Microgrid Business Cases

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Distributed Energy Resources Integration Research Program

Public Interest Energy Research Program

California Energy Commission

This document covers Phase I of a two-phase project.

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

- Estimate the market opportunity for the potential business models
- Characterize the market, business and information gaps identified in developing the market opportunity
- Produce a research assessment report

Three tasks were completed to determine the attractiveness of potential microgrid business cases.

Phase 1

Task 1
Review of Prior Microgrid R&D

Gather Information
- Literature search
- Interviews

Task 2
Microgrid Definition

What is a Microgrid?
- The Concept: What is a microgrid?
- What is the general consensus about the definition of a microgrid?
- What elements are necessary to clearly articulate the technology and R&D needs?

Task 3
Microgrid Business Models

Test Business Models
- What value propositions can be supported through the application of microgrid technology?
- What capabilities does a microgrid offer that can enhance DER?
- What are the factors influencing the development and adoption of microgrids?

Key insights were gained through defining microgrids, developing five business cases and analyzing microgrid economics.

Definition

- There is no universally accepted definition for microgrids. However, certain characteristics are generally common.
- Based on Navigant Consulting's literature search and discussions with technical experts, the universal characteristics of a microgrid appear to be the ability to operate islanded or grid-parallel (and to switch seamlessly between these two modes), and significant DER capacity.
- Many microgrid concepts appear to be driven by DER technology rather than by energy service requirements.

Business Cases

- Electricity cost reduction and energy efficiency are the most common benefits delivered by microgrids. Service reliability and support of renewable energy resources are important considerations in some applications. Better energy efficiency appears to be the greatest public benefit that microgrids can provide
- Navigant Consulting identified five business cases supporting three basic value propositions:
  - Custom Energy Solutions: Provide customized power to individual customers or groups of customers
  - Independence/Security: Support enhanced energy and infrastructure availability and security
  - Reduced energy cost: Provide end users with less expensive energy over current rates.

Microgrid Economics

- Microgrids don't generally reduce the price of electricity when compared to grid power.
- However, a microgrid can improve the economics of DER, and can support service features that some stakeholders will value (e.g., enhanced reliability, energy efficiency, environmental benefits).
- CHP is essential to most of these business cases

Follow-on research

- More work needs to be done to understand public benefits and how the government could address barriers/constraints.
- Microgrid technologies can be applied to traditional power distribution systems, and may have benefits independent of the microgrid application.

Five microgrid business cases were developed around three value propositions.

			Value Proposition Addressed		
Business Case	**Microgrid Owner/ Operator**	**Customer**	**Custom Energy**	**Independence and Security**	**Reduced Cost**
Custom Power	Electric Utility (IOU or REC)	End users that want custom energy solutions	✓		
Municipal Energy	Municipal Utility	Municipality	✓	✓	✓
Renewable	Municipal Utility, IOU or REC	End users that want 100% "green energy"	✓		
Landlord/ Aggregator	"Landlord"	Tenants			✓
Open Access Distribution	Electric Utility (IOU or REC)	DG owners		✓	✓

Three of the five business cases have value propositions that warrant further investigation: Custom Power, Municipal Energy and Landlord.

			Strength of Case Study Microgrid Value Proposition	
Business Case	**Microgrid Owner/ Operator**	**Customer**	**Versus DG**	**Versus the Grid**
Custom Power	Electric Utility (IOU or REC)	End users, customers that want custom energy solutions	●	◐
Municipal Energy	Municipal Utility	Municipality	●	●
Renewable	Municipal Utility, IOU or REC	End users that want 100% “green energy”	○	○
Landlord/ Aggregator	“Landlord”	Multi-Facility Tenants	●	◐
		Single-Facility Tenant	○	○
Open Access Distribution	Electric Utility (IOU or REC)	DG owners	---	---

● Investigate ◐ Consider ○ Wait

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Microgrids must have the ability to operate islanded or grid parallel, with DER serving a significant portion of the microgrid load.

*Points of Universal Agreement**

- A microgrid consists of interconnected distributed energy resources capable of providing sufficient and continuous energy to a significant portion of internal load demand
- A microgrid possesses independent controls, and intentional islanding takes place with minimal service interruption

*Points of Varying Agreement**

- A microgrid must contain more than one generation source
- The total generation capacity must be less than 1 MW
- A microgrid must be connected to the grid at a single point
- A microgrid must contain storage devices (batteries, flywheels, etc)
- A microgrid must be capable of meeting the full load requirement of the facility
- Generation sources must not be connected to the same electrical bus (ensures that there is some impedance between units, requiring voltage controls)
- A microgrid employs combines heat power (CHP) technology, where the generation technology permit

*Based on interviews with technical experts, see appendix for details

Microgrids Definition — Microgrid Characteristics Matrix

Technical Attributes / Source of Characterization	Capable of islanded operation	Capable of operating parallel to the grid	Self/ autonomous control systems	Single point of connection to the grid, if interconnected	Non-interconnected systems can be microgrids	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	●	◑	NC	◑	●	NC	●	●	●	◑	●
CERTS Microgrid Concept	●	●	●	NC	○	NC	◑	●	NC	●	●
EPRI	●	◑	NC	○	◑	◑	NC	◑	○	◑	NC
European Research Project Cluster	●	◑	●	◑	●	NC	NC	NC	NC	NC	NC
Northern Power (Jonathan Lynch)	●	◑	●	◑	●	○	NC	●	◑	◑	◑
PSERC (Bob Lasseter)	●	●	NC	●	○	●	NC	NC	NC	NC	NC
ENCORP (Randy West)	●	●	NC	NC	○	○	NC	○	○	◑	NC
Sandia NL (John Stevens)	●	●	●	○	○	NC	NC	●	●	◑	◑
NREL (Ben Kroposki)	●	●	NC	●	○	NC	NC	◑	◑	NC	NC
LBNL (Chris Marnay)	●	●	●	NC	○	NC	○	◑	NC	◑	NC
GE (Keith White)	●	●	●	NC	●	NC	◑	●	●	◑	◑

Necessity ● Preferred, but Optional ◑ Not required ○ No comment was made NC

A working definition for microgrids was developed to facilitate the development of business cases.

Working Definition: 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

This working definition is:

- Consistent with the other definitions identified in Task 1
- Broad enough to allow us to transcend technology and focus on the business cases.

In identifying microgrid business cases we asked: "what unique value(s) does a microgrid provide, and who would pay for it?"

The microgrid allows operation with a larger power system; this provides two key capabilities:

- Flexibility in how the power delivery system is configured and operated
- Optimization of a large network of load and Distributed Energy Resources and the broader power system (microgrid-internal customer focused)

These two capabilities can deliver three important value propositions:

1. Custom Energy Solutions: Provide customized power to individual customers or groups of customers
2. Independence/Security: Support enhanced energy and infrastructure availability and security
3. Reduced energy cost: Provide end users with less expensive energy over current rates.

Five preliminary business cases have been developed where microgrids may be able to address three value propositions.

Business Case	Microgrid Owner/ Operator	Customer	Value Proposition Addressed: Custom Energy	Independence and Security	Reduced Cost
Custom Power	Electric Utility (IOU or REC)	End users that want custom energy solutions	✓		
Municipal Energy	Municipal Utility	Municipality	✓	✓	✓
Renewable	Municipal Utility, IOU or REC	End users that want 100% “green energy”	✓		
Landlord/ Aggregator	“Landlord”	Tenants			✓
Open Access Distribution	Electric Utility (IOU or REC)	DG owners		✓	✓

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Microgrids can help reduce electricity cost, and can support other values for key stakeholder groups.

