced cost would be driven by conditions more favorable to CHP, increasing the CHP market.

2020 Scenario	Microgrid Market Penetration
High (H)	**12.5 GW**
Med (M)	**8 GW**
Low (L)	**4.5 GW**
Very Low (VL)	**1 GW**

	Technical Market Potential[(1)]	×	Market Penetration	+	Market Expansion	=	Microgrid Market Potential
H	25 GW		2.75 GW (11%)		9.75 GW (~3.5x)		12.5 GW
M	16 GW		1.75 GW (11%)		6.25 GW (~3.5x)		8 GW
L	8.5 GW		1 GW (11%)		3.5 GW (~3.5x)		**4.5 GW** (1GW + 3.5GW)
VL	2 GW		0.25 GW (11%)		0.75 GW (~3.5x)		1 GW

Notes: (1) Technical Market Potential based on NCI analysis of existing market studies of CHP market potential, including: a) Integrated Energy Systems (IES) for Buildings: A Market Assessment, Resource Dynamics Corporation, ORNL: September 2002. (ORNL/SUB/409200), b) Assessment of Large Combined Heat and Power Market, (ORNL Subcontract 400021456 Task2, April 200 c), Assessment of California CHP Market and Policy Options for Increased Penetration, EPRI, Palo Alto, CA, California Energy Commission, Sacramento, CA: 2005, d) Analysis of CHP Potential at Federal Sites, (ORNL/TM-2001/280, February 2002),

Descriptions for each market condition and value proposition were created and used to guide the market penetration estimates.

	2020 Market Conditions (Favorability to Microgrids)			
Value	**Very Low**	**Low**	**Medium**	**High**
Reduced Cost	Deteriorating spark spreads. Limited emissions constraints or DG/CHP generation technology improvements.	Regionally favorable spark spreads, limited emissions constraints or DG/CHP technology improvements.	Improvement in spark spreads, moderate emissions constraints, moderate DG/CHP generation technology improvements.	Nationally favorable spark spreads, rigid emissions constraints, significant DG/CHP generation technology improvements.
Reliability	Overall improved reliability. Back-up generation cheaper and easier to deploy.	Overall reliability is good. Certain areas and customers are challenged.	Overall reliability is good, but more areas and customers are challenged.	Overall reliability has deteriorated. Back-up generators are not as viable for improving reliability.
Security	Other security needs are given higher priority.	Grid security a priority. Inroads made to use microgrids for security.	Grid security a priority. Microgrids have both federal, state, and local support. Limited mandates.	Government mandates exist for communities to use microgrids to provide secure areas.
Green Power	Renewable energy is demanded in only niche markets.	RE is demanded, but limited impact on the grid from intermittency . Cost of deploying RE is similar with/ without a microgrid.	Numerous states have Renewable Portfolio Standards. Intermittency is a problem, and microgrids are used to manage intermittency.	Broad national use of renewable energy. Intermittency is a problem, and microgrids help lower the cost of renewable energy significantly.
Power System	Upgrades made easily using traditional methods. System constraints low.	Select areas have sizable system constraints, have difficulty with upgrades.	Siting issues and system constraints become more prevalent. Microgrids provide significant value to utilities.	Siting issues and system constraints are widespread. Microgrids provide significant value to utilities.
Service Differentiation	Demand for premium power / service differentiation decreases	Limited number of customers wanting to pay for premium power / service differentiation	Electricity use increasing for complex applications requiring high reliability. Certain customer segments looking to pay extra for higher reliability.	Electricity use increasingly for complex applications. Many customer segments paying for added reliability.

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The scenarios were created by selecting market conditions.

Market Conditions Selected: More Central Power Scenario

	2020 Market Conditions (Favorability to Microgrids)			
Value	**Very Low**	**Low**	**Medium**	**High**
Reduced Cost	Deteriorating spark spreads. Limited emissions constraints or DG/CHP generation technology improvements.	Spark spreads are favorable in certain regions, similar emissions constraints as 2005.	Improvement in spark spreads, additional emissions constraints, moderate DG/CHP generation technology improvements.	Nationally favorable spark spreads, rigid emissions constraints, significant DG/CHP generation technology improvements.
Reliability	Overall improved reliability. Back-up generation cheaper and easier to deploy.	Overall reliability is good. Certain areas and customers are challenged.	Overall reliability is good, but more areas and customers are challenged.	Overall reliability has deteriorated. Back-up generators are not as viable for improving reliability.
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Power System	Upgrades made easily using traditional methods. System constraints low.	Select areas have sizable system constraints, have difficulty with upgrades.	Siting issues and system constraints become more prevalent. Microgrids provide significant value to utilities.	Siting issues and system constraints are widespread. Microgrids provide significant value to utilities.
Service Differentiation	Demand for premium power / service differentiation decreases	Limited number of customers wanting to pay for premium power / service differentiation	Electricity use increasing for complex applications requiring high reliability. Certain customer segments looking to pay extra for higher reliability.	Electricity use increasingly for complex applications. Many customer segments paying for added reliability.

The scenarios were created by selecting market conditions.

Market Conditions Selected: Base Case

	2020 Market Conditions (Favorability to Microgrids)			
Value	**Very Low**	**Low**	**Medium**	**High**
Reduced Cost	Deteriorating spark spreads. Limited emissions constraints or DG/CHP generation technology improvements.	Spark spreads are favorable in certain regions, similar emissions constraints as 2005.	Improvement in spark spreads, additional emissions constraints, moderate DG/CHP generation technology improvements.	Nationally favorable spark spreads, rigid emissions constraints, significant DG/CHP generation technology improvements.
Reliability	Overall improved reliability. Back-up generation cheaper and easier to deploy.	Overall reliability is good. Certain areas and customers are challenged.	Overall reliability is good, but more areas and customers are challenged.	Overall reliability has deteriorated. Back-up generators are not as viable for improving reliability.
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Power System	Upgrades made easily using traditional methods. System constraints low.	Select areas have sizable system constraints, have difficulty with upgrades.	Siting issues and system constraints become more prevalent. Microgrids provide significant value to utilities.	Siting issues and system constraints are widespread. Microgrids provide significant value to utilities.
Service Differentiation	Demand for premium power / service differentiation decreases	Limited number of customers wanting to pay for premium power / service differentiation	Electricity use increasing for complex applications requiring high reliability. Certain customer segments looking to pay extra for higher reliability.	Electricity use increasingly for complex applications. Many customer segments paying for added reliability.

The scenarios were created by selecting market conditions.

Market Conditions Selected: Reliability Constrained

	2020 Market Conditions (Favorability to Microgrids)			
Value	**Very Low**	**Low**	**Medium**	**High**
Reduced Cost	Deteriorating spark spreads. Limited emissions constraints or DG/CHP generation technology improvements.	Spark spreads are favorable in certain regions, similar emissions constraints as 2005.	Improvement in spark spreads, additional emissions constraints, moderate DG/CHP generation technology improvements.	Nationally favorable spark spreads, rigid emissions constraints, significant DG/CHP generation technology improvements.
Reliability	Overall improved reliability. Back-up generation cheaper and easier to deploy.	Overall reliability is good. Certain areas and customers are challenged.	Overall reliability is good, but more areas and customers are challenged.	Overall reliability has deteriorated. Back-up generators are not as viable for improving reliability.
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Power System	Upgrades made easily using traditional methods. System constraints low.	Select areas have sizable system constraints, have difficulty with upgrades.	Siting issues and system constraints become more prevalent. Microgrids provide significant value to utilities.	Siting issues and system constraints are widespread. Microgrids provide significant value to utilities.
Service Differentiation	Demand for premium power / service differentiation decreases	Limited number of customers wanting to pay for premium power / service differentiation	Electricity use increasing for complex applications requiring high reliability. Certain customer segments looking to pay extra for higher reliability.	Electricity use increasingly for complex applications. Many customer segments paying for added reliability.

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The scenarios were created by selecting market conditions.

Market Conditions Selected: Environmental Push

	2020 Market Conditions (Favorability to Microgrids)			
Value	**Very Low**	**Low**	**Medium**	**High**
Reduced Cost	Deteriorating spark spreads. Limited emissions constraints or DG/CHP generation technology improvements.	Spark spreads are favorable in certain regions, similar emissions constraints as 2005.	Improvement in spark spreads, additional emissions constraints, moderate DG/CHP generation technology improvements.	Nationally favorable spark spreads, rigid emissions constraints, significant DG/CHP generation technology improvements.
Reliability	Overall improved reliability. Back-up generation cheaper and easier to deploy.	Overall reliability is good. Certain areas and customers are challenged.	Overall reliability is good, but more areas and customers are challenged.	Overall reliability has deteriorated. Back-up generators are not as viable for improving reliability.
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Green Power	Renewable energy is demanded in only niche markets.	RE is demanded, but limited impact on the grid from intermittency . Cost of deploying RE is similar with/ without a microgrid.	Numerous states have Renewable Portfolio Standards. Intermittency is a problem, and microgrids are used to manage intermittency.	Broad national use of renewable energy. Intermittency is a problem, and microgrids help lower the cost of renewable energy significantly.
Power System	Upgrades made easily using traditional methods. System constraints low.	Select areas have sizable system constraints, have difficulty with upgrades.	Siting issues and system constraints become more prevalent. Microgrids provide significant value to utilities.	Siting issues and system constraints are widespread. Microgrids provide significant value to utilities.
Service Differentiation	Demand for premium power / service differentiation decreases	Limited number of customers wanting to pay for premium power / service differentiation	Electricity use increasing for complex applications requiring high reliability. Certain customer segments looking to pay extra for higher reliability.	Electricity use increasingly for complex applications. Many customer segments paying for added reliability.

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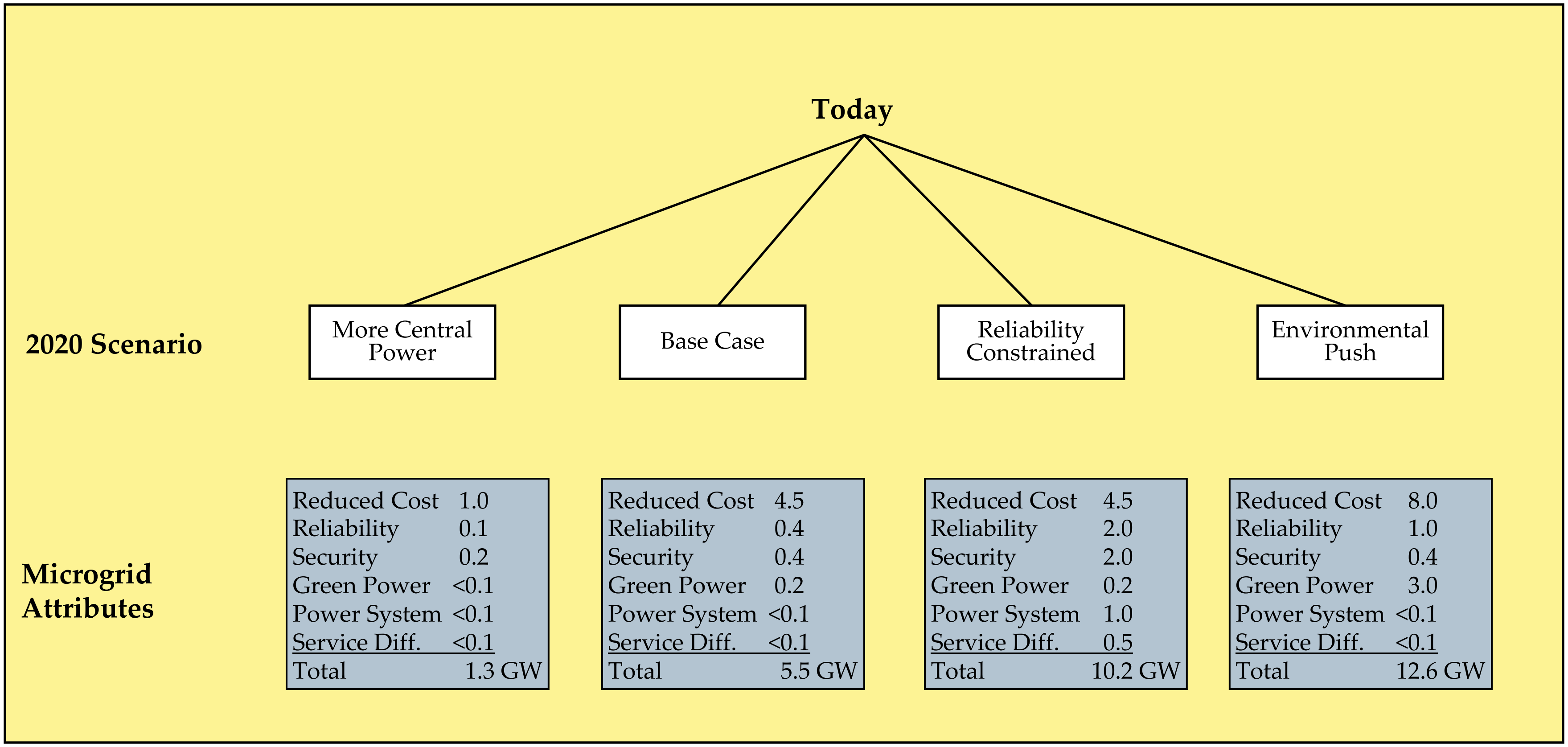
The total market could range between approximately 1 and 13 GW depending on market conditions in 2020.



Selected scenarios were chosen to illustrate how microgrids could perform given select market conditions, but do not represent "likely" or "desired" scenarios.

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Microgrid benefits will support the goals of the DOE.

Benefit	DOE Goals	Microgrid Benefits
Energy Efficiency	Increase efficiency of the electric delivery system through reduced energy losses.	•Lower cost of energy to end users - *estimated 20% - 30% savings vs. CHP based on the business case.* •Improved primary energy efficiency – *> 70% efficient via CHP. Increases the market for CHP by tackling <20MW market.* •Reduced T&D losses – *use of on-site power limits line losses.* •Increased Penetration of Renewables
System Efficiency	Reduce peak price and price volatility of electricity, increased asset utilization and provide accessibility to a variety of fuel sources.	•Power system optimization (reduced volatility, reduced peak prices, fewer constraints) through the provision of services - *microgrids can help manage the intermittency of renewables, provide services, like demand response, system capacity, spinning reserve, T&D relief.* •Increased Penetration of Renewables
Reliability	Strengthen grid stability and reduce the frequency and duration of operational disturbances.	•Improved reliability for microgrid customers - *Microgrids can achieve 99.999% reliability vs. 99.9% for the grid.* •Improved reliability for the entire grid – *provision of services, and integration of renewables can help improve system reliability.*
Security	The energy infrastructure is hardened to detect, prevent and mitigate external disruptions to the energy sector.	•Increased resiliency and security of the power delivery system by promoting the dispersal of power resources. •Provides safe havens – *microgrids provide energy during grid outages.*

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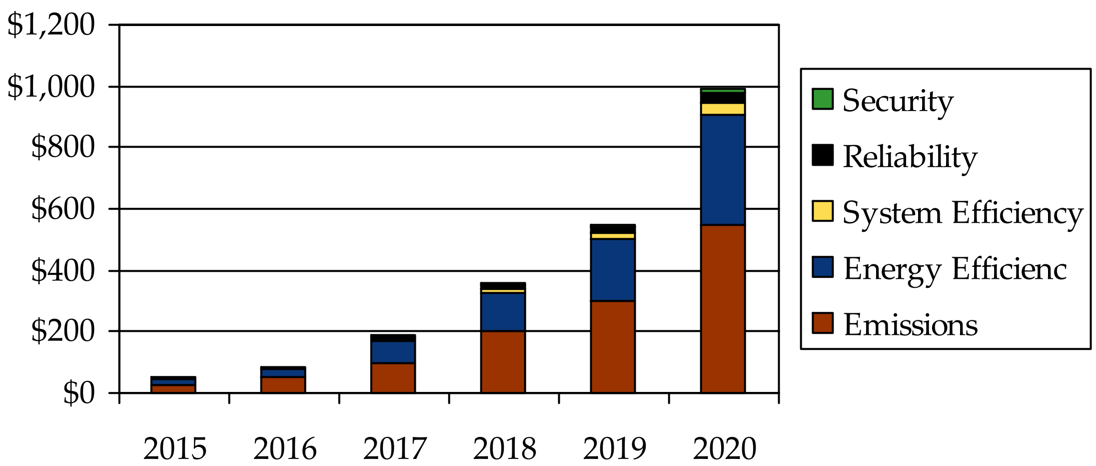
Microgrid benefits could total almost $1 billion per year by 2020 under the base case scenario.