Business Case	Electricity Price Impact	Additional Value	Key Stakeholders
Custom Power	Commercial customers realize savings over grid supplied electricity and costs are substantially lower than DG+grid	• T&D construction deferral • Alignment of service requirements and price	• Utility • Electricity End Users
Municipal Energy	Commercial customers realize savings over grid supplied electricity and costs are substantially lower than DG+grid	• Independence • Significantly enhanced reliability • Improved survivability • Supports public policy	• Municipal government • Citizens
Renewable	Cost of service significantly higher than grid supplied electricity, but slightly lower than DG+grid	• Higher reliability than DG+grid or grid only • Increased penetration of renewables • Environmental credits	• Resource Owners • Utilities • Regulators
Landlord/Aggregator	Commercial customers realize savings over grid supplied electricity and costs are substantially lower than DG+grid	• Significantly enhanced reliability • Resource efficiency with use of CHP • Improved survivability	• Landlord • Energy End Users (tenants)

Note: Electricity price credits have been assumed in cases where CHP and renewables have applied.

Navigant Consulting developed some general assumptions for the economic analysis of the microgrid case studies.

- Microgrids are compared against a DG+Grid (standard DER) scenario and a grid-only scenario
- Distribution infrastructure costs do not apply to DG+Grid scenarios
- Microgrid are load-following with peak generation capacity matching peak load
- All microgrids contain at least two generation sources
- All microgrid distribution lines are assumed to be underground
- Grid back-up is available for the full load on the microgrid system where there are no constraints limiting grid back-up
- Service is prioritized as follows: industrial, then commercial, then residential, with each customer group having its own unique load profile.
- DG capital carrying cost is allocated to each market segment based on the peak demand of the segment
- Capital carrying costs are amortized over 10 years at a discount rate of 15%
- Cogeneration credits and RECs are included, where applicable
- Rate for grid supplied electricity assumed to be average retail electricity rates
- Stand-by charges are estimated at $2 / kW / month*

* Approximately a 50% reduction below average stand-by rates in CA

Navigant Consulting applied economic assumptions for the analysis of the microgrid case studies.

Capital Carrying Costs	*All in costs ($/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	$ 6,000	10	15%	$1,195.51
PV	$ 7,000	10	15%	$1,394.76

Distribution Costs	*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)	
Industrial	$ 0.102
Commercial	$ 0.137
Residential	$ 0.123

Key microgrid cost components including DER and power delivery costs were modeled, but other values were not quantified.

Microgrid Cost Components

• DER Costs
  • Capital (annualized)
  • O&M Cost (includes fuel)
• T&D Costs
  • Capital (annualized)
  • O&M Cost
• Grid Electricity Costs
  • Retail energy and capacity
  • Standby charges
• Cogen / renewable energy credits

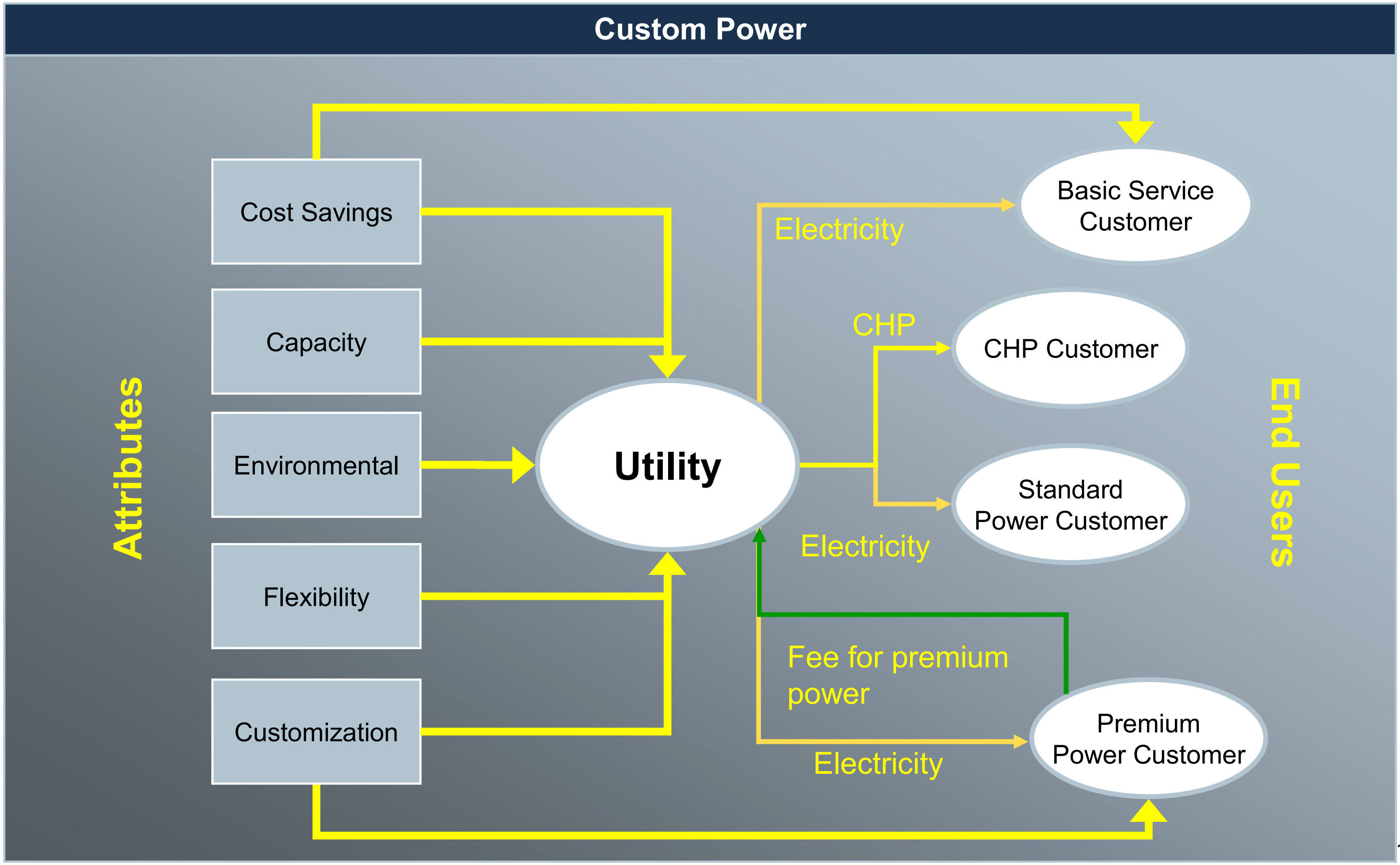
Net cost of delivery energy (cents/kWh)

Non-Monetized Values
• Reliability • Power Quality • Independence • Survivability • Other Environmental Benefits
Could be captured through price