Annual Microgrid Benefits – Base Case Scenario ($Million)



Annual Emission Reductions – Base Case Scenario (tons)

Emission	2015	2016	2017	2018	2019	2020
CO_2	793,000	1,590,000	3,170,000	6,340,000	9,510,000	17,400,000
SOx	4,000	9,800	19,700	39,400	59,100	108,000
NOx	821	1,640	3,290	6,570	9,850	18,000
PM-10	90	181	361	723	1,084	1,987

Examples of Benefits in 2020

- $360MM in energy savings due to 10% reduction in energy bills at ~0.5% of U.S. total capacity
- 550 microgrids of an average 10MW serving primarily C&I markets with improved reliability and supporting grid stability.
- Forty or more communities with 10MW of facilities that can have energy during a grid outage.
- 200MW of renewable energy deployed within a microgrid.
- Reduction of 17.4 Million tons of CO2, 108,000 tons of SOx, and 18,000 tons of NOx.

Notes: (1) Assumes emissions emission prices per ton of $25 for CO2, $5,000 for NOx, and $200 for SOx. SOx and NOx prices are based on 2005 prices, and CO2 prices based on low-range estimates of carbon prices from the Massachusetts Institute of Technology's EPPA model.

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The benefits calculations are based on the following assumptions:

Annual Microgrid Benefits – Assumptions[2]

Category	2015	2016	2017	2018	2019	2020
Energy Efficiency						
Cumulative Microgrid Capacity Installed (GW)	0.25	0.50	1.00	2.00	3.00	5.50
Microgrid Capacity Factor (70%)	70%	70%	70%	70%	70%	70%
Microgrid Output (GWh)	1,640	3,280	6,570	13,100	19,700	36,100
Cost of Grid Power ($/kWh)	$0.10	$0.10	$0.10	$0.10	$0.10	$0.10
Microgrid Savings (%)	10%	10%	10%	10%	10%	10%
Value of Savings ($MM)	**$20**	**$30**	**$70**	**$130**	**$200**	**$360**
System Efficiency						
Value of System Efficiency at 10%[3] of Energy Effic.($MM)	**$2**	**$3**	**$7**	**$13**	**$20**	**$36**
Reliability						
Grid Reliability	99.9	99.9	99.9	99.9	99.9	99.9
Microgrid Reliability	99.999	99.999	99.999	99.999	99.999	99.999
Avoided Downtime (MWh)	1,640	3,280	6,570	13,100	19,700	36,100
Value of Avoided Downtime at $1,000[4] MWh ($MM)	**$2**	**$3**	**$7**	**$13**	**$20**	**$36**
Security						
Avoided Back-Up Generation at 10% of installed capacity (GW)	0.025	0.05	0.1	0.2	0.3	0.55
Value of Avoided Back-Up Gen at $25/kW/year[5] ($MM)	**$1**	**$1**	**$3**	**$5**	**$8**	**$14**

Emissions Assumptions

Category	Grid[1]	Microgrid[2]
CO_2 (lbs/kWh)	1.36	0.4
SOx (lbs/kWh)	0.006	0
NOx (lbs/kWh)	0.002	0.001
PM-10 (lbs/MWh)	0.19	0.08

Notes: (1) Energy Information Administration, total annual U.S. emissions and output for electric power.
(2) NCI Economic Analysis and technology assumptions.
(3) NCI subject matter experts.
(4) NCI subject matter experts.
(5) NCI technology assumptions for typical back-up generator costing $250/kW amortized for 10 years.

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Microgrids can help provide significant benefits in many scenarios by expanding CHP, increasing the penetration of renewables, and providing increased reliability and security.

Today

2020 Scenario	More Central Power	Base Case	Reliability Constrained	Environmental Push
Annual Benefits ($MM)	Energy Efficiency 90 System Efficiency 10 Reliability 10 Security 5 Emissions[(1)] 120 Total ($MM) $235	Energy Efficiency 360 System Efficiency 40 Reliability 40 Security 10 Emissions 550 Total ($MM) $1,000	Energy Efficiency 690 System Efficiency 70 Reliability 70 Security 30 Emissions 1,050 Total ($MM) $1,900	Energy Efficiency 820 System Efficiency 80 Reliability 80 Security 30 Emissions 1,250 Total ($MM) $2,260
Benefit Description	Although market conditions are unfavorable, there are still pockets of areas where microgrids will help provide reduced cost, increased reliability, and security.	.Benefits driven by microgrids ability to expand the CHP market, enhance energy, and thus reduce emissions. Additional benefits accrue due to expansion of renewables, security, and reliability.	Microgrids help provide additional reliability to individual customers and to the grid. In doing so, microgrids improve energy efficiency and reduce emissions through the use of CHP.	Microgrids help the system accommodate more renewables and other energy efficient technologies, like CHP and demand response. This helps reduce emissions and improve energy efficiency as well as provide reliability and security.

The objective of Task 2 was to identify the technical and functional requirements.

Phase 2

Task 1 – Customer / Owner Interviews

- Understand customer needs
- Test value proposition of 3 business cases
- Identify changes to business cases
- Identify potential applications and challenges

Task 2 – Technical & Functional Assessment

- Identify technical and functional requirements of 3 business cases
- Assess ability of current technology to satisfy functional requirements
- Examine approaches to overcome technical gaps

Task 3 – Market & Benefits Assessment

- Estimate the potential size of the microgrid market
- Understand public benefits resulting from microgrids

Task 4 – Workshop

- Solicit feedback & input from microgrid owners, customers, researchers, equipment suppliers
- Develop a consensus vision & roadmap for microgrids

Task 5 – Final Report

- Final report which clearly answers overall objectives of Phase II and incorporates insights from multiple stakeholders

The technology assessment identified functional requirements; gaps in the ability of current technology to satisfy these requirements; and approaches to overcome gaps.

Are microgrids an attractive area for additional government investment?

- Is there a single definition for microgrids?
- Are there attractive microgrid business cases?
- Is the market attractive?
- Are the public benefits attractive?
- Are there technology or policy challenges that require gov't support?
  - Do we know the functional requirements?
    - Identify the technical functional requirements of the microgrid business cases
  - Does current technology meet the functional requirements?
    - Assess the ability of current technology to satisfy functional requirements
  - Is current technology cost-effective in meeting functional requirements?
    - Examine approaches to overcome technical gaps

NCI identified six primary functional areas (each with three to seven specific functional requirements) that need to be met by microgrids.

Microgrid Working Definition

General Definition

A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources which as an integrated system can operate in parallel with the grid or in an intentional island mode.

Key Defining Characteristics

The integrated distributed energy resources are capable of providing sufficient and continuous energy to a significant portion of the internal demand. The microgrid possesses independent controls and can island and reconnect with minimal service disruption.

Functional Area	Functional Requirements
Performance Requirements	•Meet IEEE 1547 requirements •Power quality •Steady-state and dynamic performance
Design	•NEC/NESC code requirements •Switching (Generation and Load isolation) •Load transfer •Line and equipment ratings •Regulation (voltage and power factor) •Critical loads
Monitoring and Control	•Control system algorithm •Frequency (load following) •Voltage (load following) •Power Factor •Load •Generation •Communications infrastructure
Protection	•Fault current interruption •Coordination (normal vs. reconfigured) •Under/Over voltage •Fault isolation (voltage and current) •Auto synchronization with the grid •Black start capability
Operations	•Safety •Plan and protocol (O&M plan) •Spare parts and inventory •Labor
Infrastructure	•Utility system and equipment upgrades •Interconnection requirements •Communication Infrastructure & Controls

See the appendix for detailed explanation of the requirements, key issues, assessment of the gaps, and approach to close gaps for each functional requirement.

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Microgrids must be able to meet the functional requirements for the value propositions and the business cases inherent in the 2020 vision.

Value Propositions

- **Reduced Cost** – Reducing the cost of energy and managing price volatility
- **Reliability** – Improving reliability
- **Security** – Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources
- **Green Power** – Helping to manage the intermittency of renewables, Promoting the deployment and integration of energy-efficient and environmentally friendly technologies
- **Power system** – Assisting in optimizing the power delivery system, including the provision of services
- **Service differentiation** – Providing different levels of service quality and value to customers segments at different price points

Business Cases

	Scope of Service			
Owner	**Single Facility**	**Multi Facility**	**Feeder**	**Sub-Station**
Utility				
Municipal				
Landlord				

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The ability of microgrids to satisfy functional requirements depends on what the microgrid is designed to do, and the gaps arise from system integration issues as well as some technology gaps.

- Microgrids should be able to meet the requirements for Reduced Cost, Security, and Reliability value propositions and a Single Facility scope of service with fairly low challenges.
- The gaps and level of technical challenged increases as the microgrid delivers more value propositions and the scope of service increases.
  - As the scope of service increases, the size increases beyond single facilities and loads and generation sources become larger and more dispersed.
  - As value propositions become more complex (e.g. move from reduce cost to managing the intermittency of renewables and helping optimize the power system), there are increased requirements to interact with the grid, and more complex optimization and control algorithms.
- The challenges in meeting the requirements are primarily due to system integration/design issues, but also due to gaps in technologies and the need for standards.

The ability to meet the functional requirements is based on a detailed functional assessment and a summary of both the importance of each requirement and the level of the gaps.

Explanation and Assessment of Functional Requirements

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Monitoring and Control	▪ Control system algorithm	▪ If the microgrid is operated via a central controller (as opposed to relying on local generation control) sophisticated algorithms may need to be developed to accommodate a wide range of load and generation output [illegible]ios, and ne[illegible]	▪ Effectiveness of control system and algorithm should be monitored and adjusted based on actual operation ▪ Algorithms also may need to perform economic dispatch of generation, which may add to the complexity of the system	▪ Control systems capable of performing these functions are available, but experience on microgrids that include a range of generating technologies and power delivery configurations may be limited	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to test and adjust algorithms

Importance of Requirement

Each functional requirement given an importance ranking from low to high

Level of Gaps

Each functional requirement given a gap ranking from low to high

Ability to Meet Functional Requirements (Level of Challenge to Meet Requirement)

Functional Area	Security	Reliability	Reduced Cost	Green Power	Power System	Service Differentiation
Performance Requirements	Med-High	Med-High	Med	Med-High	Med-High	Med-High
Design	Low	Low-Med	Low-Med	Low-Med	Med	Med
Monitoring and Control	Low-Med	Low-Med	Low-Med	High	Med	Med-High
Protection (parallel vs. isolation modes)	Low	Low-Med	Low-Med	Low	Med	Med
Operations	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med
Infrastructure	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med
Overall Assessment	Low-Med	Low-Med	Low-Med	Med	Med	Med

Technical challenges for microgrids will be highest when delivering green power, power system, and service differentiation values.

Level of Technical Challenge by Value Proposition

Functional Area	Reduced Cost	Security	Reliability	Service Differentiation	Power System	Green Power	Key Factors
Performance Requirements	Low-Med	Low-Med	Low-Med	Med-High	Med-High	Med-High	•Ability of a microgrid to meet minimum PQ requirements depends on size, load level, impedance. •Interconnection – applies to all.
Design	Low-Med	Low-Med	Low-Med	Med	Med	Med	•Code requirements uncertain. •Design can increase cost by increasing number and type of switches and infrastructure upgrades.
Monitoring and Control	Low-Med	Low-Med	Low-Med	Med-High	Med-High	Med-High	•Level of coordination of financial, physical, and operational elements with the larger power system.
Protection	Low	Med	Med	Med	Med	Med	•Auto-synchronization with the grid. • Black start capability in stand-alone. •Protection unproven for microgrids with numerous generators.
Operations	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med	•Experienced personnel critical for design and operation, especially for complex systems.
Infrastructure	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med	Low-Med	•Interconnection requirements unresolved.
Overall Assessment	Low-Med	Low-Med	Low-Med	Med	Med	Med	•Complexity of the microgrid can drive costs and technical requirements.

Increasing Difficulty of Meeting Technology Requirements →

•Complexity is driven by level of interaction with the grid; number, type and dispersal of generation sources; shape and size of the loads; and the type of values being delivered:

- •Green Power can have highest dispersal and complexity of generation
- •Power System can have highest interaction with the grid
- •Service Differentiation requires complex control algorithms
- •Security, Reliability, and Reduced Cost can have limited complexity

As microgrids deliver different value propositions, the importance of the functional requirements increases.

Importance of Functional Requirements by Value Proposition - Summary

Functional Area	Reduced Cost	Security	Reliability	Service Differentiation	Power System	Green Power	Key Factors
Performance Requirements	High	High	High	High	High	High	•Interconnection requirements must be resolved. •Ability of microgrids to meet Power Quality and Steady-state and Dynamic performance requirements must be proven.
Design	Low-Med	Med	Med	Med-High	Med-High	Med-High	•Design needs to comply with most restrictive codes. •Design can drive cost (# of switches, voltage regulators, capacitor banks) and performance – especially as complexity increases.
Monitoring and Control	Med	Med	Med	Med-High	Med-High	Med-High	•Control algorithms must be able to incorporate the complexity of the value proposition, e.g. intermittency of renewables, value to the power system, service differentiation.
Protection	Low	Med	Med	Med	Med	Med	•Protection must coordinate for all ranges of generation output levels. •Auto-synchronization with grid may be more complex for microgrids with numerous generators that all must be in phase for successful synchronization. •Black-start capability required if microgrid to operate in stand-alone during grid outage.
Operations	Med	Med	Med	Med	Med	Med	•Safety and operations driven by a trained labor force.
Infrastructure	Low	Low	Low-Med	Low-Med	Low-Med	Low-Med	•Communication requirements may not be as stringent for reduced cost only.
Overall Assessment	Med	Med	Med	Med-High	Med-High	Med-High	•More complexity with GP, PS, SD heighten importance of design and monitoring and control requirements.

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As microgrids deliver different value propositions, the importance of the functional requirements increases.