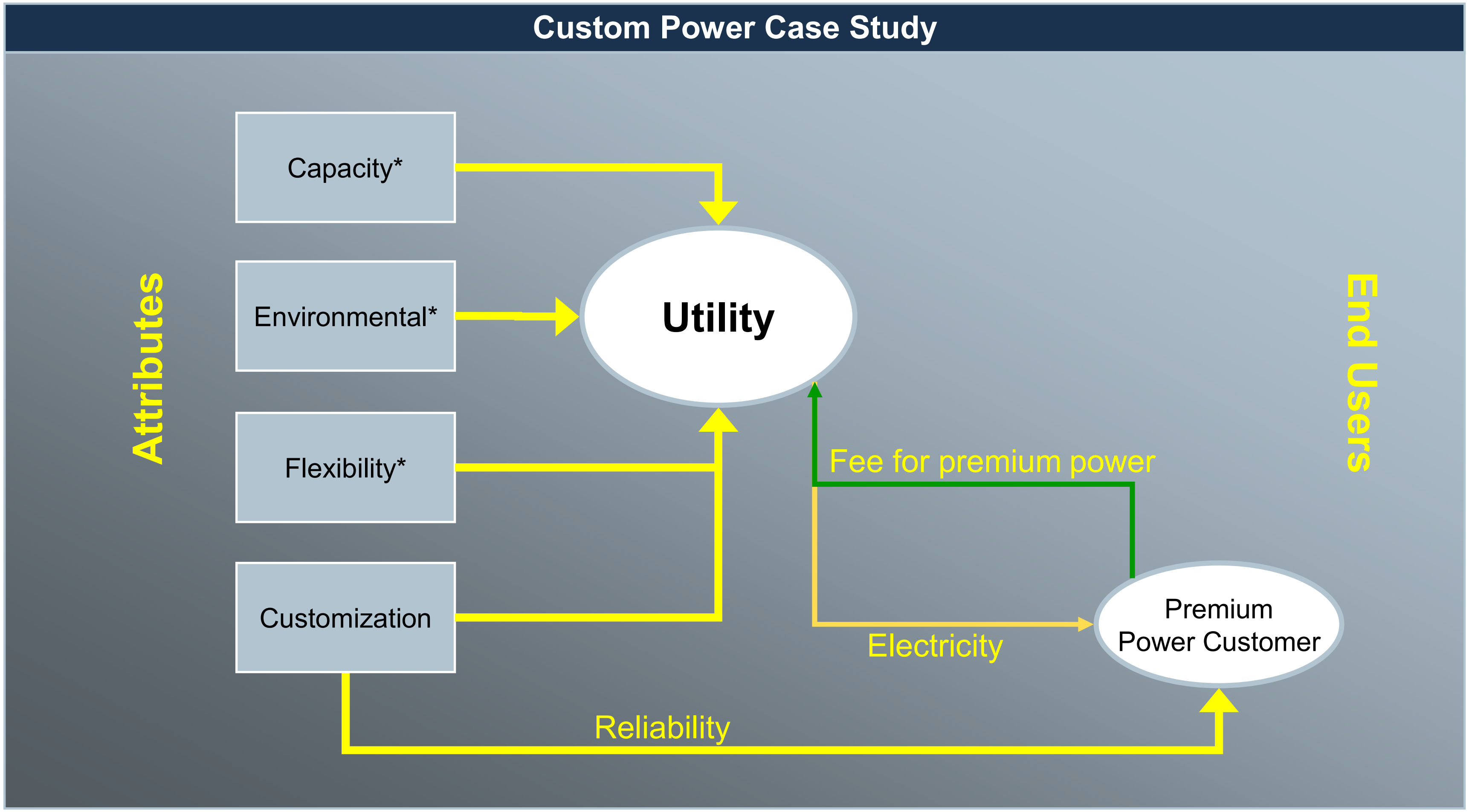
In the Custom Power business case, a utility offers custom power solutions for different market segments.

Ownership	Utility owned microgrid
Customer	Customers in service territory seeking different levels (higher and lower) of service
Value Delivered	• Customers receive the power they want based on the price they are willing to pay. • For example, some customers would receive higher reliability and pay a higher price, others would receive lower reliability and pay a lower price • Utilities could offer different levels of service in regards to other quality aspects
Economic Factors	• Customers who need higher reliability electricity pay a premium over standard customers. • Customers who seek cost savings receive a discount for less reliable power. • To improve the economics, utilities could use the microgrid as a way to defer T&D infrastructure investments.
Concerns	• Visible multi-level service offering may be unacceptable • Regulations may prohibit utilities from using DER to avoid making T&D upgrades • In some states, utility ownership of generation assets is greatly limited

Custom Power allows the utility to charge variable rates and deliver different levels of service based on customer preferences.



The Custom Power case studies assumes that the utility provides higher reliability service to some customers who pay a higher price.



**Likely to be present but not monetized in this case study*

The Custom Power microgrid tested includes two 3 MW gas turbines that do not have cogeneration capabilities.

Loads

Market Segment	Peak Load	Load Factor	Distribution
Industrial	2 MW	100 %	1 mile
Commercial	1 MW	68.8 %	2 miles
Residential	3 MW	35.4 %	8 miles

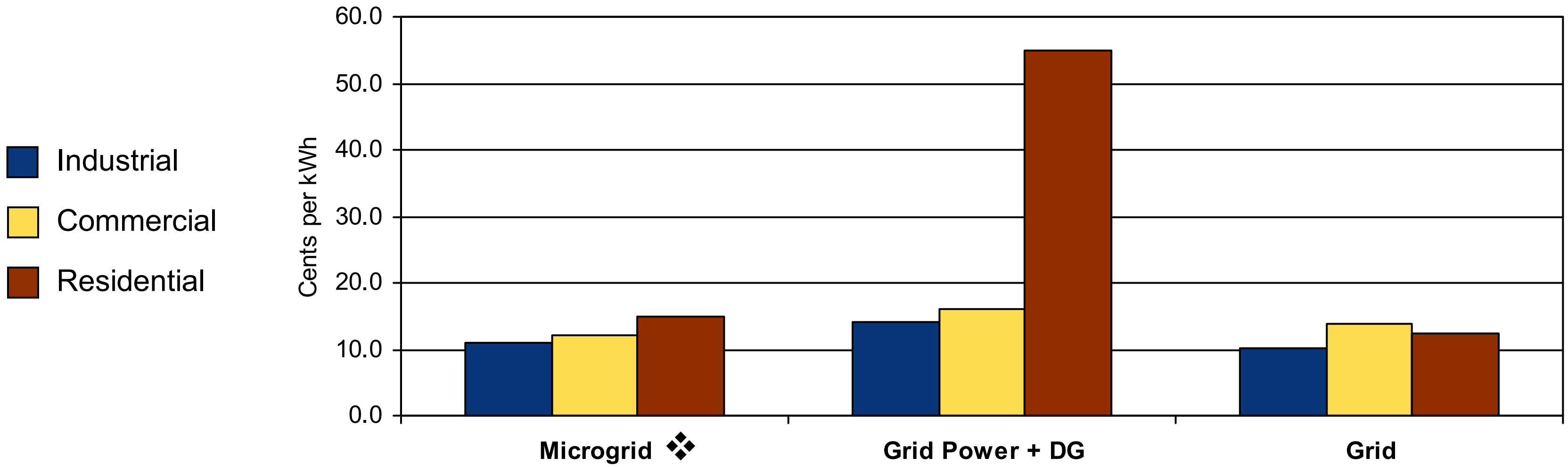
Microgrid

Technology	Number of Units	Size (each)
Gas Turbines (without cogeneration)	2	3 MW

DG + Grid

Market Segment	Technology	Number of Units	Size (each)
Industrial	Recip engines (with cogeneration)	1	2 MW
Commercial	Recip engines (with cogeneration)	4	250 kW
Residential	PV	600	5 kW

One Custom Power case shows that commercial customers can receive five 9s reliability at an electricity price below grid-supplied rates.



Reliability	I	99.99952%	99.99025%	99.9%
	C	99.99952%	99.99025%	99.9%
	R	99.99045%	99.92850%	99.9%
Energy Efficiency	I	39.8%	75.4%	33%
	C	39.8%	75.4%	33%
	R	39.2%	27.9%	33%

❖ Custom Power

An alternate Custom Power case uses a microgrid to defer a distribution system upgrade by the local utility to increase capacity by 3 MW.

Loads

Market Segment	Peak Load	Load Factor	Distribution
Industrial	2 MW	100 %	1 mile
Commercial	1 MW	68.8 %	2 miles
Residential	3 MW	35.4 %	8 miles