Importance of Functional Requirements by Value Proposition

Functional Area	Functional Requirements	Reduced Cost	Security	Reliability	Service Differentiation	Power System	Green Power
Performance Requirements	•Meet IEEE 1547 requirements	high	high	high	high	high	high
	•Power quality	high	high	high	high	high	high
	•Steady-state and dynamic performance	high	high	high	high	high	high
Design	•NEC/NESC code requirements	high	high	high	high	high	high
	•Switching (Generation and Load isolation)	low	low	low	high	high	high
	•Load transfer	low	low	low	high	high	high
	•Line and equipment ratings	med	med	med	med	med	med
	•Regulation (voltage and power factor)	med	med	med	med	med	med
	•Critical loads	low	high	high	high	med	med
Monitoring and Control	•Control system algorithm	low	low	med	high	high	high
	•Frequency (load following)	med	med	med	med	med	high
	•Voltage (load following)	med	med	med	med	med	high
	•Power Factor	low	low	low	low	low	med
	•Load	high	high	high	very high	high	high
	•Generation	high	high	high	high	high	high
	•Communications infrastructure	low	low	low	high	high	high
Protection	•Fault current interruption	low	med	med	med	med	med
	•Coordination (normal vs. reconfigured)	low	med	med	med	med	med
	•Under/Over voltage	low	med	med	med	med	med
	•Fault isolation (voltage and current)	low	med	med	med	med	med
	•Auto synchronization with the grid	low	med	med	high	high	high
	•Black start capability	low	high	high	high	med	low
Operations	•Safety	high	high	high	high	high	high
	•Plan and protocol (O&M plan)	med	med	med	med	med	med
	•Spare parts and inventory	med	med	med	med	med	med
	•labor	med	med	med	med	med	med
Infrastructure	•Utility system and equipment upgrades	low	low	low	low	low	low
	•Interconnection requirements	med	med	med	med	med	med
	•Communication Infrastructure & Controls	low	med	med	med	med	med

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As microgrids deliver different value propositions, the gaps also increase

Gaps in Meeting Functional Requirements by Value Proposition - Summary

Functional Area	Reduced Cost	Security	Reliability	Service Differentiation	Power System	Green Power	Key Factors
Performance Requirements	Low	Low	Low	Med	Med	Med	•Interconnection requirements may take time. •Meeting performance requirements is more difficult for Green Power (dispersed, intermittent gen), Power System (interaction with the grid), Service (optimization of generation and load)
Design	Low-Med	Low-Med	Low-Med	Med	Med	Med	•Limited experience with code compliance. •Existing switch technology sufficient, but need to prove cost-effective designs for more complex configurations.
Monitoring and Control	Med	Med	Med	Med-High	Med-High	Med-High	•Need to prove the ability to control multiple configurations. •Need to prove control algorithms for managing intermittency of RE, helping optimize the macrogrid, and provide service differentiation •May need to integrate communications infrastructure with the utility or ISO.
Protection	Med	Med	Med	Med	Med	Med	•Auto-synchronization, Black Start, and fault current protection needs to be proven for larger grids with numerous generating devices.
Operations	Low	Low	Low	Low	Low	Low	•Labor force may be a big gap for owners of microgrids.
Infrastructure	Med	Med	Med	Med	Med	Med	•Need to understand interconnection and communications infrastructure requirements.
Overall Assessment	Low-Med	Low-Med	Low-Med	Med	Med	Med	•Microgrids untested in complex configurations, e.g. delivering values for with GP, PS, SD.

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As microgrids deliver different value propositions, the gaps also increase.

Gaps in Meeting Functional Requirements by Value Proposition

Functional Area	Functional Requirements	Reduced Cost	Security	Reliability	Service Differentiation	Power System	Green Power
Performance Requirements	•Meet IEEE 1547 requirements	med	med	med	med	med	med
	•Power quality	low	low	low	med	med	med
	•Steady-state and dynamic performance	low	low	low	med	med	med
Design	•NEC/NESC code requirements	med	med	med	med	med	med
	•Switching (Generation and Load isolation)	low	low	low	high	high	med
	•Load transfer	low	low	low	high	high	med
	•Line and equipment ratings	med	med	med	med	med	med
	•Regulation (voltage and power factor)	med	med	med	med	med	med
	•Critical loads	low	low	low	low	low	med
Monitoring and Control	•Control system algorithm	med	med	med	high	high	high
	•Frequency (load following)	med	med	med	high	high	high
	•Voltage (load following)	med	med	med	med	med	med
	•Power Factor	med	med	med	med	med	med
	•Load	med	med	med	med	med	high
	•Generation	med	med	med	med	med	med
	•Communications infrastructure	med	med	med	med	med	med
Protection	•Fault current interruption	med	med	med	high	high	high
	•Coordination (normal vs. reconfigured)	med	med	med	med	med	med
	•Under/Over voltage	med	med	med	med	med	med
	•Fault isolation (voltage and current)	med	med	med	med	med	med
	•Auto synchronization with the grid	med	med	med	med	med	med
	•Black start capability	med	med	med	med	med	med
Operations	•Safety	low	low	low	low	low	low
	•Plan and protocol (O&M plan)	low	low	low	low	low	low
	•Spare parts and inventory	low	low	low	low	low	low
	•labor	med	med	med	med	med	med
Infrastructure	•Utility system and equipment upgrades	med	med	med	med	med	med
	•Interconnection requirements	med	med	med	med	med	med
	•Communication Infrastructure & Controls	med	med	med	med	med	med

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Technical challenges will also be higher as the scope of service increases and the business model becomes more complex.

Level of Technical Challenge by Scope of Service

Functional Area	Single-Facility	Multi-Facility	Feeder	Substation	Key Factors
Performance Requirements	Med	Med	Med	Low-Med	The ability of a microgrid to meet minimum PQ requirements depends on size, load level, impedance. Interconnection – not critical for substation.
Design	Low-Med	Low-Med	Med	Med	•Code requirements uncertain. •Design can drive cost and performance – as complexity of values and size increases– *smaller systems likely to be less complex.*
Monitoring and Control	Low-Med	Med	Med	Med	•Control algorithms will be more complex as the microgrid size increases and the loads and generation become more diverse and disperse.
Protection	Low	Low-Med	Med	Med-High	•Auto-synchronization, Black start capability in stand-alone, and Protection unproven for microgrids with numerous generators – becomes more complex as size increases.
Operations	Low-Med	Low-Med	Med	Med	•Experienced personnel critical for design and operation, especially for complex systems. •Complexity of O&M and Spare Parts increases with size.
Infrastructure	Low-Med	Low-Med	Low-Med	Low-Med	•Interconnection requirements unresolved
Overall Assessment	Low-Med	Low-Med	Med	Med	•Complexity of the microgrid can drive costs and technical requirements.

Increasing Difficulty of Meeting Technology Requirements →

- Level of complexity driven by level of interaction wit the grid; number, type and dispersal of generation sources; shape and size of the loads; and the type of values being delivered
- Increasing the scope of service increases the complexity, especially for design, monitoring and control, and protection.

As the scope of service increases, the importance of the functional requirements increases.

Importance of Functional Requirements by Scope of Service - Summary

Functional Area	Single-Facility	Multi-Facility	Feeder	Substation	Key Factors
Performance Requirements	High	High	High	high	•Interconnection requirements must be resolved. •Ability of microgrids to meet Power Quality and Steady-state and Dynamic performance requirements must be proven.
Design	Low	Med	High	high	•Design needs to comply with most restrictive codes. •Design can drive cost (# of switches, voltage regulators, capacitor banks) and performance – especially as complexity increases – *smaller systems likely to be less complex.*
Monitoring and Control	Med	Med	Med-high	Med-high	•Control algorithms will be more complex as the microgrid size increases and the loads and generation become more diverse and disperse.
Protection	Low	Med	Med-high	Med-high	•Protection must coordinate for all ranges of generation output levels . •Auto-synchronization with grid may be more complex for microgrids with numerous generators that all must be in phase for successful synchronization. •Black-start capability required if microgrid to operate in stand-alone during grid outage.
Operations	Med	Med	Med-high	Med-high	•Safety and operations driven by a trained labor force. •O&M and spare parts more important for larger systems.
Infrastructure	Low-med	Low-med	Med	Low-med	•Infrastructure upgrades to utility system line and equipment more likely for larger systems, but interconnection requirements lower for substation application.
Overall Assessment	Med	Med	Med-high	Med-high	•More complexity with GP, PS, SD heighten importance of design and monitoring and control requirements.

As the scope of service increases, the importance of the functional requirements increases.

Importance of Functional Requirements by Scope of Service

Functional Area	Functional Requirements	Single-Facility	Multi-Facility	Feeder	Substation
Performance Requirements	•Meet IEEE 1547 requirements •Power quality •Steady-state and dynamic performance	high high high	high high high	high high high	high high high
Design	•NEC/NESC code requirements •Switching (Generation and Load isolation) •Load transfer •Line and equipment ratings •Regulation (voltage and power factor) •Critical loads	high low very low low low med	high med low med med med	high high med high high high	high high high high high high
Monitoring and Control	•Control system algorithm •Frequency (load following) •Voltage (load following) •Power Factor •Load •Generation •Communications infrastructure	low med med low high high low	med med med low high high low	high med med low high high high	very high med med low high high high
Protection	•Fault current interruption •Coordination (normal vs. reconfigured) •Under/Over voltage •Fault isolation (voltage and current) •Auto synchronization with the grid •Black start capability	low low low low med med	med med med med med med	high high high high med med	high high high high med med
Operations	•Safety •Plan and protocol (O&M plan) •Spare parts and inventory •labor	high med med med	high med med med	high med high med	high med high med
Infrastructure	•Utility system and equipment upgrades •Interconnection requirements •Communication Infrastructure & Controls	low med med	low med med	med med med	med low Med

As the scope of service increases, the gaps also increase.

Gaps in Meeting Functional Requirements by Scope of Service - Summary

Functional Area	Single-Facility	Multi-Facility	Feeder	Substation	Key Factors
Performance Requirements	Low-Med	Low-Med	Low-Med	Low	•Interconnection requirements may take time. •Meeting performance requirements depends on the values provided, e.g. Green Power, Power System, Service.
Design	Med	Med	Med	Med	•Limited experience with code compliance. •Existing switch technology sufficient, but need to prove cost-effective designs for more complex configurations – complexity depends on the values provided.
Monitoring and Control	Med	Med	Med	Med	•Need to prove the ability to control multiple configurations. •Need to prove control algorithms for managing intermittency of RE, helping optimize the macrogrid, and provide service differentiation •May need to integrate communications infrastructure with the utility or ISO.
Protection	Low	Low-Med	Med	Med-High	•Auto-synchronization, Black Start, and fault current protection needs to be proven for larger grids with numerous generating devices.
Operations	Low	Low-Med	Low-Med	Low-Med	•Labor force may be a big gap for owners of microgrids. •O&M and spare parts plans become more complex as the size of the microgrid increases.
Infrastructure	Low-Med	Low-Med	Med	Low-Med	•Need to understand interconnection and communications infrastructure requirements.
Overall Assessment	Low-Med	Low-Med	Med	Med	•Microgrids untested in complex configurations, e.g. design and monitoring and controlling complex configurations (different values), protection for larger scale operation (larger scope of service). •Less interconnection requirements for substation, but more gaps meeting protection requirements.

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As the scope of service increases, the gaps also increase.

Gaps in Meeting Functional Requirements by Scope of Service

Functional Area	Functional Requirements	Single-Facility	Multi-Facility	Feeder	Substation
Performance Requirements	•Meet IEEE 1547 requirements •Power quality •Steady-state and dynamic performance	med low-med low-med	med low-med low-med	med low-med low-med	low low low
Design	•NEC/NESC code requirements •Switching (Generation and Load isolation) •Load transfer •Line and equipment ratings •Regulation (voltage and power factor) •Critical loads	med med med med med low	med med med med med low	med med med med med low	med med med med med low
Monitoring and Control	•Control system algorithm •Frequency (load following) •Voltage (load following) •Power Factor •Load •Generation •Communications infrastructure	med-high med-high med med med med med	med-high med-high med med med med med	med-high med-high med med med med med	med-high med-high med med med med med
Protection	•Fault current interruption •Coordination (normal vs. reconfigured) •Under/Over voltage •Fault isolation (voltage and current) •Auto synchronization with the grid •Black start capability	low low low low low low	low-med low-med low-med low-med low-med low-med	med med med med med med	med-high med-high med-high med-high med-high med-high
Operations	•Safety •Plan and protocol (O&M plan) •Spare parts and inventory •labor	low low low med	low low-med low-med med	low med med med	low med med med
Infrastructure	•Utility system and equipment upgrades •Interconnection requirements •Communication Infrastructure & Controls	low med med	low med med	med med med	med low med

Table of Contents

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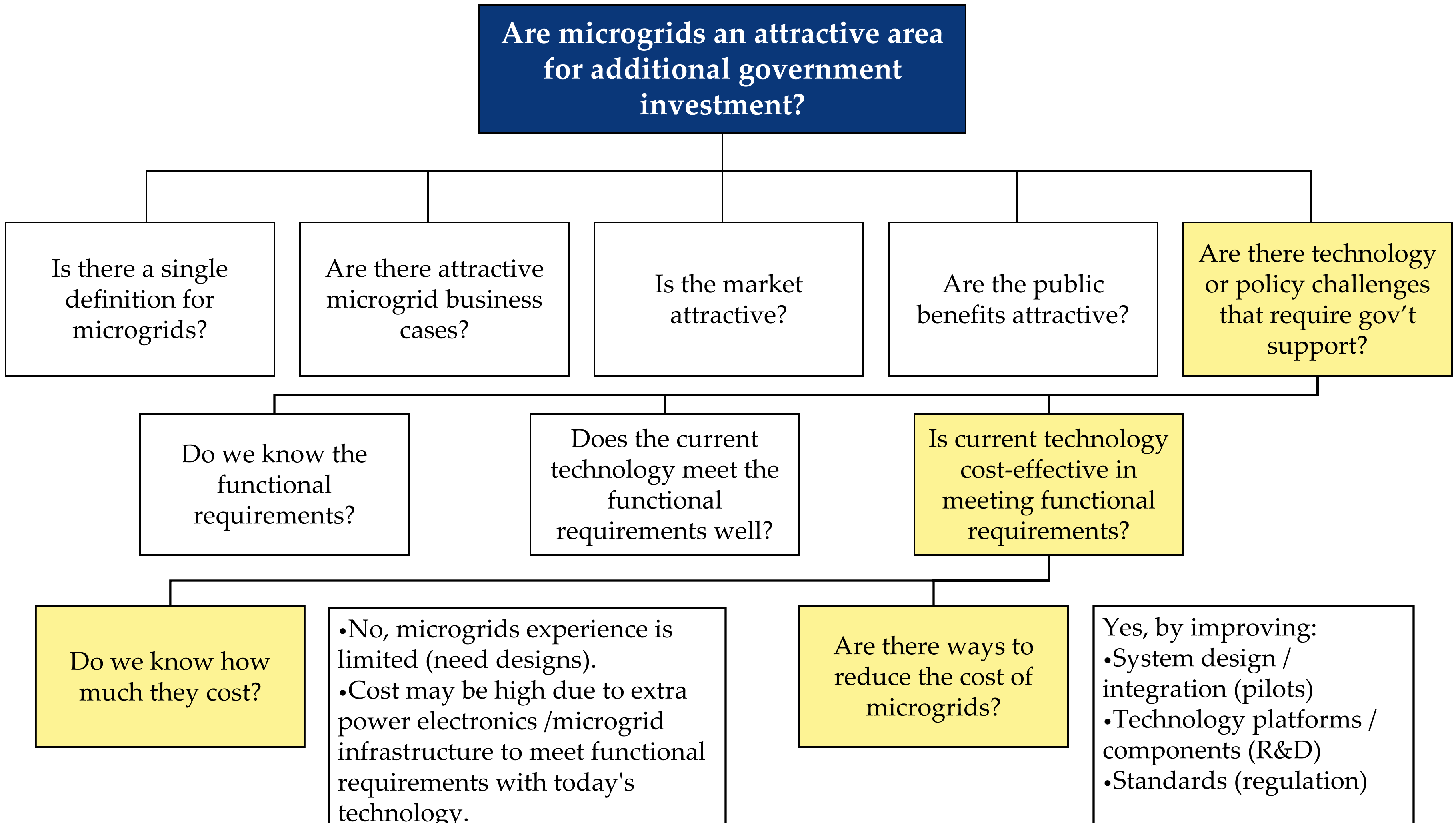
Microgrids are not likely to be cost-effective today without improved system design, technology investmen, and standards development.

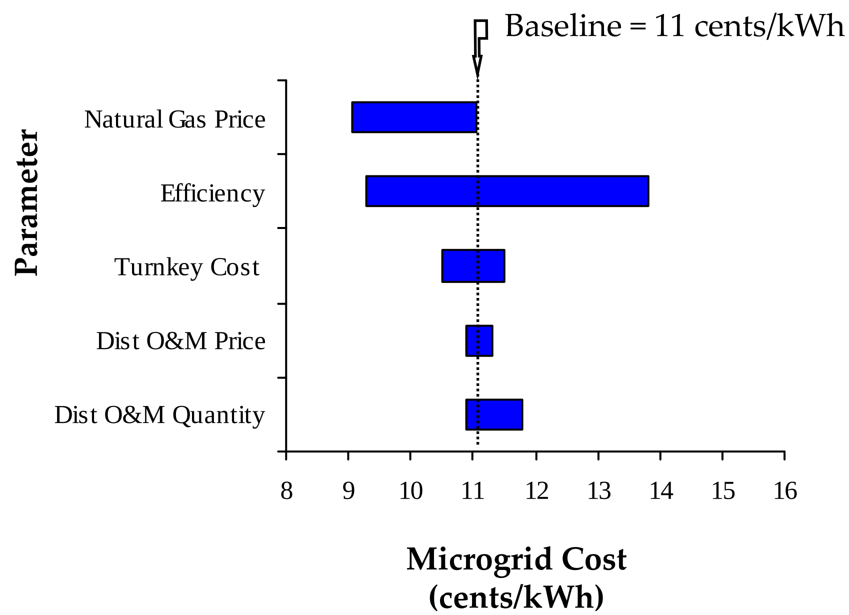


Phase 1 analysis showed that generation technology and fuel costs drive microgrid economics.

Cost Model Settings and Sensitivity Range (Custom Power, Industrial Bus. Case)

	Parameter	Baseline Setting	Range Tested
Fuel Cost	Natural Gas Price	$9/MMBtu	$7 - $9
Capital Costs	Efficiency	40%	30% - 50%
	Turnkey Cost – No CHP	$600/kW	$400 - $800
Infrastructure and Other	Distribution O&M Price	$8,000/ mi/year	$2,000 - $32,000/mi/ year
	Distribution O&M Quantity	1 mile	0 to 10 miles

Cost Sensitivity – Custom Power, Industrial Bus. Case (cents/kWh)



With experience and advances in technology and design, infrastructure costs should not be a limiting factor in the economics.

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The challenges are primarily due to system integration issues, but also due to gaps in technologies and the need for standards.

Drivers of Gaps (X denotes a significant factor in meeting a requirement)

Functional Area	Functional Requirements	System Integration	Standards / Certification	Technology Platforms: Control System – Asset	Control System – Internal	Control System – External	Fast Switch	Energy Storage	Demand Response	Power Electronics	Sensors, processing
Performance Requirements	•Meet IEEE 1547 requirements	X	X								
	•Power quality	X	X	X	X			X	X		
	•Steady-state and dynamic performance	X	X	X	X			X	X		
Design	•NEC/NESC code requirements	X	X								
	•Switching (Generation and Load isolation)	X		X	X		X		X	X	
	•Load transfer	X		X	X	X	X	X	X		
	•Line and equipment ratings	X									
	•Regulation (voltage and power factor)	X		X	X	X	X	X	X	X	X
	•Critical loads	X									
Monitoring and Control	•Control system algorithm	X		X	X	X	X	X			X
	•Frequency (load following)	X		X			X	X			
	•Voltage (load following)	X		X	X		X	X		X	
	•Power Factor	X		X	X		X	X		X	
	•Load	X		X			X	X		X	
	•Generation	X		X	X		X	X			X
	•Communications infrastructure	X		X	X	X				X	X
Protection	•Fault current interruption	X								X	X
	•Coordination (normal vs. reconfigured)	X			X					X	X
	•Under/Over voltage	X									X
	•Fault isolation (voltage and current)	X								X	X
	•Auto synchronization with the grid	X	X	X	X	X	X				X
	•Black start capability	X		X	X	X					
Operations	•Safety	X									
	•Plan and protocol (O&M plan)	X									
	•Spare parts and inventory	X									
	•Labor	X									
Infrastructure	•Utility system and equipment upgrades	X	X								
	•Interconnection requirements	X	X								
	•Communication Infrastructure & Controls	X		X	X	X					

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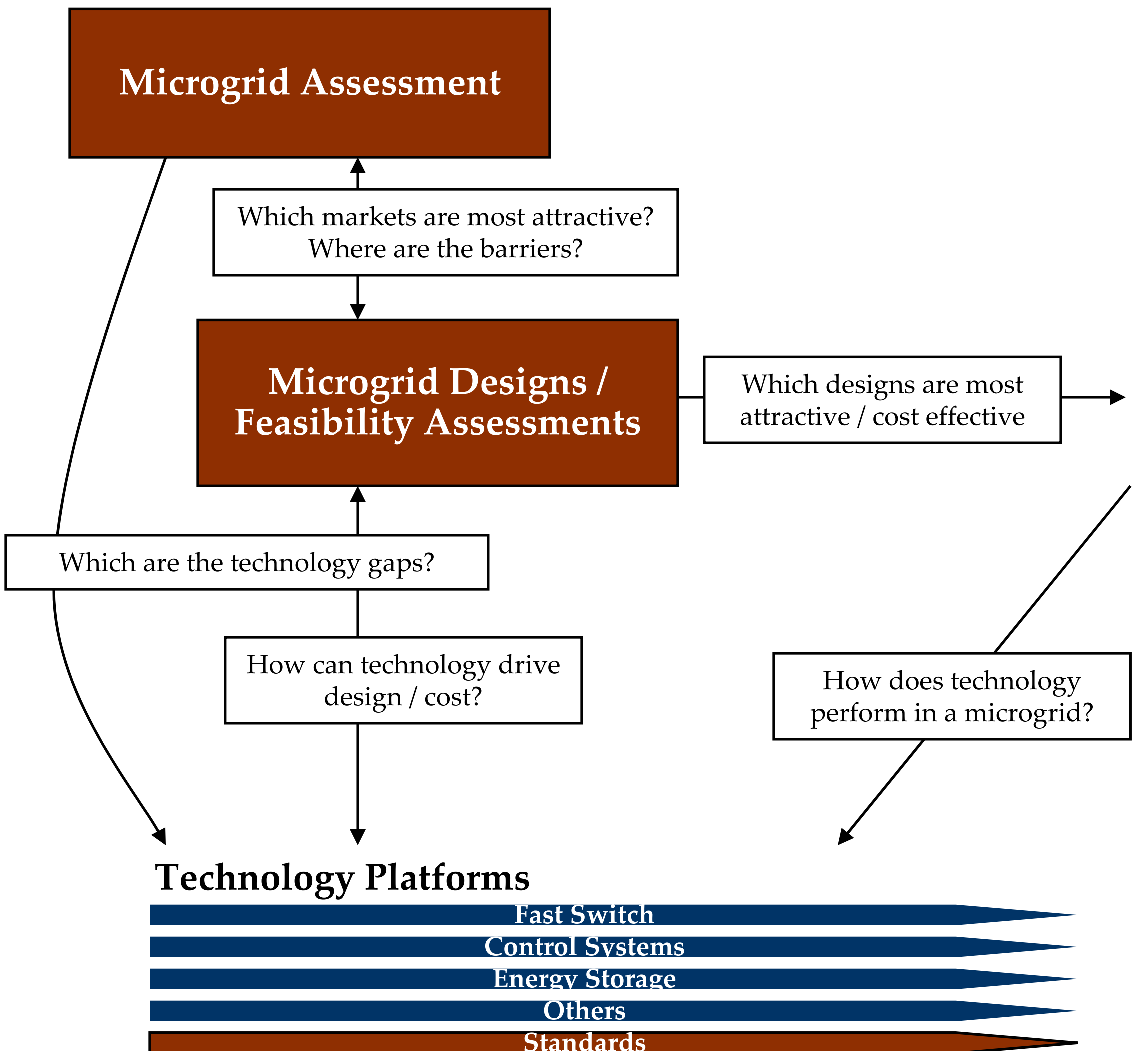
Pilots should be a key part of helping close the technology gaps.

Approach to Close Gaps by Functional Area

Functional Area	Key Factors	Approach to Close Gaps
Performance Requirements	•The ability of a microgrid to meet minimum PQ requirements depends on size, load level, impedance. •Interconnection – applies to all.	•**Feasibility studies** and pilots will identify compliance with current and subsequent IEE ***interconnection standards***, including 1547-2003 and related guidelines. •**Pilots** involving a range of DG technologies, grid configurations and load levels can provide importance performance and operating experience and data.
Design	•Code requirements uncertain •Design can increase cost by increasing number and type of switches and infrastructure upgrades	•**Feasibility studies and pilots** will identify compliance with code requirements. •System **feasibility studies** and operating experience for increasingly complex delivery systems (e.g. power system optimization, integration of green power, service diff), is needed to test the effectiveness of switching procedures, the ability of generation sources to serve the load, and *identify the most economic structure*.
Monitoring and Control	•Complexity of control algorithms driven by level of interaction with the grid, and complexity of generation and loads	•**Pilots** involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to test algorithms, confirm performance of individual technologies, and provide *data to help guide technology R&D*. •Reduced voltage systems or dynamic Var controlllers may be required to enable induction motors to start.
Protection	•Auto-synchronization, fault current interruption and isolation are more complex and unproven for microgrids with numerous generators	•**Pilots** for a range of DG technologies, grid configurations and load levels – prove black-start capability and auto-synchronization. •Coordination studies must be performed to ensure devices will isolate faults as intended and to avoid spurious operations. •Resolution of protection coordination issues will be case specific.
Operations	•Experienced personnel critical for design and operation, especially for complex systems	•Procedures must be developed that fully address all safety-related issues. •O&M plans and training documents would be helpful for prospective owners.
Infrastructure	•Interconnection requirements unresolved	•State commissions and FERC will need to reach a consensus on what interconnection standards will apply. •Infrastructure requirements will be more clear after pilots are conducted and other design, monitoring and control, and protection issues are resolved.
Overall Assessment	•Complexity of the microgrid can drive costs and technical requirements	•Studies and pilots should be designed to address the most important gaps given the market assessment and roadmap.

The approach to close gaps is the same when viewed by value proposition or scope of service.

Improved designs, feasibility assessments, pilots, support for technology platforms and standards are needed.



Microgrid Pilots

Pilot 1
- Application focus: Small Multi-facility with Landlord
- Value Proposition: Reduced Cost
- Technology Requirements: a, b, c

Pilot 2
- Application focus: Large Multi-facility with Muni
- Value Proposition: Security
- Technology Requirements: e, f, g

Pilot 3
- Application focus: Feeder with Utility
- Value Proposition: Reliability
- Technology Requirements: h, i, j

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Performance Requirement	▪ Meets IEEE 1547 requirements	▪ Microgrids must meet IEEE 1547, at the point of common coupling, to enable integration with utility grid (for primary or back-up service). The individual DGs should ride through voltage and frequency events for which 1547 requires tripping ▪ DG interconnection and microgrid interconnection performance also should comply with IEEE 1547 ▪ It may also be desirable, from the microgrid owner's perspective to have units within the microgrid conform with IEEE 1547	▪ IEEE 1547 periodically will be updated and it is anticipated that updates will clarify and possibly, impose increasingly stringent requirements ▪ Technologies and interconnection arrangements need to provide sufficient flexibility to adapt to future IEEE 1547 updates/revisions ▪ 1547 does not address islanding situations	▪ Several DG technologies currently meet IEEE 1547 performance requirements. This should help individual microgrid installations meet 1547 at the point of common coupling ▪ The impact of non-compliant technologies or devices on the ability of a microgrid to be 1547-compliant is a function of technology type and status; i.e., solutions will be case-specific rather than generally applicable solutions ▪ 1547 needs 1547.4 (microgrid requirements) as a complement to current requirements for microgrids	▪ Studies and potential pilot will identify compliance with current and subsequent IEEE interconnection standards, including 1547-2003 and related technical and applications guidelines ▪ Development of 1547.4 is key

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Performance Requirement	▪ Power Quality (PQ)	▪ A microgrid must maintain proper voltage, frequency, harmonic injection, transients/stability ▪ Includes IEEE 1547, CBEMA and minimum customer/grid PQ requirements	▪ PQ standards may differ in some states ▪ The ability of microgrids to meet PQ requirements depends on the logic and speed of response of the switch at the point of common coupling; the ability of the DG units to support voltage; and the rate at which the DG units can balance power ▪ The extent of the PQ challenge is a function of the microgrid size, impedance, load level (real and reactive), which can vary significantly for different grid concepts. Prudent grid design and equipment selection is essential to ensure PQ.	▪ Parallel operation with grid may provide improved PQ performance; frequency, voltage stability when compared to stand-alone operating mode. Today's 1547 requirements may detract from stability, not improve it, by requiring generation to get off line when ever there is a stability-flavored event. ▪ Stand-alone grid operation more likely to experience perturbations and degraded PQ due to absence of "stiff" busses and high available fault current ▪ Stand-alone operation with low fault currents may cause PQ problems due to slow clearing intervals. Protection devices that do not depend on high fault current may be required.	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data ▪ Use of synchronous generators is one way to provide stability. With proper controls, static inverters could provide stability.

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Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Performance Requirement	▪ Steady-state and dynamic performance simulation	▪ Accurate predictive models, data bases and analyses are essential to ensure DGs within multi-unit systems will remain on line (i.e. connected to the utility (area EPS) or connected to an islanded microgrid), both during normal and fault conditions, particularly rotating devices.	▪ Existing simulation models should be suitable; however, there may be limited experience in applying these models for the range of microgrid configurations that may be proposed. Further, DG performance parameters need to be measured and confirmed to ensure accurate results ▪ The controls required to simulate DG in microgrids is unavailable in commercial software.	▪ Steady-state and dynamic performance for complex grid configurations with multiple DG types and dispersed locations is less predictable compared to grids using fewer DG's	▪ System studies that predict steady state and dynamic performance are essential for complex grids. ▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to supplement and confirm predicted simulation model results ▪ Improvement to Load management strategies could increase responsiveness.