Microgrid

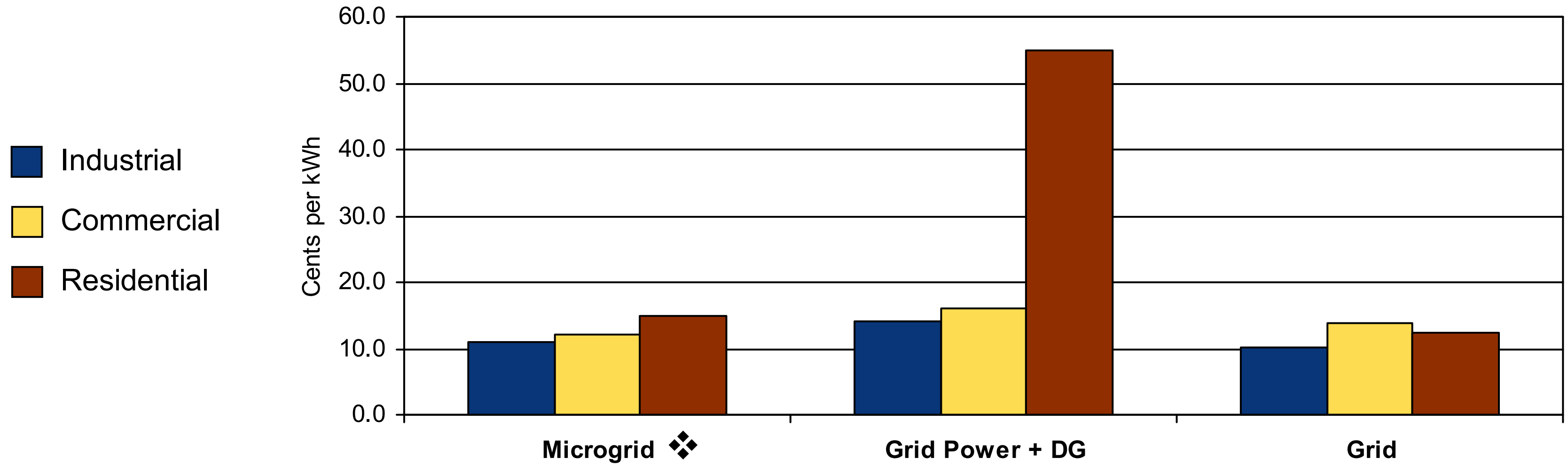
DG Technology	Number of Units	Size (each)
Gas Turbines (without cogeneration)	2	3 MW

Grid	MW Available
Grid Backup	3 MW

DG + Grid

Market Segment	Technology	Number of Units	Size (each)
Industrial	Recip engines (with cogeneration)	1	2 MW
Commercial	Recip engines (with cogeneration)	4	250 kW
Residential	PV	600	5 kW

For this scenario, the average cost of electricity is reduced, but the theoretical reliability for residential customers suffers slightly.



		Microgrid	Grid Power + DG	Grid
Reliability	I	99.99952%	99.99025%	99.9%
	C	99.99952%	99.99025%	99.9%
	R	99.65472%	99.92850%	99.9%
Energy Efficiency	I	39.8%	75.4%	33%
	C	39.8%	75.4%	33%
	R	39.2%	27.9%	33%

❖ Custom Power

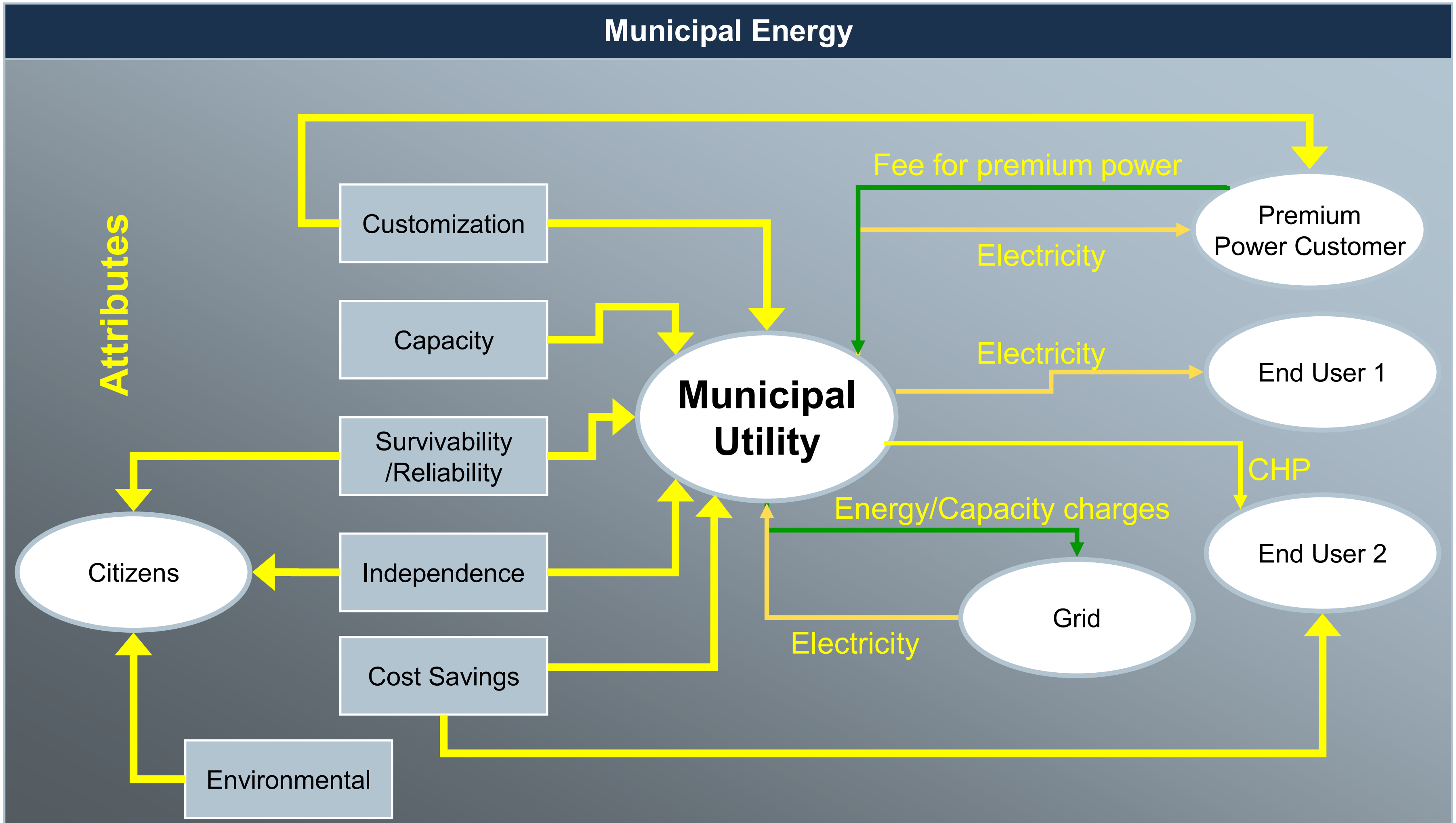
The Custom Power business case appears to offer higher service value at prices similar to, or slightly lower than, grid power or DG solutions.

- This Microgrid is more attractive to customers and the utility than the customers installing individual DG units (Grid Power+DG)
  - Customers will pay a lower price for electricity with better reliability
  - The utility retains its customers, and may be able to charge more for better service
- The microgrid would have varying degrees of impact on the cost of service for different customer classes, potentially leading to different changes in price.
  - Compared to Grid Power, the cost of service is lower for commercial customers, but higher for industrial and residential customers.
  - Rather than passing all of the commercial cost of service reductions on to commercial customers, the utility may choose to use the savings from the commercial customer to reduce the impact of higher costs associated with serving industrial and residential customers.
- Overall, the microgrid offers higher energy efficiency than the grid, but it is lower than the Grid Power + DG option.
- The value of distribution upgrade deferral was not modeled for the Custom Power business case. Considering the potential cost savings from such deferral could improve the attractiveness of the microgrid for this case.
- Offering variable service levels and rates could be challenges from both a technical and regulatory perspective.