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Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Design	▪ NEC/NESC code requirements	▪ Internal grid power delivery system may need to comply with both NEC and NESC. The NESC typically applies to electric utilities; NEC applies to commercial, residential, industrial systems and is more prescriptive.	▪ Design of power delivery system for microgrid should comply with the most restrictive codes for the portions of the system that are owned by non-utility entities	▪ There is limited experience to identify code compliance, including where NESC versus NEC applies	▪ Studies and potential pilot will identify compliance with current and subsequent code requirements
	▪ Switching (Generation and Load isolation)	▪ Sufficient switching capability to isolate generation, loads and equipment for maintenance or fault isolation ▪ Microgrid system design should provide allowance for sufficient switching to meet isolation and load transfer criteria	▪ Care must be exercised to ensure real or reactive flow-through do not occur via unintended parallel operation caused by closing switches among 2 or more independent sources	▪ Existing switch technology is sufficient to meet the requirement ▪ Switches may be operated manually, but motor-operated devices are necessary if operated remotely via SCADA or a central control system	▪ Operating experience for actual systems involving increasingly complex delivery systems is needed to test the effectiveness of switching procedures

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Design	▪ Load transfer	▪ Depending on its size, a microgrid may have to be able to transfer loads, within the microgrid, for maintenance or during a failure in one part of the microgrid. ▪ Microgrid system design should provide allowance for sufficient switching to meet load transfer criteria	▪ Generation sources may be insufficient or additional generating capacity may be needed to serve the entire grid load under various microgrid system reconfigurations ▪ Lines and equipment may need to be rated to carry high than expected normal loads to accommodate load transfer ▪ Each of the above could substantially raise costs	▪ Existing switch technology is sufficient to meet the requirement ▪ Switches may be operated manually, but motor-operated devices are necessary if operated remotely via SCADA or a central control system ▪ Load transfer for more complex grid configurations may be desirable and would require additional switches at additional cost	▪ Microgrid design and system operating experience for actual systems is needed to test the effectiveness of switching procedures and ability of generation sources to serve the load.
	▪ Line and equipment ratings	▪ Fault contribution from microgrid generating sources may cause total fault current to exceed on utility equipment fault duty ratings	▪ If fault duty or normal capacity limits are exceeded, equipment may need to be replaced or upgraded, sometimes at significant cost; e.g., substation breakers ▪ These issues may have greater significance for large systems such as the substation model, where large amounts of generation can contribute high fault currents and line loadings	▪ This issue has limited DG on some utility systems; for example urban utilities, and steps have been or must be taken to upgrade or replace the equipment as a condition of DG installation ▪ Normal power flows for high exports may exceed line, device or equipment ratings ▪ Fault current contribution from microgrid DG, particularly synchronous machines, may produce fault currents that may exceed utility equipment duty limits when operating in parallel mode	▪ Fault studies can determine additional fault duty contribution from DG devices; fault model must include network Thevenin Equivalent impedances or fault levels at delivery bus to produce accurate fault calculations (utility may need to perform these studies) ▪ A correctly designed static switch may prevent generation in a microgrid from contributing to the utility's fault current duty ratings.

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Design	▪ Regulation (voltage and power factor)	▪ Microgrids must be designed to control voltage and meet regulation requirements ▪ Microgrids must manage power factor ▪ It is important to regulate each source's reactive power to control voltage at the connection point. If this is done with a V vs Q droop as used in large generators or static var compensators the system will be much more stable than regulating pf. Pf regulation is important for loads but is a poor solution for small or large generation. All large utility generation regulates voltage not pf. If power factor was regulated there would be power oscillation between generators.	▪ Design should assess need to add fixed/switched capacitor banks and/or voltage regulators and/or to coordinate with existing regulation equipment	▪ Power factor issues may be significant for highly inductive loads when operating in a stand-alone model	▪ System studies must be performed to ensure resonant conditions, capacitor "hunting" and undesirable transients are avoided

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Design	▪ Critical loads	▪ Microgrids are likely to be designed to have some critical loads that require continuous power, in both islanded and grid parallel mode. These critical loads would need to be served by generation capable of following load when the microgrid is in island operation. ▪ If a microgrid is to island it needs to load follow. This is a generic requirement of microgrids.	▪ The cost of load isolation devices may increase microgrid costs ▪ The control system must be capable of directing portions of the generation system to serve critical load centers when operating in a stand-alone mode. ▪ For dispersed critical loads, microgrid line configuration may need to accommodate routing and switching options, which could result in redundancy and additional cost	▪ Synchronous generators and power delivery facilities rated to carry the load would enable the system to serve the load ▪ The ability of inverter-based and/or induction generation to serve the load under various configuration is uncertain	▪ Microgrid power delivery system should be designed to ensure critical loads can be served by generation capable of following load
Monitoring and Control	▪ Control system algorithm	▪ If the microgrid is operated via a central controller (as opposed to relying on local generation control), sophisticated algorithms may need to be developed to accommodate a wide range of load and generation output scenarios, and power flow constraints created by line capacity limits and generation availability ▪ These control algorithms will be critical to the operation of the microgrid.	▪ Effectiveness of control system and algorithm should be monitored and adjusted based on actual operation ▪ Algorithms also may need to perform economic dispatch of generation, which may add to the complexity of the system ▪ The microgrid may not be able to operate in a safe manner or may not be able to operate at all if the control system and/or its algorithms fail.	▪ Control systems capable of performing these functions are available, but experience on microgrids that include a range of generating technologies and power delivery configurations may be limited	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to test and adjust algorithms ▪ Failure analysis also needs to be done to insure reasonable operation with loss of the central controller or communication system

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Monitoring and Control	▪ Frequency (load following)	▪ Generation output must respond rapidly to changes in load to maintain frequency, particularly for small microgrids using a small number of generators	▪ Control systems and algorithm must be set to maintain minimum frequency and voltage tolerance to prevent shut-down of the grid for stand-alone operation	▪ Control systems capable of performing these functions are available, but experience on microgrids that include a range of generating technologies and power delivery configurations may be limited	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to confirm microgrid in both the stand-alone and parallel operating modes
	▪ Voltage (load following)	▪ Generation output must respond rapidly to changes in load to maintain voltage, particularly for small microgrids using a small number of generators	▪ Voltage may be controlled via regulators and/or capacitors ▪ Resonance and hunting needs to be avoided	▪ Control systems capable of performing these functions are available, but experience on microgrids that include a range of generating technologies and power delivery configurations may be limited	
	▪ Power Factor	▪ Control system needs to be able to monitor real and reactive loads throughout the grid to maintain steady-state power factor	▪ Large industrial loads using induction motors may require large starting currents and reactive power, which may impact power quality; the motor also may stall ▪ Algorithm may need to include capacitor and regulator controls, set to maintain power factor and voltage	▪ Control systems capable of performing these functions are available, but experience on microgrids that include a range of generating technologies and power delivery configurations may be limited	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to confirm microgrid in both the stand-alone and parallel operating modes ▪ Reduced voltage systems or dynamic Var controllers may be required to enable induction motors to start

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Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Monitoring and Control	▪ Load	▪ Generation output must respond rapidly to changes in load to maintain frequency and load, particularly for small microgrids using a small number of generators	▪ Inverter-based systems may present operational challenges if they are to follow load in stand-alone mode ▪ Control systems and algorithm must be set to maintain minimum frequency and voltage tolerance to prevent shut-down of the grid for stand-alone operation	▪ Inverter-based systems are used for small remote load applications; however, there is limited experience operating inverter-based systems for larger systems.	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to confirm microgrid in both the stand-alone and parallel operating modes
	▪ Generation	▪ Generation output must respond rapidly to changes in load to maintain frequency and load, particularly for small microgrids using a small number of generators	▪ Control systems and algorithm must be set to maintain minimum frequency and voltage tolerance to prevent shut-down of the grid during stand-alone operation	▪ Large load perturbations and load loss (real and reactive) may strain capability of generators to respond	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience and data to confirm microgrid in both the stand-alone and parallel operating modes

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Monitoring and Control	▪ Communications infrastructure	▪ A communications infrastructure is needed for all microgrid systems for energy management (slow control) and possibly to control generation during dynamic changes, e.g. for load following (fast control) ▪ Closely tied to automation activities and distribution system automation is increasingly important	▪ Devices such as motor-operated switches and breakers may need to be equipped with receivers for RF applications ▪ The communications infrastructure may need to be integrated with or accessible by the electric utility ▪ If communications system is used for dynamic control is must be fast and highly reliable (cost will be an issue). ▪ Need to address the issues in parallel with automation issues and ensure standardization (IEC 61850 series)	▪ Several communications infrastructure options are available using existing technology ▪ The most suitable communications infrastructure typically will be a function of microgrid size and configuration: ▪ Hard wire, direct connection suitable for most compact installations such as building complexes ▪ Radio frequency (RF) Cellnet systems may be needed for larger grids	▪ Design and operating experience is needed to confirm performance and to identify the most economic infrastructure options ▪ Local control could be used for all fast changes in the system such as load following, load balance after islanding and reconnection to the grid. ▪ There are approaches, such as the CERTS Microgrid design, that only use slow communications for energy management functions, and this communication is not critical to microgrid operation. That is, if communications is lost, the microgrid will continue to function properly. ▪ Participate actively in IEC TC 57 WG17 ▪ Review distribution system automation strategies and conduct studies for microgrid (build on experience gained by some utilities)

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Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Protection (parallel versus isolation modes)	▪ Fault current interruption	▪ Protection must coordinate for all ranges of generation output levels, which may present issues when fault currents are low during stand-alone operating modes; on-line generation that is (or entirely) mostly inverter-based will exacerbate the problem ▪ System also must coordinate for stand-alone and parallel operation, which may present significant coordination issues	▪ Fault current levels must be sufficiently high or relays should be set to highly sensitive trip levels to ensure PQ is maintained and to minimize equipment damage or public safety risk	▪ Protection must coordinate for all ranges of generation output levels, which may present issues when fault currents are low during stand-alone operating modes; on-line generation that is (or entirely) mostly inverter-based will exacerbate the problem ▪ System also must coordinate for stand-alone and parallel operation, which may present significant coordination issues	▪ Coordination studies must be performed to ensure devices will isolate faults as intended, and to avoid spurious operations ▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience to confirm protective coordination and clearing times ▪ There are approaches, such as are being used in the CERTS Microgrid project, that utilize residual current and voltage excursions to avoid the issues associated with the low fault currents of inverters while the microgrid is islanded.
	▪ Coordination (normal vs. reconfigured)	▪ The microgrid protective devices must be capable of properly clearing faults (and avoiding unintended operation)	▪ Reconfiguration of the microgrid for maintenance or load transfer may compromise protection coordination	▪ Protection coordination may be temporarily compromised when microgrid power delivery system is temporarily reconfigured; change-out of fuses or resetting of devices may be necessary if the risk of miscoordination problems are deemed to be unacceptable	▪ Resolution of protection coordination issues often will be case-specific; however, pilot studies and actual operating experience is necessary to assure protection is capable of isolating fault and avoiding equipment damage

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Protection (parallel versus isolation modes)	▪ Under/Over voltage	▪ Devices must be set to ensure voltages are within tolerances	▪ Greater latitude for stand-alone operation may be desirable to avoid frequent and unintended relay operation, particularly for microgrid generation and system configuration that produce low fault currents	▪ Acceptable operating performance generally has been proven for smaller grid configurations; very limited experience exists for more complex grids operating in a stand-alone mode	▪ Pilot studies involving a range of DG technologies, grid configurations and load levels can provide important performance and operating experience to confirm performance
	▪ Fault isolation	▪ Protection devices must be able to detect and isolate faults for a range of grid configurations and operating scenarios. Fault current must be sufficiently high or sensitive control systems in place to ensure coordination ▪ Protection system design and coordination must be consistent with prudent practices. The system must be designed to accommodate both stand-alone and parallel operation with compromising protection coordination.	▪ Parallel operation may be necessary at times to ensure devices coordinate, particularly when generation is mostly off-line	▪ Acceptable operating performance generally has been proven for smaller grid configurations; very limited experience exists for more complex grids operating in a stand-alone mode	▪ Resolution of protection coordination issues often will be case-specific; however, pilot studies and actual operating experience is necessary to assure protection is capable of isolating fault and avoiding equipment damage

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Protection (parallel versus isolation modes)	▪ Auto synchronization with the grid	▪ The microgrid's reconnection to the grid requires that the switch be able to close on "point on wave". Most motor-operated switches cannot achieve this. If synchronization is not correct there will be major current transients that could damage equipment and will disrupt sensitive loads. ▪ Utility-approved devices are needed to enable parallel operation (existing technology) ▪ System must be designed to ensure generators will properly synchronize, particularly for larger systems where voltage phase angles may drift (frequency is not an issue); inverter-based generation should synchronize properly as the devices rely on the presence of line voltages to operate	▪ Auto-synchronization may be more complex for microgrids with numerous generators that must all be in phase for successful synchronization	▪ Auto-synchronization devices are commercially available and have proven for small girds; however, there is very limited experience for larger grids with numerous generating devices	▪ Conceptual design studies and pilots are needed to confirm operating performance for larger microgrids using a range of generating technologies

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Protection (parallel versus isolation modes)	▪ Black-start capability	▪ If the microgrid is to operate in a stand-alone mode after an outage when generation sources have shut down, some type of black start capability must be in place to avoid high demand charges to meet high cold load pick-up	▪ Microgrid design must include back-start capability if intended to operate independent of the utility grid during start-up	▪ Acceptable operating performance generally has been proven for smaller grid configurations; very limited experience exists for more complex grids operating in a stand-alone mode	▪ Conceptual design studies and pilots are needed to confirm operating performance for larger microgrids using a range of generating technologies
Operations (Grid and Generation)	▪ Safety	▪ Standard operating procedures will have to be developed. ▪ To ensure microgrid safety is not compromised, the system must be operated and maintained by knowledgeable and trained personnel. Also, protection systems must clear faults quickly, consistent with prudent practices.	▪ Experience gained through actual microgrid operation using highly trained personnel to maintain and control the grid is necessary. ▪ Due diligence via careful monitoring and control during the initial phase-in is essential	▪ Electric utilities and industrial/commercial systems equipped with on-site generation may be familiar with or have such procedures in place	▪ Procedures must be developed that fully address all safety-related issues ▪ Actual system operations is necessary to ensure protection systems will clear faults as intended
	▪ Plan and protocol (O&M plan)	▪ Similar to electric utility practices, clear and concise plans and protocols should be prepared that address microgrid system operations, maintain, controls, outage restoration, inspection and testing and internal/external communications	▪ Personnel qualified to implement the plans are essential to successful microgrid performance and operation ▪ State and or federal (FERC) interconnection requirements also may specific certain operating, testing and maintenance requirements	▪ Electric utilities and industrial/commercial systems equipped with on-site generation may be familiar with or have such procedures in place	▪ O&M plans that address a range of microgrid operating scenarios prepared by independent expert organizations would be helpful for prospective owners and operators

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Operations (Grid and Generation)	▪ Spare parts and inventory	▪ A full set of spare parts, devices and inventory for the generation and power delivery system is essential, particularly if the system is expected to operate mostly in the stand-alone mode	▪ Judicious selection of necessary inventory is necessary to avoid high carrying charges for stock	▪ The cost for a complete inventory may substantially raise costs	▪ Supplier alliances that provide Just-in-Time inventory could reduce inventory
	▪ Labor	▪ A sufficient number of trained personnel is necessary to operate and maintain the system, particularly for larger grid systems involving a range of generation, power delivery and control technologies	▪ A trained labor force must be part of the microgrid system implementation plan ▪ Personnel trained to operate and maintain industrial or commercial electric systems designed to the NEC may not be as familiar with the NESC or utility-grade equipment or power delivery system operation	▪ Electric utility and many contractors have personnel that qualified to operate microgrids in stand-alone or parallel mode.	▪ Preparation of training, operating and maintenance documents prior to implementation would be useful for prospective owners and operators
Infrastructure	▪ Utility system line and equipment upgrades	▪ Generation exports (planned or unintentional) and/or fault current contribution may exceed utility line and equipment ratings. The cost of these upgrades, if extensive, could be substantial and erode project economic benefits	▪ Note that exports above net metering levels may be subject to state and federal jurisdiction, which may impose additional cost and complexity	▪ Technology exists predict utility impacts. The cost of replacement equipment or upgrades generally is known. However, costs may be prohibitive for some microgrids	▪ A balance must be struck between the values of exports versus the cost of utility upgrades. ▪ One approach is to group loads with generation. This makes the likelihood of high export of power small in well designed microgrids

Functional Area	Functional Requirements	Explanation	Key Issues	Assessment of Gaps	Approach to Close Gaps
Infrastructure	▪ Interconnection requirements	▪ Microgrid design must meet state and/or federal (FERC) interconnection requirements; these may vary among states ▪ Microgrid interconnection design and protection must comply with interconnection standards	▪ Some states have not yet developed interconnection requirements, which raises some uncertainty (FERC Small Generator Interconnection Requirements may be used as a default)	▪ This issue has not been fully resolved at the state or federal level as to whether the FERC interconnection procedures can be used as a default	▪ State commissions and FERC will need to reach a consensus on what standards will apply
	▪ Communication infrastructure and controls	▪ Microgrid interconnection design and protection must comply with utility requirements, interconnection standards and microgrid communications infrastructure and control requirements	▪ The communications infrastructure may differ significantly depending on the design, configuration and size of the microgrid	▪ Utility system upgrades, including infrastructure, and control system upgrades/additions may be needed	▪ Additional experience is needed to assess the level of upgrades that may be needed for various microgrid configurations and generating technologies

Table of Contents

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A workshop was held with industry, government and researchers to develop a common vision and roadmap for microgrids.

Phase 2

Task 1: Customer / Owner Interviews

- Understand customer needs
- Test value proposition of 3 business cases
- Identify changes to business cases
- Identify potential applications and challenges

Task 2: Technical & Functional Assessment

- Identify technical and functional requirements of 3 business cases
- Assess ability of current technology to satisfy functional requirements
- Examine approaches to overcome technical gaps

Task 3: Market & Benefits Assessment

- Estimate the potential size of the microgrid market
- Understand public benefits resulting from microgrids

Task 4: Workshop

- Solicit feedback & input from microgrid owners, customers, researchers, equipment suppliers
- Develop a consensus vision & roadmap for microgrids

Task 5: Final Report

- Final report which clearly answers overall objectives of Phase II and incorporates insights from multiple stakeholders

The workshop was a 3-day event.

Day 1 — Wednesday, June 22

3:00 p.m. **Check-in**

3:15 p.m. – 5:15 p.m. **Introduction to Workshop**

- » *Welcome and opening remarks*
- » *Brief: Navigant Consulting (NCI) remarks on progress to date*

5:15 p.m. – 6:15 p.m. **Icebreaker**

6:15 p.m. – 7:00 p.m. **Workshop Process**

- » *Objectives of Visioning Workshop*
- » *NCI introduction to the visioning process*
- » *Questions and comments*

7:00 p.m. **Adjourn**

Day 2 — Thursday, June 23

7:30 a.m. – 8:00 a.m. **Check-in (Light Breakfast Provided)**

Session 1 — Envisioning the Future

8:00 a.m. – 8:15 a.m. **Introduction to the Exercise**

- » *Guidelines for breakout groups*

8:15 a.m. – 11:30 a.m. **Breakout Groups**

- » *Two groups, each with Scenario I of a 2020 future*
- » *Groups "build on" the scenario, creating an end-state for 2020*
- » *Nominate a spokesperson to report back*
- » *Groups schedule their own break*

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153

The workshop was a 3-day event; the second day focused on developing a vision for microgrids.

Day 2 — Thursday, June 23 (continued)

11:30 a.m. – 12:00 p.m. **Groups Report Back**

12:00 p.m. – 12:30 p.m. **Rationalize the Breakout Outbriefs for Scenario I**

- » *Compare and contrast similarities, differences*

12:30 p.m. – 1:30 p.m. **Lunch (Provided)**

Session 2 — Envisioning the Future

1:15 p.m. – 3:30 p.m. **Breakout Groups**

- » *Two groups, each with Scenario II of 2020 future*
- » *As Session I, above*

3:30 p.m. – 4:00 p.m. **Groups Report Back**

4:00 p.m. – 4:30 p.m. **Rationalize the Breakout Out-briefs for Scenario II**

- » *Compare and contrast similarities, differences*

4:30 p.m. – 5:00 p.m. **Compare and Contrast the Breakouts of Scenarios I & II**

5:00 p.m. **Adjourn**

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154

The workshop was a 3-day event; the third day focused on a timeline to get to the vision.

Day 3 — Friday, June 24

Session 2 — Envisioning the Future (continued)

7:30 a.m. – 8:00 a.m.	**Check-in (Light Breakfast Provided)**
8:00 a.m. – 9:30 a.m.	**Agree on Desired End-State and Emerging Vision Themes for 2020**

Session 3 — Defining a Timeline

9:30 a.m. – 11:30 a.m.	**Breakout Groups** » *What do we need to do and when to achieve our end-state?* » *Create timeline for regulatory, legislative, promotional, etc., activities*
11:30 a.m. – 12:00 p.m.	**Groups Report Back**
12:30 p.m.	**Wrap-up and Closing Remarks**

The purpose of this visioning workshop was to develop guiding themes and a preliminary vision for Microgrids in the United States.

- Collect and share diverse inputs from key industry and government stakeholders. This is an opportunity to share ideas and creative thoughts in an open environment.
- Look at two scenarios of possible futures, considering:
  - ▲Changing market needs
  - ▲Evolving technologies
  - ▲Value chain considerations
- Identify the implications of each scenario for regulatory, legislative, technical and other drivers.
- Take into consideration lessons learned.
- Compare and contrast key scenario outcomes.
- Align common themes into guiding principles and, eventually, into a draft vision for microgrids.
- Develop a timeline of needed actions to make the vision happen.

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156

Futures Visioning techniques were used to encourage out-of-the-box thinking.

- Places one far enough in the future that most current constraints can be assumed resolved
- Focuses on a "desirable" future which effectively meets the needs of key stakeholders in the context of different environments
- Uses multiple scenarios to explore "desirability" from multiple perspectives
- Identifies key issues to be resolved to allow a preliminary vision to unfold

Futures Visioning

An approach to ambition-driven strategic planning in situations where proactive outside-the-box solutions are desired

- A preferred 2020 end-state is defined around alternative scenarios ("Envision the Future")
- We create precepts or themes that bound the preliminary visions ("Themes Development")
- We identify action steps to move us toward the end-state ("Timeline")
- Alternate views of the preferred end-state and additional analysis are eventually consolidated into a final strategic "Vision"

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157

Scenario Planning was leveraged to explore a range of possible futures and identify key needs.

- Scenarios are not the vision, only a planning exercise to identify the key issues and explore alternatives
- The scenarios are meant to bracket the range of credible future possibilities; they are not predictive
- By comparing the similarities between scenarios, potentially "robust" actions can be identified
- By evaluating differences between scenarios, critical triggering events (signposts) can be determined

Scenario Planning

An approach to long-term planning in situations with significant uncertainty about important future events

- Originally developed by Shell, widely used in industry
- Future scenarios developed around high impact/moderate probability "change events"
- Preliminary infrastructure plans developed under alternative scenarios, then compared for similarities and differences

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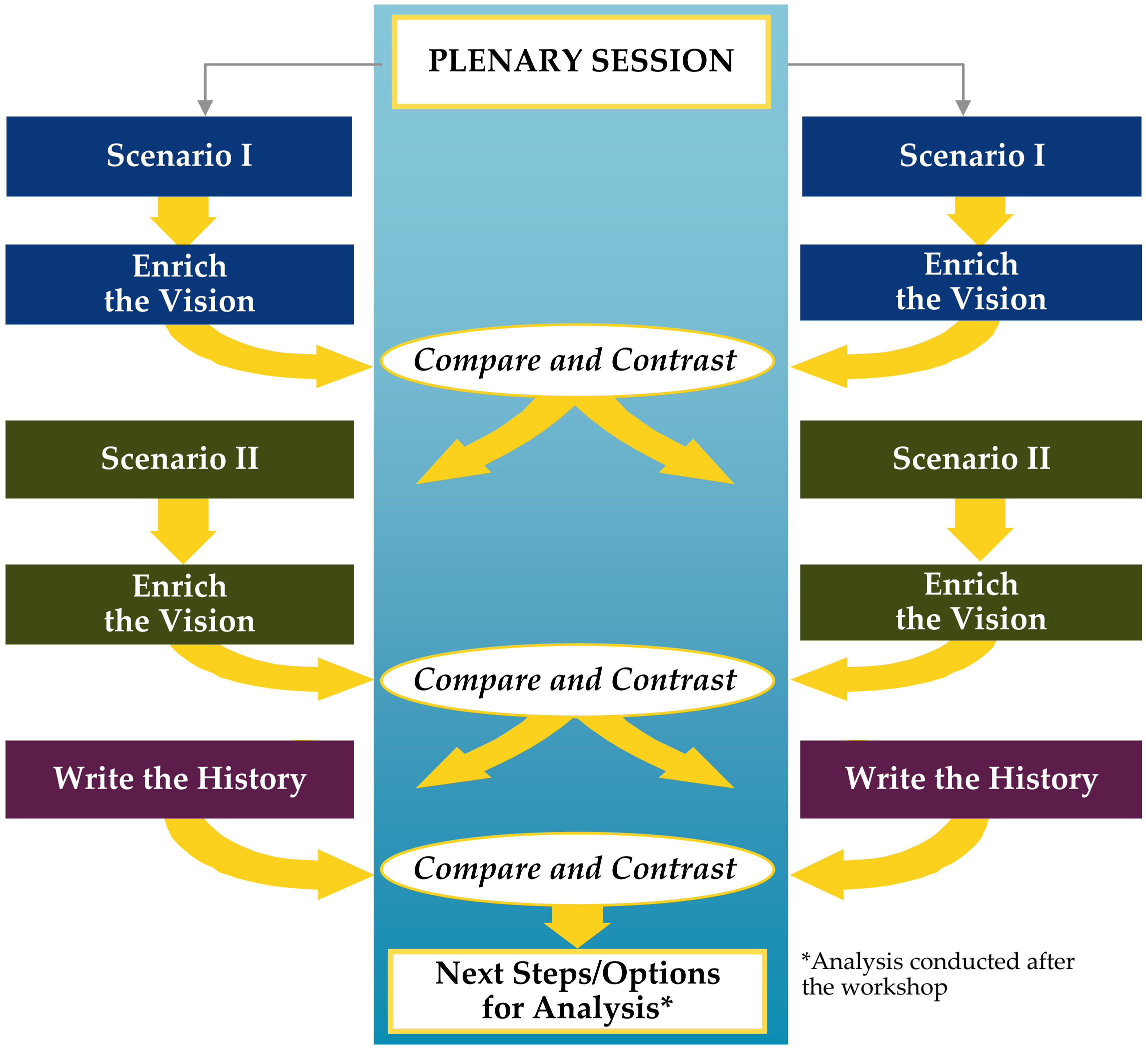
158

Breakout groups examined two different scenarios; this approach allows identification of key areas of convergence and divergence.



*Analysis conducted after the workshop

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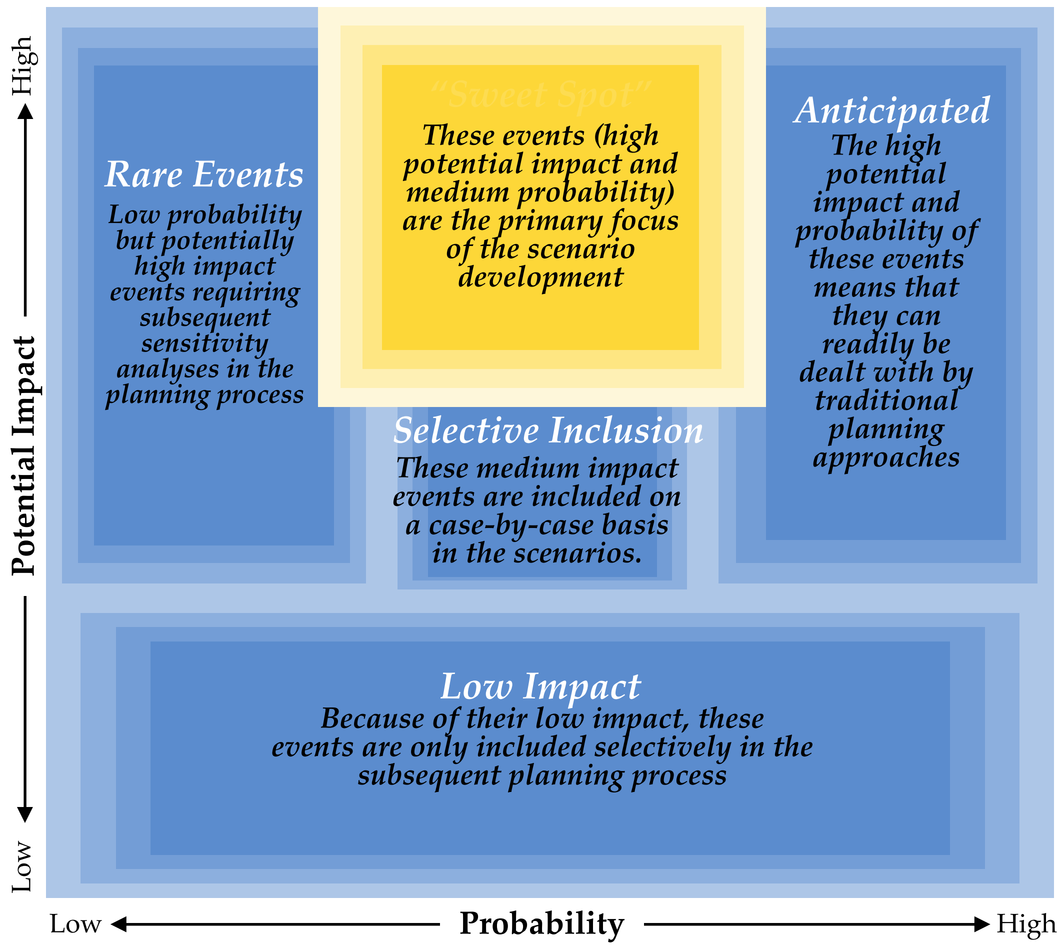
Prior to the workshop, scenarios were built around possible change events that have high potential impact moderate probability.



Probability: *The likelihood of an event occurring*

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In Scenario I (Déjà vu all over again? Not!), it is 2020 and the industry is again heavily regulated, but not all is the same as before.

1. The Nation is facing tightening of supply as limited new generation and T&D capacity has been added over the past two decades of regulatory uncertainty. This period of trial and error regulation has ended and resulted in the generation, transmission and distribution of electricity being highly regulated today.
2. Shifts in the U.S. economy and demographics have had an impact on the pattern of electricity consumption. The commercial/residential mix is now 40%/35%. New energy-efficient technologies and standards, however, have helped control demand growth.
3. Gas and electricity prices are back up to 2003 levels, but price volatility is low. LNG facilities have been added. Natural gas and coal capacities have increased, nuclear capacity has benefited from uprates, and renewable energy has seen modestly increased penetration.
4. CO_2 emissions have continued to rise particularly from the power sector which now makes up a larger percentage of overall CO_2 emission than it did in 2005. SO_2 and NOX emissions have reduced, however mercury emissions are up and there are major concerns on mercury, putting additional pressure on coal generation. Siting issues have significantly delayed new transmission line construction.
5. Regulators favor policies supporting alternatives to central power and use their regulatory oversight, particularly with electric utilities to implement these policies. Utilities, who have to meet rising demand with scarce resources, have a financially attractive regulatory structure to implement these alternatives.
6. Central power still dominates but DG has made significant inroads and is an important part of the resource mix. Government mandates, portfolio standards and other non-mandatory goals have increased the use of CHP and various forms of DG. DG technology has made significant improvements and barriers have been removed, but many states are having difficulty meeting renewable portfolio standards.
7. Large companies continue to dominate, as DG equipment suppliers and smaller developers survive but face stiff competition from utilities, who administer the demand response and energy efficiency programs.
8. There is little customer choice; utilities offer plain vanilla services.
9. Industry consolidation has resulted in less than half a dozen dominant wires companies, and generation companies have also consolidated. The muni and coop business model has survived and still thrives.
10. The utilities have wrung out all economies from consolidation and are looking for further cost reductions. Their workforce has aged and many tenured employees have retired.
11. Utilities and federal government work together to ensure critical infrastructure protection.