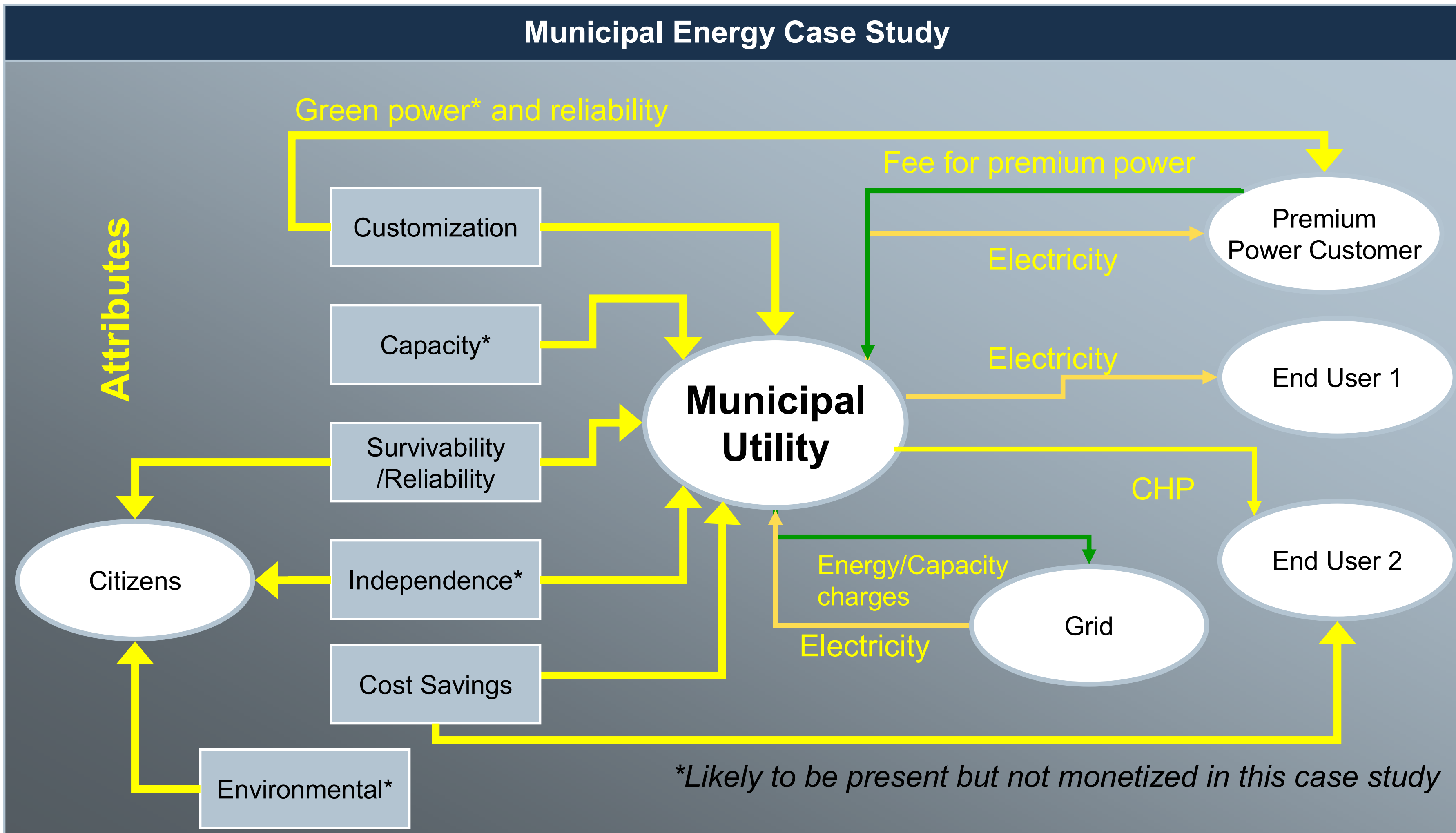
In the Municipal business case, the municipality gains energy independence and use of greener energy resources.

Ownership	Municipal utility owned microgrid
Customer	• Citizens seeking greater independence and environmental performance • Electricity customers looking reduced costs or greener electricity
Value Delivered	• Municipal utility generates and provides reliable, independent power • Increased independence from the grid and enhanced survivability • Municipal utility microgrid employs CHP and renewables based on citizens' values and possible efficiency or REC benefits • Municipal utilities are able to offer custom power solutions for customer willingly to pay for it
Economic Factors	• Municipal utility may build the system to suit community desire for "green energy", CHP or increased reliability • Energy and capacity charges are paid to the "grid"
Concerns	• Long-term contractual obligations with third party generation sources • Generation plants co-owned with other municipalities • Stand-by charges may be prohibitive

A municipal utility can use a microgrid to provide reliable, independent electricity and CHP and renewable services to different customers.



The Municipal Energy model assumes that the utility uses a microgrid including CHP and renewables, to provide higher reliability service.



The case study assumes two 20 MW cogen gas turbines, two 20 MW non-cogen gas turbines, and a total of 10 MW of wind and PV systems.

Loads

Market Segment	Peak Load	Load Factor	Distribution
Industrial	20 MW	100 %	20 miles
Commercial	20 MW	68.8 %	40 miles
Residential	60 MW	35.4 %	80 miles

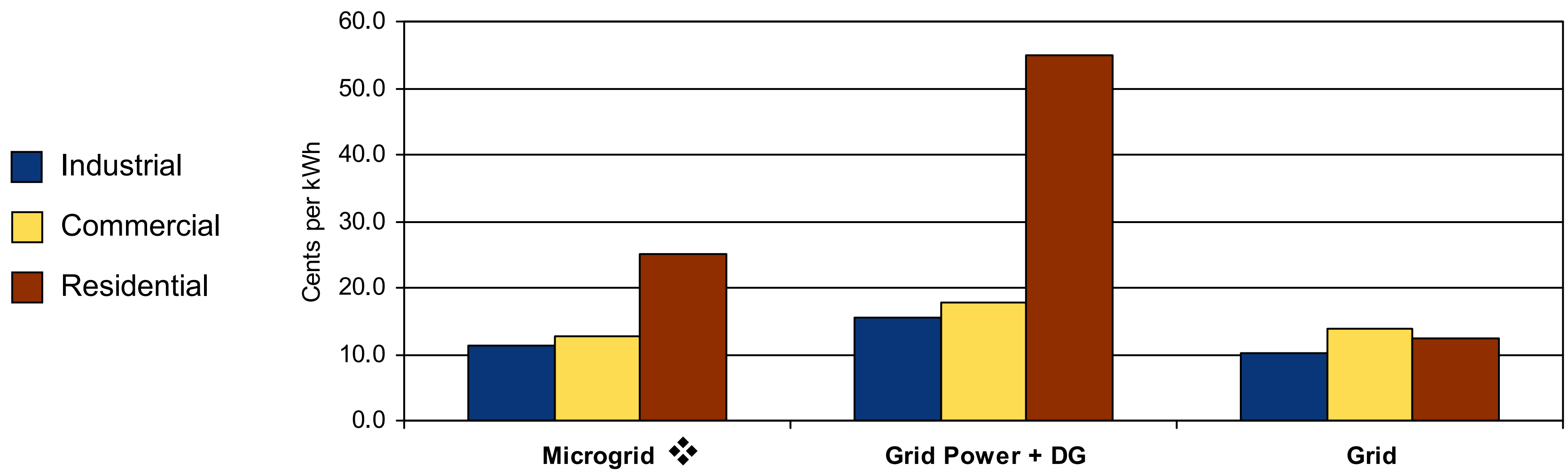
Microgrid

Technology	Number of Units	Size (each)
Gas Turbines (with cogeneration)	2	20 MW
Gas Turbines (without cogeneration)	2	20 MW
Wind (single system)	1	10 MW
PV (single system)	1	10 MW

DG + Grid

Market Segment	Technology	Number of Units	Size (each)
Industrial	Recip engines (with cogeneration)	1	20 MW
Commercial	Recip engines (with cogeneration)	4	5 MW
Residential	PV	12,000	5 kW

The Municipal Energy microgrid delivers higher reliability for much less than the DG option, despite using high-cost renewable generation.



		Microgrid ❖	Grid Power + DG	Grid
Reliability	I	99.99999%	99.99025%	99.9%
	C	99.99994%	99.99025%	99.9%
	R	99.98138%	99.92850%	99.9%
Energy Efficiency	I	79.8%	75.4%	33%
	C	74.6%	75.4%	33%
	R	34.8%	27.9%	33%

❖ Municipal

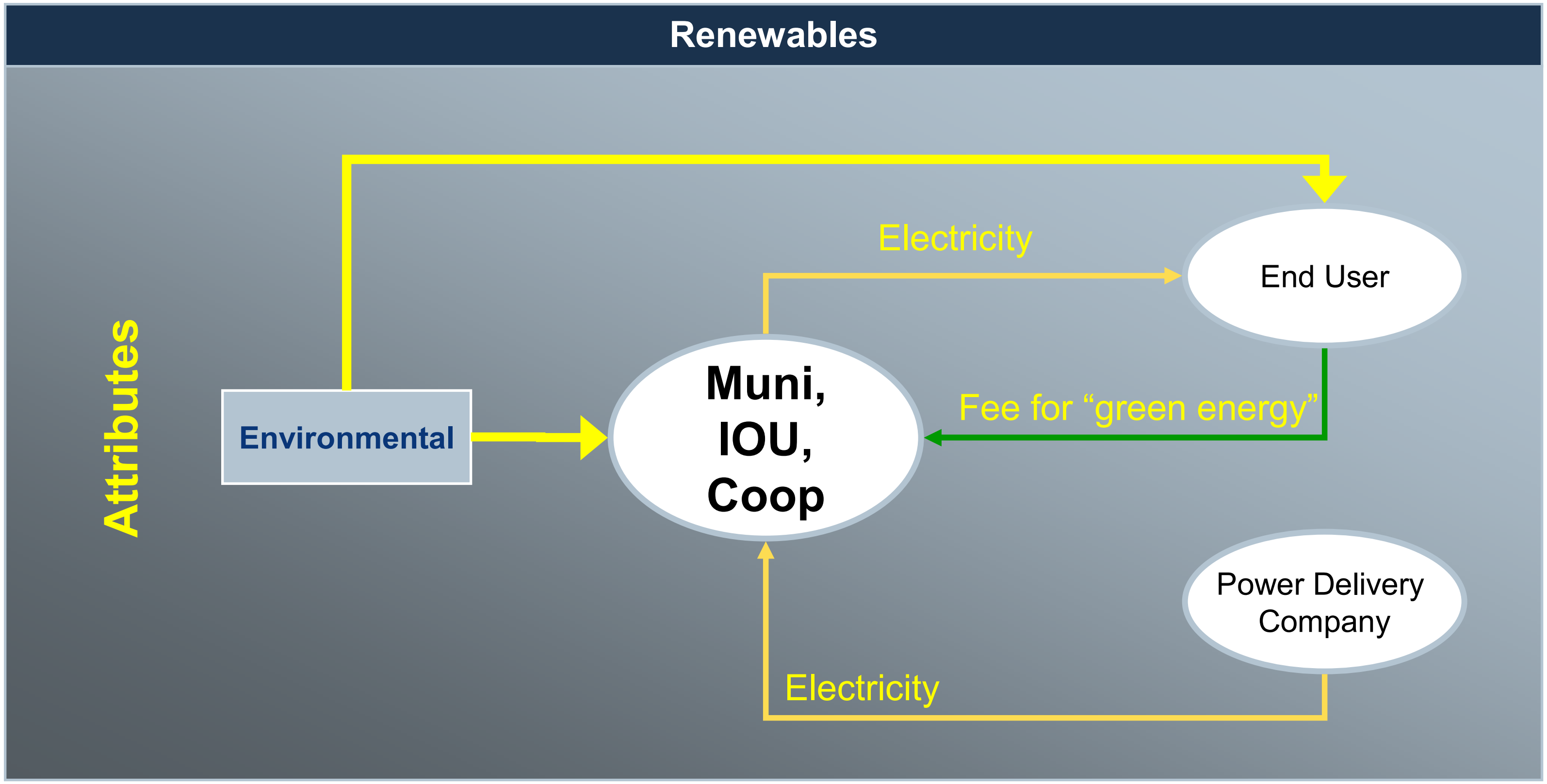
The Municipal Energy business case can support municipal energy goals while keeping costs in line with traditional Grid alternatives.

- The microgrid cost of service for residential customers is much higher than grid power. However, this is driven by the capital cost of the renewable resources used.
- Compared to the Grid+DG option, the microgrid is cheaper and provides higher reliability. The microgrid is more efficient that the Grid option, and is comparable to the Grid+DG option.
- This microgrid would allow the Municipal Utility to have renewable energy in its portfolio equal to 20% of the capacity of the microgrid. (Note: this analysis did not assume that a microgrid would reduce the costs of renewables. Larger sized installations of renewables that could be accommodated by the microgrid may lead to lower installed costs.)
- Although not captured in this analysis, this microgrid may be able to increase the survivability of the distribution system.

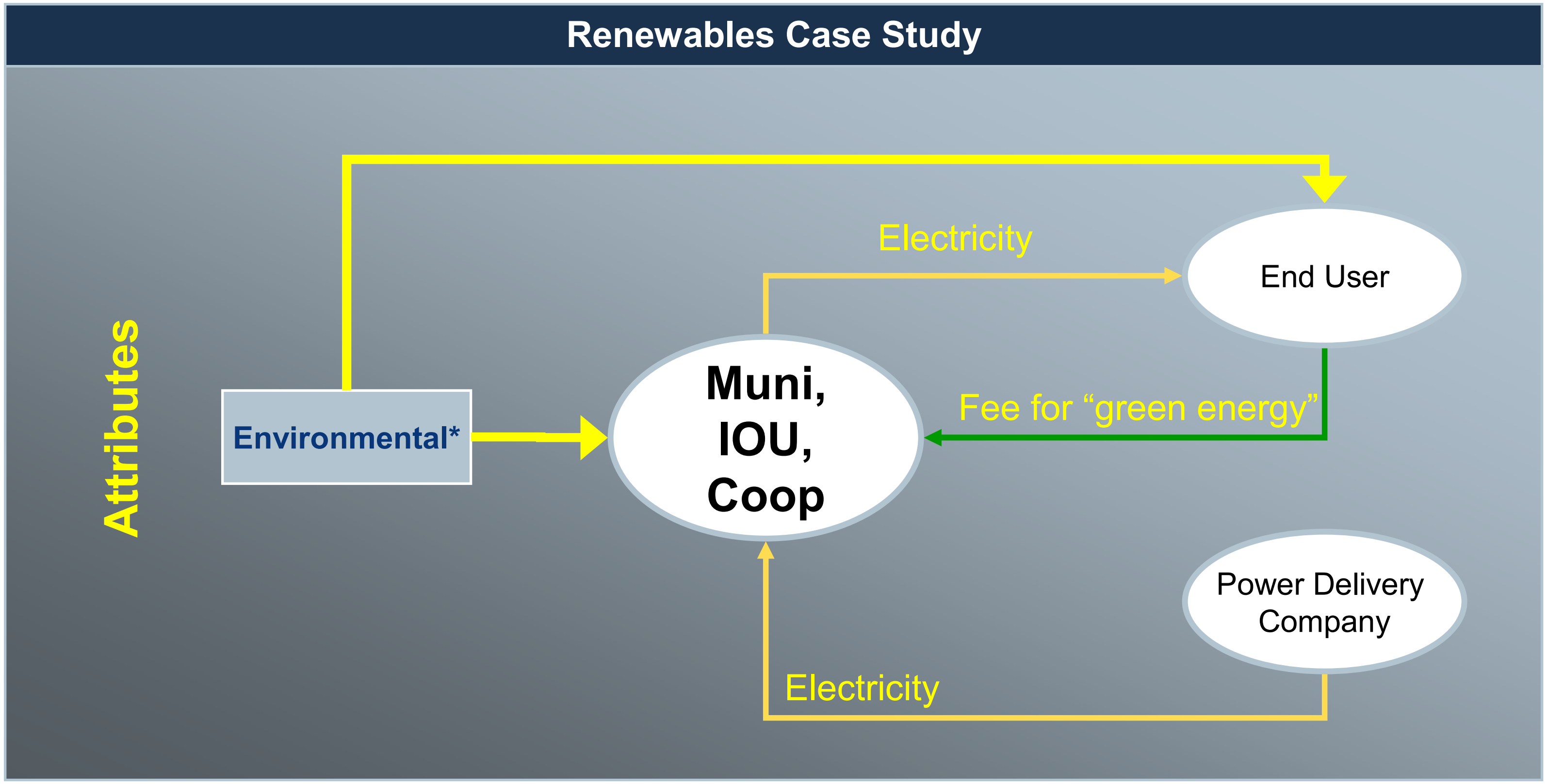
In the Renewables business case, a microgrid can be established to help Munis, IOUs or RECs meet Renewable Energy Portfolio Standards.