In Scenario II (Informed Energy), it is 2020 and the United States energy industry is market-driven.

1. There has been limited new generation and T&D capacity, mainly due to regulatory and environmental concerns and years of regulatory uncertainty. There are pockets of high prices and low reliability throughout the country, and several parts of the nation have seen rolling blackouts in recent years. New energy efficient technologies and standards have helped control the growth of demand.
2. The shifts in the US economy and demographics has had an impact on the mix of electricity consumption. The commercial sector now accounts for 40% and residential 35% as air conditioning loads have increased as population has shifted to warmer climates.
3. Given the nation's priorities to reduce CO2 emissions and long lead times to build new transmission facilities and nuclear power plants, it is clear that the US can no longer rely on central power plants or regulation alone.
4. Government is counting on market forces to provide generation and infrastructure resources, including alternatives to central power plants. To encourage more investment in the industry, regulators have eased up on regulation preventing open competition with utilities and have reduced protections of utility franchises. New business models have been tested and adopted and new, stronger players are evident.
5. Nuclear and green power, gas, DG and hydro; along with demand response and energy efficiency; exist side-by-side driven by customer demands.
6. Distributed generation is owned by the customer, utility and third-parties, with PV and CHP as primary technologies.
7. Government performs an oversight role, supporting development and refereeing the rules, but relying on market forces rather than regulation.
8. Customers have increased choice in energy supplier and energy services. There are no subsidies for CHP or green power, but prices for these are provided by the utility and prices are transparent. The customer is well-informed, choosing energy and supplier on the basis of environmental impact, cost and quality.
9. But customers are exposed to transparent, dynamic price signals reflecting capacity and locational/temporal systems constraints. Price volatility is thus very high.
10. The electricity industry has become a model for innovation with new technologies and business models being developed; tested; and discarded or implemented rapidly.
11. Critical infrastructure protection is achieved with new technologies and public/private partnerships.

The workshop participants developed a vision around three central themes.

Microgrid Vision – One GW of Microgrids was installed during the year 2020

Value Proposition

Microgrids are providing added value to society, the grid, and to customers by:
- Improving reliability,
- Reducing the cost of energy and managing price volatility,
- Assisting in optimizing the power delivery system, including the provision of services,
- Providing different levels of service quality and value to customers segments at different price points,
- Helping to manage the intermittency of renewables.
- Promoting the deployment and integration of energy-efficient and environmentally friendly technologies, and
- Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources.

Technology

Technologies exist to support these microgrid value propositions, and can:
- Operate to provide transition between grid-parallel and islanded-operation modes,
- Rely on monitoring, information exchange (including price signals), control technologies, open architecture, and interoperability,
- Fully coordinate financial, physical, and operational elements with the larger power system,
- Integrate demand response, renewables, CHP, storage, power conversion, metering, and other DER, and
- Operate under appropriate interconnection and interoperability standards.

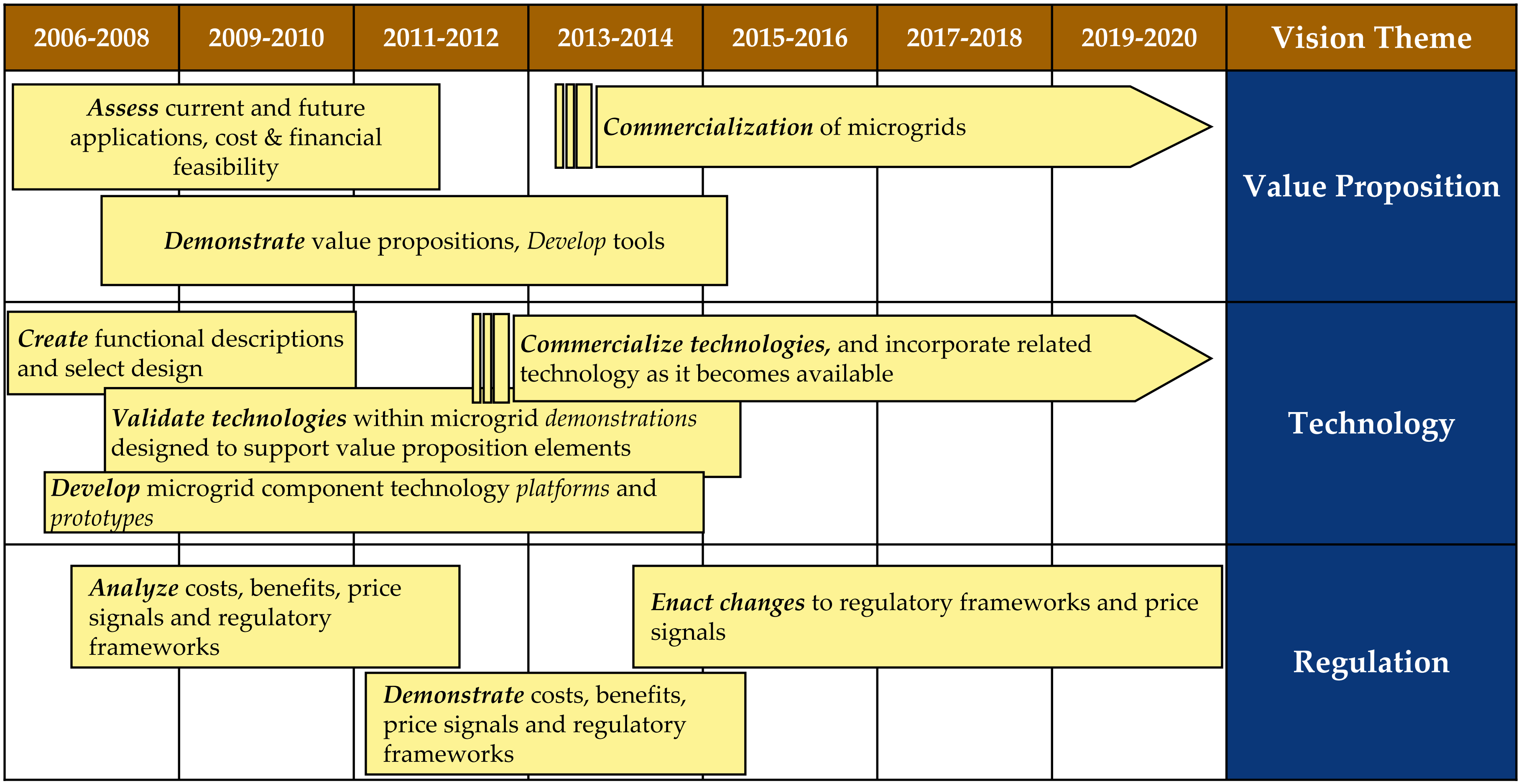
Regulation

Regulations have changed to:
- Allow competition, while maintaining an obligation to serve,
- Fairly compensate utilities for services provided and investments made,
- Provide transparent compensation for environmental, system reliability, and homeland security benefits,
- Permit customers to see the real cost of electricity, including real-time, locational and environmental attributes
- Remove barriers for utility deployment of DER, and
- Adopt nationally recognized interconnection standards.

Utilities, new investors, and customers own and operate microgrids, under arrangements which allow:
- Utility-owned generation and wires,
- Privately owned generation and wires,
- Hybrid ownership and operational structures.

The participants also developed a roadmap to get to the vision.

Microgrids Roadmap



2006-2008	2009-2010	2011-2012	2013-2014	2015-2016	2017-2018	2019-2020	2020 Vision Themes Value Proposition
Assess current and future applications, cost & financial feasibility			*Commercialization* of microgrids				
	Demonstrate value propositions, *Develop* tools						
		Several Significant Outages (2005-2011)	**Difficulty with central power**				1a) improving reliability
			Develop Financial Instruments				1b) reducing the cost of energy and managing price volatility
		Microgrids are included in integrated resources planning		**NIMBY**	**Weak spots, aging infrastructure**		1c) assisting in optimizing the power delivery system including the provision of services
							1d) providing different levels of service quality and value to customer segments at different price points
			Instability of system due to DG, RE		**Increased penetration of DG, RE**		1e) helping to manage the intermittency of renewables
Cost/Financial analysis (cost shift, regulatory)							1f) promoting the deployment and integration of energy efficient and environmentally friendly technologies
					Microgrids are part of FEMA toolbox		1g) increasing the resiliency and the security of the power delivery system by promoting the dispersal of power resources
Current Assessment (2005-6) Feasibility studies (2005-6)	Conduct Demo projects (existing and greenfield)	Develop new modeling and analytic tools	**Time of use rates and metering** **Siting Difficulty (T, D, G)**				2 – cross cutting

Boldface indicates Signposts

2006-2008	2009-2010	2011-2012	2013-2014	2015-2016	2017-2018	2019-2020	2020 Vision Themes Technology
Create functional descriptions and select design			*Commercialize technologies*, and incorporate related technology as it becomes available				
	Validate technologies within microgrid *demonstrations* designed to support value proposition elements						
Develop microgrid component technology *platforms* and *prototypes*							
	Low cost fast switch prototype (2008)			Low cost fast switch commercial (2015)			**2a) operate to provide transition between grid parallel and islanded operation modes**
Validation of internal microgrid controls (2008)	Wide area controls demo (2009) Commercial internal microgrid controls (2010)			Wide area controls commercial (2015)			**2b) rely on monitoring, information exchange (including price signals), control technologies, open architecture, and interoperability.**
							2c) fully coordinate financial, physical, and operational elements with the larger power system
Asset control validation (2007)				Cost effective energy storage (2015)			**2d) integrate demand response, renewables, CHP, storage, power conversion, metering and other DER.**
							2e) operate under appropriate interconnection and interoperability standards.
Prototypes for controls and systems (2008)	Sensors prototype (2008) Sensors demo (2009) Communication demo (2010)						**2 – cross-cutting**

2006-2008	2009-2010	2011-2012	2013-2014	2015-2016	2017-2018	2019-2020	2020 Vision Themes
Analyze costs, benefits, price signals and regulatory frameworks				*Enact changes* to regulatory frameworks and price signals			
		Demonstrate costs, benefits, price signals and regulatory frameworks					
	Complete analysis of microgrid regulatory frameworks including the appropriate roles of players and the obligation to serve (2010)			Enact changes to implement roles of players in microgrids including responsibilities for the obligation to serve) (2015)			**3a) allow competition, while maintaining obligation to serve.** **3b) fairly compensate utilities for services provided and investments made.**
	Determine the costs and benefits of microgrids including reliability, security, temporal, locational, environmental (2010)			Complete demonstrations of the benefits and costs of microgrids (2015)	Design and implement price signals (2018)	Implement regulatory changes to allocate benefits and costs (2015-2020)	**3c) provide transparent compensation for environmental, system reliability, and homeland security benefits.**
	Create models to understand price signals (2009)	Complete analysis of approaches to provide price signals (2011)		Complete microgrid demonstrations responding to price signals (2015)			**3d) permit customers to see the real cost of electricity, which include real-time, location, and environmental attributes.**
Begin education of regulators on micro-grid benefits and costs (2006-2020)				State legislation passed to remove DER barriers (2015)			**3e) remove barriers to utility deployment of DER.**
			Complete 1547.4 for microgrids (2013) Complete research on interconnection for microgrids (2013)	Adopt national interconnection standards – legislation or regulation at state level (2016)			**3f) Adopt nationally recognized interconnection standards.**

The technology group discussed the process for technology development and the key microgrid technology platforms.

Development Process for Technology
1. Create Functional Description 2. Select Design/Methodology 3. Develop Systematic Tools 4. Create Prototype 5. Perform Demonstrations/Validation 6. Deploy Technology

Micro Technology Areas

• Control systems/algorithms
  • Asset – DER control
  • Internal - microgrid optimization and control
  • External - wide area control and dispatch
• Low-cost, fast switchgear
• Energy storage
• Demand response
• Power electronics
• Differential Protection
• Sensors, processing and algorithms
• Metering
• Certification process

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Breakout Groups

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To meet the 2020 vision, microgrids must prove they can meet functional requirements for a scope of service beyond a single facility and for value propositions beyond reduced cost.

Today's Capabilities

- Limited experience meeting performance standards for a wide range of configurations beyond single-facility applications
- Limited ability to deliver complex value propositions
  - Operate in islanded mode
  - Coordinate physical, financial, or operational elements

Microgrids must focus on meeting the technology challenges in the following areas:

Business Cases

Single and Multi - Facility
- Design
- Performance Requirements
- Operations

Feeder, Sub-station
- Protection
- Design
- Infrastructure

Value Propositions

Reduced Cost, Security, Reliability
- Performance Requirements / Interconnection requirements
- Protection / Auto-synchronization

Service Differentiation, Power System, Green Power
- Internal Controls
- Coordination of physical, financial, and operational elements

Technology Platforms

- Fast Switch
- Control Systems
- Energy Storage
- Others
- Standards

2020 Vision

- Operate to provide transition between grid parallel and islanded operation modes
- Rely on monitoring, information exchange (including price signals), control technologies, open architecture, and interoperability.
- Fully coordinate financial, physical, and operational elements with the larger power system
- Integrate demand response, renewables, CHP, storage, power conversion, metering and other DER.
- Operate under appropriate interconnection and interoperability standards.

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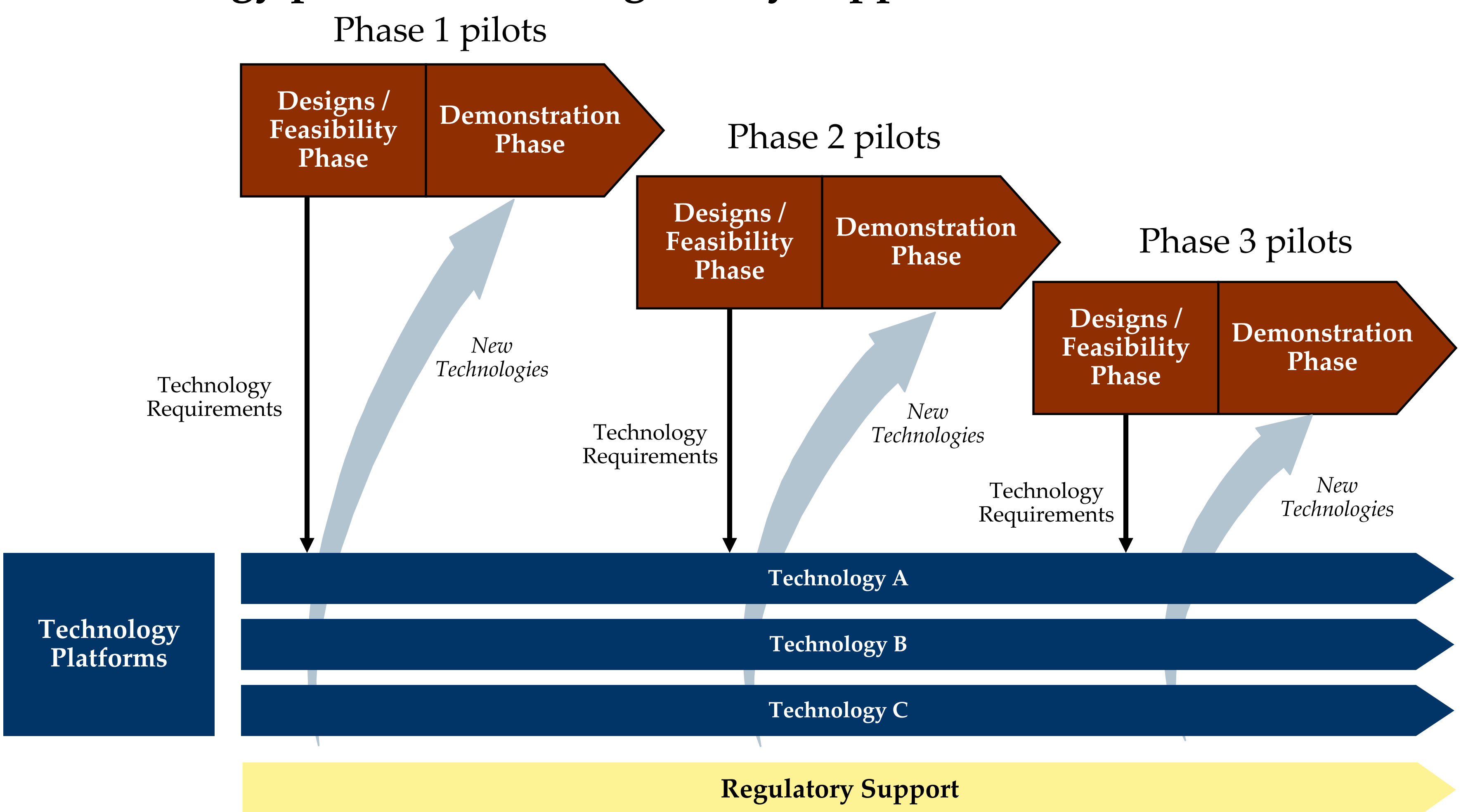
NCI recommends an integrated program of microgrid pilots, technology platforms and regulatory support.