Ownership	Municipal Utility, IOU or REC
Customer	Regulators on behalf of society, or customers in service territory seeking "green energy"
Value Delivered	• Ability to offer renewable energy as the primary source of electricity • Reliability level is higher than that delivered by non-microgrid renewables-based DER system
Economic Factors	• Customers must pay a premium for "green energy" • Stand-by charges are paid to the power delivery company
Concerns	• No CHP capabilities to help improve microgrid economics • Relatively high cost may limit the rate of adoption

This business case includes a microgrid uses renewable DG source as the primary source of electricity to satisfy Renewable Portfolio Standards.



In this case study, the microgrid uses PV and wind as the primary sources of electricity generation.



**Benefit is present, but not explicitly monetized in this case study.*

The Renewables case study assumes a 15 MW wind turbine system and a 10 MW PV system serving commercial and residential end users.

Loads

Market Segment	Peak Load	Load Factor	Distribution
Commercial	15 MW	68.8 %	2 miles
Residential	10 MW	35.4 %	8 miles

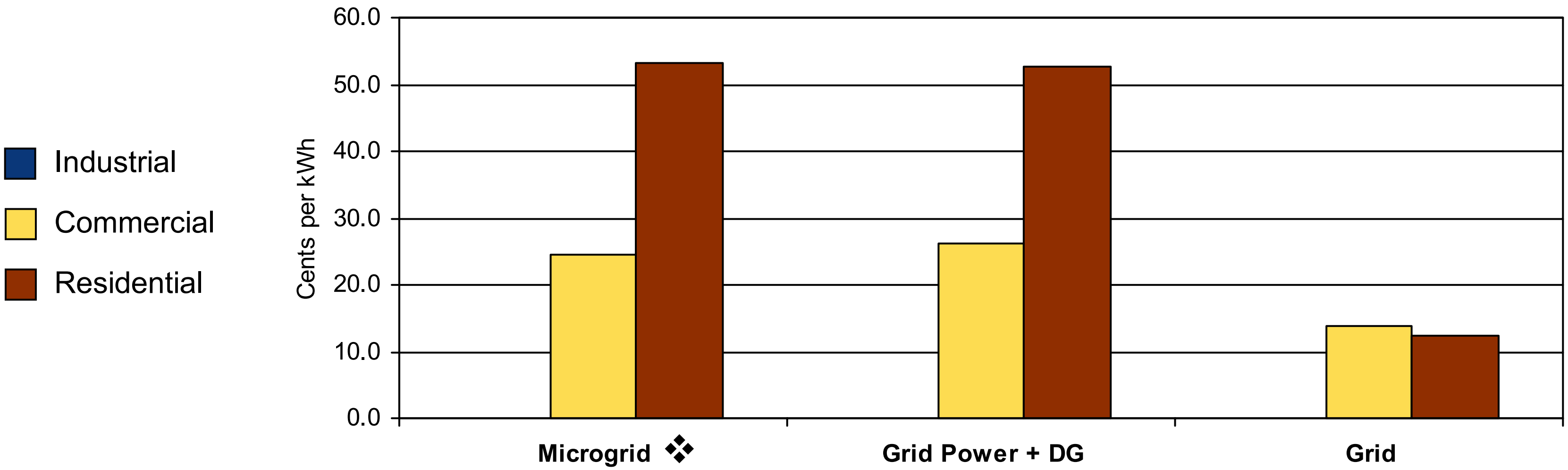
Microgrid

Technology	Number of Units	Size (each)
Wind	1 (single system)	15 MW
PV	1 (single system)	10 MW

DG + Grid

Market Segment	Technology	Number of Units	Size (each)
Commercial	Wind	1500	10 kW
Residential	PV	2,000	5 kW

The Renewables microgrid offers negligible benefits over the DG option.



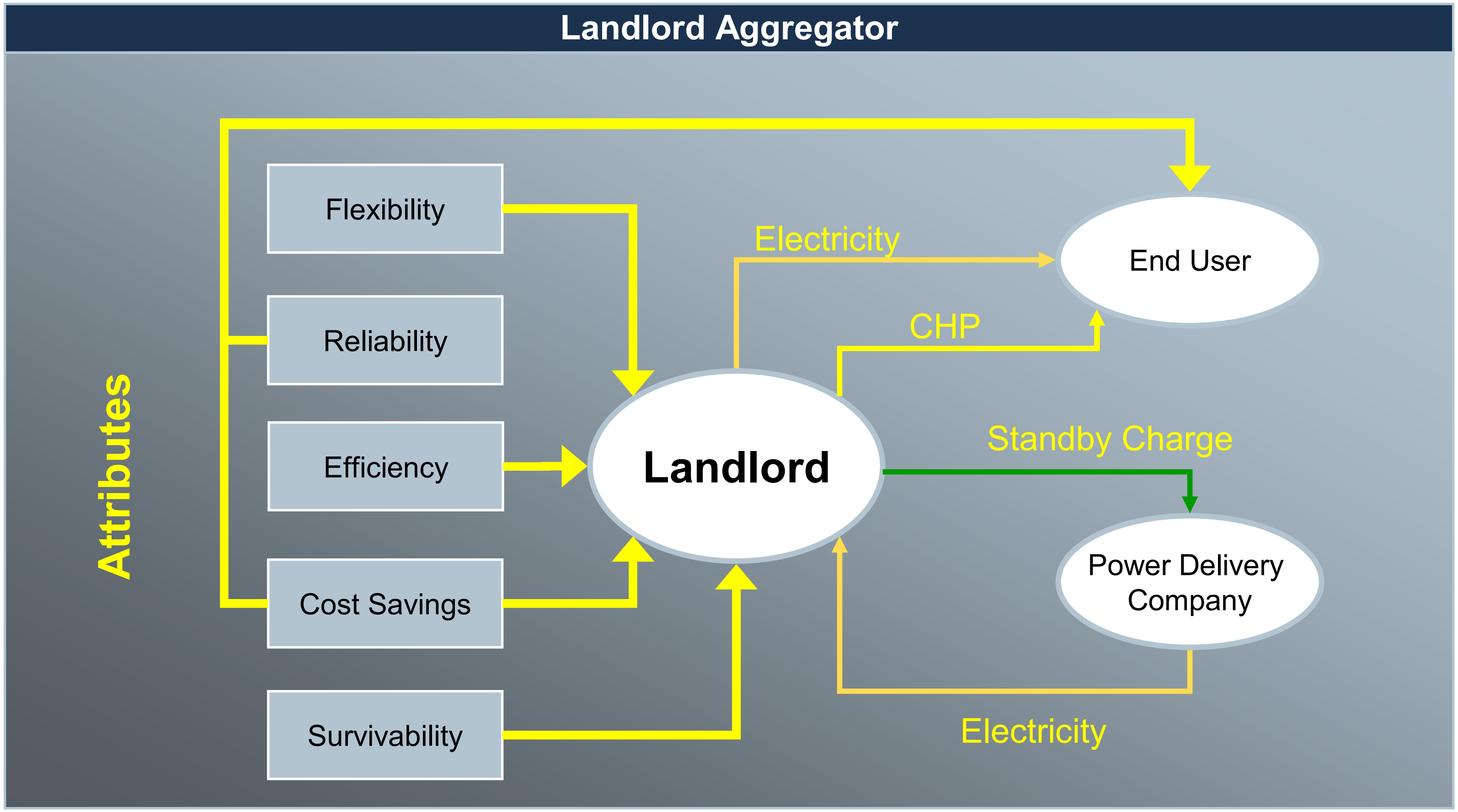
Reliability	I	N/A	N/A	99.9%
	C	99.95659%	99.94275%	99.9%
	R	99.92906%	99.92850%	99.9%
Energy Efficiency	I	N/A	N/A	33%
	C	31.4%	33.9%	33%
	R	32.1%	27.9%	33%