Microgrids are facing business model and technology barriers that could best be addressed by pilot demonstrations.

- Business Model
  - Value Proposition
  - Scope and ownership
  - Regulatory focus
- Technology
  - Control system focus
  - Functional requirements
  - Key technologies

The pilots would test different value propositions, scope and ownership options, and regulatory issues.

Phase 1 Pilots	Phase 2 Pilots	Phase 3 Pilots
Value Propositions Tested: • Reduced Cost – Reducing the cost of energy and managing price volatility • Reliability - improved reliability **Scope:** Single facility and Multi-facility **Ownership:** Landlord, Utility, Muni **Regulatory Focus** • Allow competition, while maintaining obligation to serve. • Fairly compensate utilities for services provided and investments made	**Value Proposition Tested:** • Security - Increasing the resiliency and security of the power delivery system by promoting the dispersal of power resources **Scope:** Multi-facilities, Feeder and Substation **Ownership:** Utility, Muni **Regulatory Focus**: • Cost recovery of security investments	**Value Proposition Tested:** • Power System - Optimizing the power delivery system, including the provision of services • Green Power - Managing the intermittency of renewables and promoting the integration of energy-efficient technologies **Scope:** Feeder and Substation **Ownership:** Utility, Muni **Regulatory Focus**: • Provide transparent compensation for environmental, system reliability, and homeland security benefits. • Permit customers to see the real cost of electricity, which include real-time, location, and environmental attributes

The pilots would also test the technology required to support the microgrid value propositions.

Phase 1 Pilots

Value Propositions Tested:
Reduced Cost
- Reliability

Control System Focus:
- Primary – Internal
- Secondary – External

Technical Functional Reqs Tested:
- Design
  - NEC/NESC code requirements
  - Critical loads
- Performance requirements
- Monitoring and Control
- Protection
- Operations
  - Safety

Technology Platform Focus:
- Fast Switch
- Power Electronics

Phase 2 Pilots

Value Proposition Tested:
- Security

Control System Focus:
- Primary – External

Technical Functional Reqs Tested:
- Design
  - Critical loads
- Protection
  - Black Start Capability

Technology Platform Focus:
- Fast Switch
- Power Electronics
- Energy Storage

Phase 3 Pilots

Value Proposition Tested:
- Power System
- Green Power

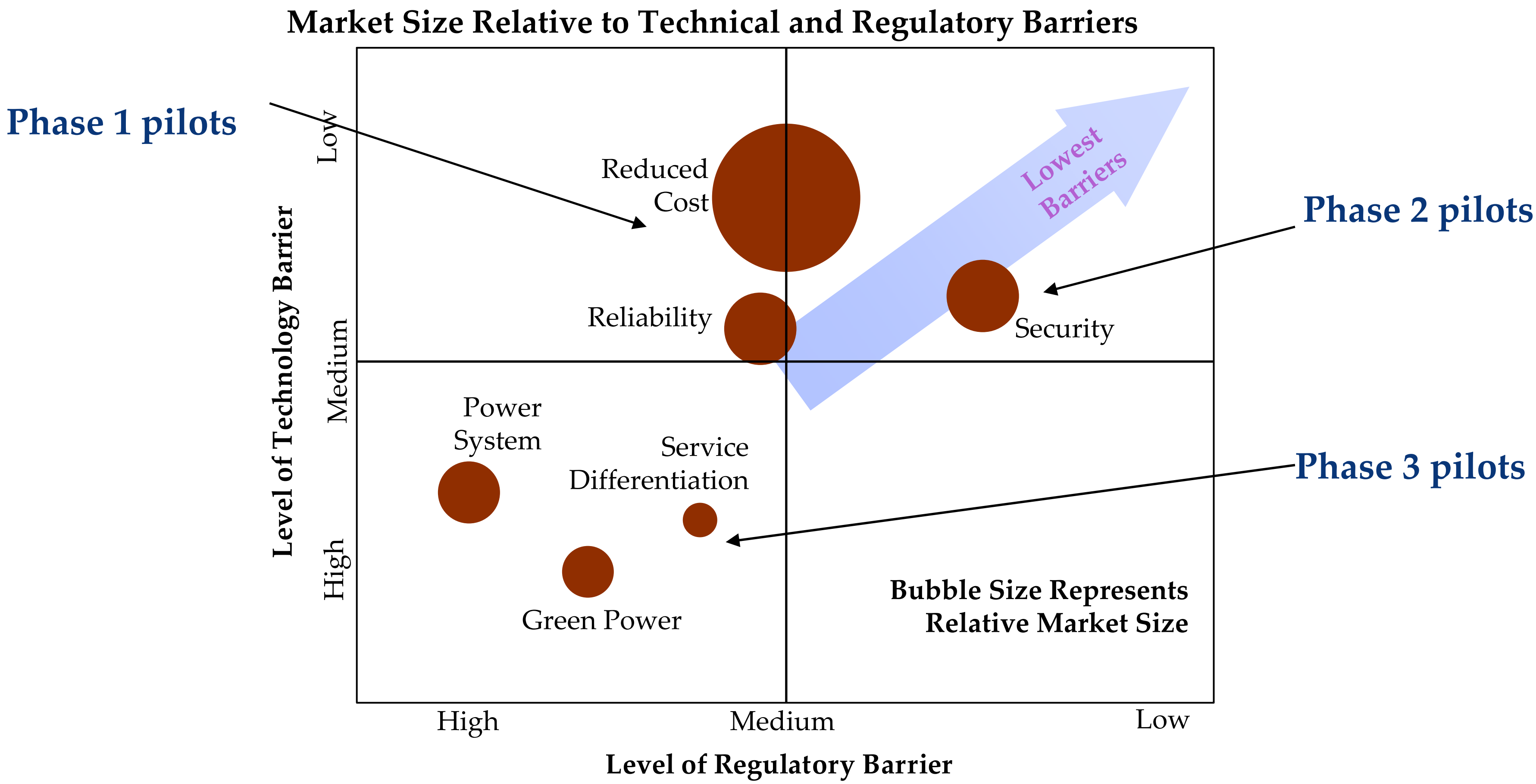
Control System Focus:
- Primary – External
- Primary – Asset

Technical Functional Reqs Tested:
- Design
  - Switching (generator/ load isolation)
  - Load transfer
- Monitoring and Control:
  - Control system algorithm
  - Load
  - Generation
  - Communications infrastructure
- Protection
  - Auto synchronization with the grid

Technology Platform Focus:
- Energy Storage
- Demand Response
- Processing/Sensing

- There are three control domains to consider for microgrids (internal, external and asset). The emphasis of these control schemes varies by value proposition.
- The Phase 1 pilots would demonstrate the majority of the functional requirements for all microgrids, regardless of value proposition. Subsequent phase pilots would include additional functional requirements unique to those value propositions.
- Technologies developed on the technology platforms would be incorporated over time to support the pilot value propositions.
- Functional requirements or emphasis on technology platforms may change during the feasibility/design phase of each pilot.

There are technical and regulatory barriers that are preventing the deployment of microgrids.



The pilots should be prioritized based on size of the opportunity and the technical and regulatory barriers.

Each pilot would address the microgrid regulatory issues that are important to the value propositions demonstrated in that phase.

Phase 1 Pilots

Phase 2 Pilots

Phase 3 Pilots

2020 Regulation Vision	Importance of Regulation						Level of Gap
	Reduced Cost	Reliability	Security	Green Power	Power System	Service Differentiation	
a) allow competition, while maintaining obligation to serve. b) fairly compensate utilities for services provided and investments made	Med	Med	Low	Med	Med	Med	High
c) provide transparent compensation for environmental, system reliability, and homeland security benefits. d) permit customers to see the real cost of electricity, which include real-time, location, and environmental attributes	Low	Low	Very Low	High	Very High	Med	Med
e) remove barriers to utility deployment of DER	Low	Low	Very Low	Med	High	Low	High
f) adopt nationally recognized interconnection standards	High	High	Med	High	High	High	Low
g) cost recovery of security investments	Very Low	Med	Very High	Very Low	Low	Med	Med

Notes: (1) Level of Regulatory Challenge is defined by combining the importance of the regulatory barrier to delivering the value proposition, and the gap in removing the regulatory barrier.

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Microgrids can also be defined by scope of service and ownership.

Microgrid Market Size – Reduced Cost – Base Case Scenario (GW)

Owner	Scope of Service (Size of Microgrid): Single Facility (<2MW)	Multi Facility (2-5MW)	Feeder (5-20MW)	Sub-Station (>20MW)	Total
Utility	0.01	0.7	1.4	0.6	2.7
Muni	0.01	0.4	0.5	0.2	1.2
Landlord	.06	0.5	-	-	0.6
Total	0.09	1.7	1.9	0.8	4.5

Based on analysis for the reduced cost value proposition, 80% of microgrids could be in multi-facility or feeder applications

Scope of Service Definitions and Insights

Single Facility	Smaller individual facilities with multiple loads, e.g. hospitals, schools. Lack of a cost advantage over DG will limit market penetration
Multi Facility	Small to larger traditional CHP facilities plus a few neighboring loads, exclusively C&I. Increased scale provides cost advantages of DG/CHP.
Feeder	Small to larger traditional CHP facilities plus many or large neighboring loads, typically C&I. Increased scale provides further cost advantages.
Sub Station	Traditional CHP plus many neighboring loads. Will include C&I plus residential. Poorer economics due to load factor, decreased thermal loads, and increased infrastructure costs.

The scope of service demonstrated would increase over the three phases. All ownership types are attractive and should be piloted.

	Scope of Service (Size of Microgrid)			
Owner	**Single Facility (<2MW)**	**Multi Facility (2-5MW)**	**Feeder (5-20MW)**	**Sub-Station (>20MW)**
Utility		Phase 2	Phase 3	
Muni				
Landlord	Phase 1			

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Phase 1 will demonstrate most of the functional requirements, Phases 2&3 will address other high importance functional requirements[1].

Phase 1 Pilots | Phase 2 Pilots | Phase 3 Pilots

Importance of Functional Requirements by Value Proposition

Functional Area	Functional Requirements	Reduced Cost	Reliability	Security	Service Differentiation	Power System	Green Power
Performance Requirements	•Meet IEEE 1547 requirements	high	high	high	high	high	high
	•Power quality	high	high	high	high	high	high
	•Steady-state and dynamic performance	high	high	high	high	high	high
Design	•NEC/NESC code requirements	high	high	high	high	high	high
	•Switching (Generation and Load isolation)	low	low	low	high	high	high
	•Load transfer	low	low	low	high	high	high
	•Line and equipment ratings	med	med	med	med	med	med
	•Regulation (voltage and power factor)	med	med	med	med	med	med
	•Critical loads	low	high	high	high	med	med
Monitoring and Control	•Control system algorithm	low	med	low	high	high	high
	•Frequency (load following)	med	med	med	med	med	high
	•Voltage (load following)	med	med	med	med	med	high
	•Power Factor	low	low	low	low	low	med
	•Load	high	high	high	very high	high	high
	•Generation	high	high	high	high	high	high
	•Communications infrastructure	low	low	low	high	high	high
Protection	•Fault current interruption	low	med	med	med	med	med
	•Coordination (normal vs. reconfigured)	low	med	med	med	med	med
	•Under/Over voltage	low	med	med	med	med	med
	•Fault isolation (voltage and current)	low	med	med	med	med	med
	•Auto synchronization with the grid	low	med	med	high	high	high
	•Black start capability	low	high	high	high	med	low
Operations	•Safety	high	high	high	high	high	high
	•Plan and protocol (O&M plan)	med	med	med	med	med	med
	•Spare parts and inventory	med	med	med	med	med	med
	•labor	med	med	med	med	med	med
Infrastructure	•Utility system and equipment upgrades	low	low	low	low	low	low
	•Interconnection requirements	med	med	med	med	med	med
	•Communication Infrastructure & Controls	low	med	med	med	med	med

1. Phases 2&3 will demonstrate functional requirements that have not been addressed in Phase 1 or are likely to need further emphasis than what could be accomplished in Phase 1.

Gaps in functional requirements could also be closed by focused research on technology platforms.

Functional Area	Functional Requirements	Technology Platforms							
		Control System			Fast Switch	Energy Storage	Demand Response	Power Electronics	Sensors, processing
		Asset	Internal	External					
Performance Requirements	•Meet IEEE 1547 requirements								
	•Power quality	X	X			X	X		
	•Steady-state and dynamic performance	X	X			X	X		
Design	•NEC/NESC code requirements								
	•Switching (Generation and Load isolation)	X	X		X		X	X	
	•Load transfer	X	X	X	X	X	X		
	•Line and equipment ratings								
	•Regulation (voltage and power factor)	X	X	X	X	X	X	X	X
	•Critical loads								
Monitoring and Control	•Control system algorithm	X	X	X	X	X			X
	•Frequency (load following)	X		X	X	X			
	•Voltage (load following)	X	X	X	X	X		X	
	•Power Factor	X	X	X	X	X		X	
	•Load	X			X	X		X	
	•Generation	X	X		X	X			X
	•Communications infrastructure	X	X	X				X	X
Protection	•Fault current interruption							X	X
	•Coordination (normal vs. reconfigured)		X					X	X
	•Under/Over voltage								X
	•Fault isolation (voltage and current)							X	X
	•Auto synchronization with the grid	X	X	X	X				X
	•Black start capability	X	X	X					
Operations	•Safety								
	•Plan and protocol (O&M plan)								
	•Spare parts and inventory								
	•Labor								
Infrastructure	•Utility system and equipment upgrades								
	•Interconnection requirements								
	•Communication Infrastructure & Controls	X	X	X					

"X" denotes a significant contributor to meeting a requirement

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Each phase would integrate technologies developed on the technology platforms into the pilot demonstrations.

Technology Platforms		Phase 1 Pilots	Phase 2 Pilots	Phase 3 Pilots
Control System	Asset			✓
	Internal	✓	✓	
	External		✓	✓
Fast Switch		✓	✓	
Energy Storage			✓	✓
Demand Response				✓
Power Electronics		✓	✓	
Sensors, Processing				✓