❖ Renewables

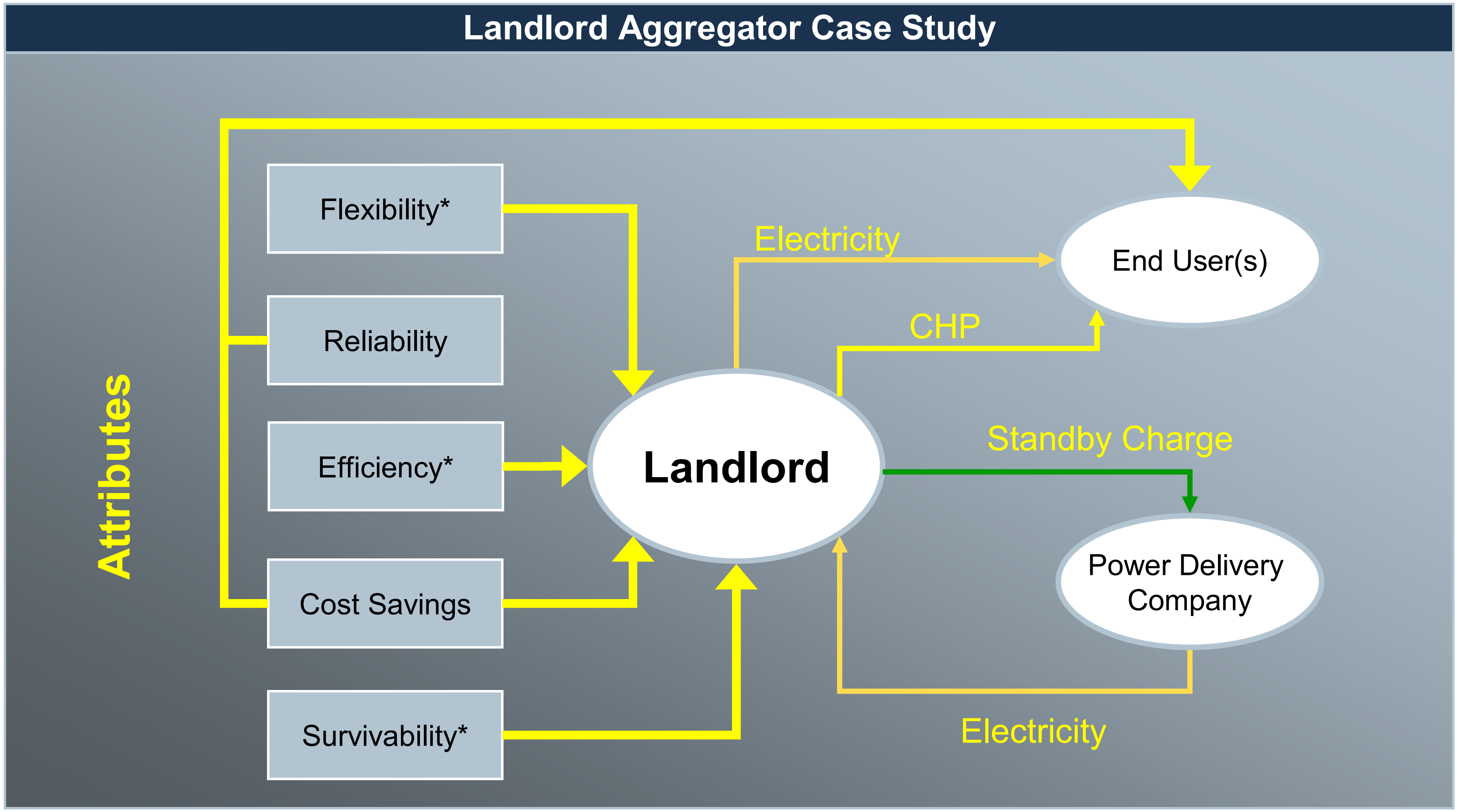
In the Landlord/Aggregator business case, a microgrid is used to reduce the tenants' electricity costs while improving reliability.

Ownership	Landlord (e.g. college campus, military base, large commercial parks)
Customer	Tenant(s)
Value Delivered	Landlord offers higher reliability electricity with CHP at lower price than options currently available.
Economic Factors	CHP is needed to reduce the costs of electricity Stand-by charges are paid to the power delivery company.
Concerns	Non-utilities are limited in their ability to generate electricity for multiple paying end users.

The Landlord Aggregator business case would offer customers cheaper electricity and provide the landlord with increased resource flexibility.



In the Landlord Aggregator case studies (single facility and multi-facility), the value of flexibility and survivability were not monetized.



**Likely to be present but not monetized in this case study*

The Multi-Facility Landlord Aggregator case study assumes two 3 MW gas turbines with cogen serving all customer segments.

Loads

Market Segment	Peak Load	Load Factor	Distribution
Industrial	2 MW	100 %	1 mile
Commercial	1 MW	68.8 %	2 miles
Residential	3 MW	35.4 %	8 miles

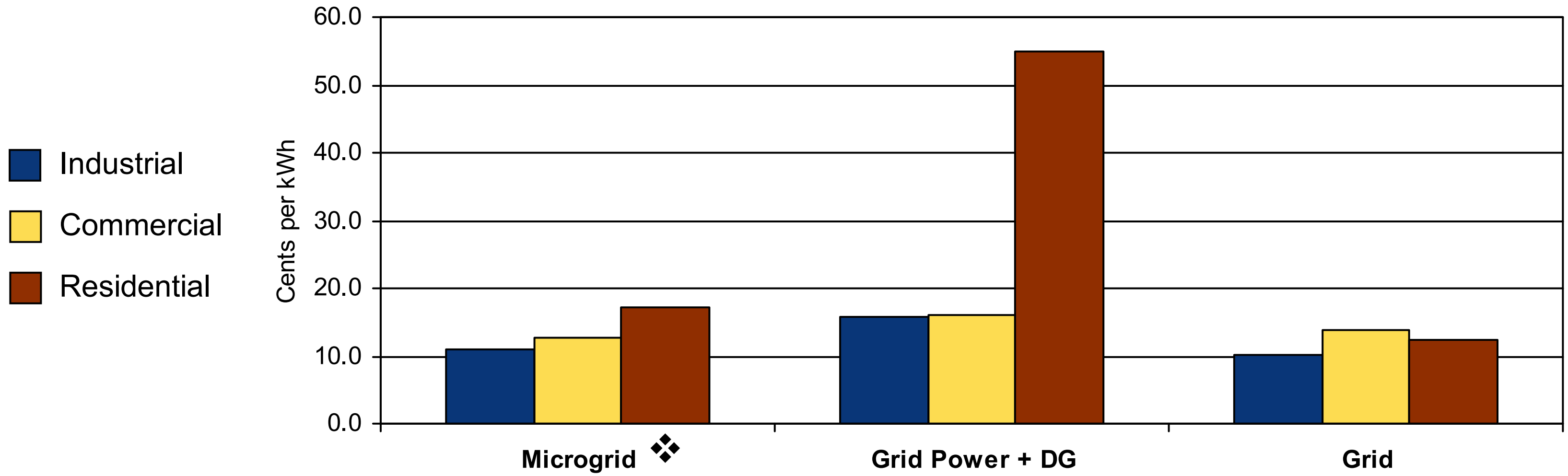
Microgrid

Technology	Number of Units	Size (each)
Gas Turbines (with cogeneration)	2	3 MW

DG + Grid

Market Segment	Technology	Number of Units	Size (each)
Industrial	Recip engines (with cogeneration)	1	2 MW
Commercial	Recip engines (with cogeneration)	4	250 kW
Residential	PV	600	5 kW

In the Multi-Facility Landlord Aggregator case study, the microgrid could be competitive against grid supplied electricity.



Reliability	I	99.99952%	99.99025%	99.9%
	C	99.99952%	99.99025%	99.9%
	R	99.99045%	99.92850%	99.9%
Energy Efficiency	I	79.8%	75.4%	33%
	C	79.8%	75.4%	33%
	R	75.5%	27.9%	33%

❖ Landlord Aggregator: *Multi-Facility*

The Single-Facility Landlord microgrid case study assumes a small facility with distributed CHP units.

Load

Market Segment	Peak Load	Load Factor	Distribution
Commercial	180 kW	68.8 %	0.25 mile

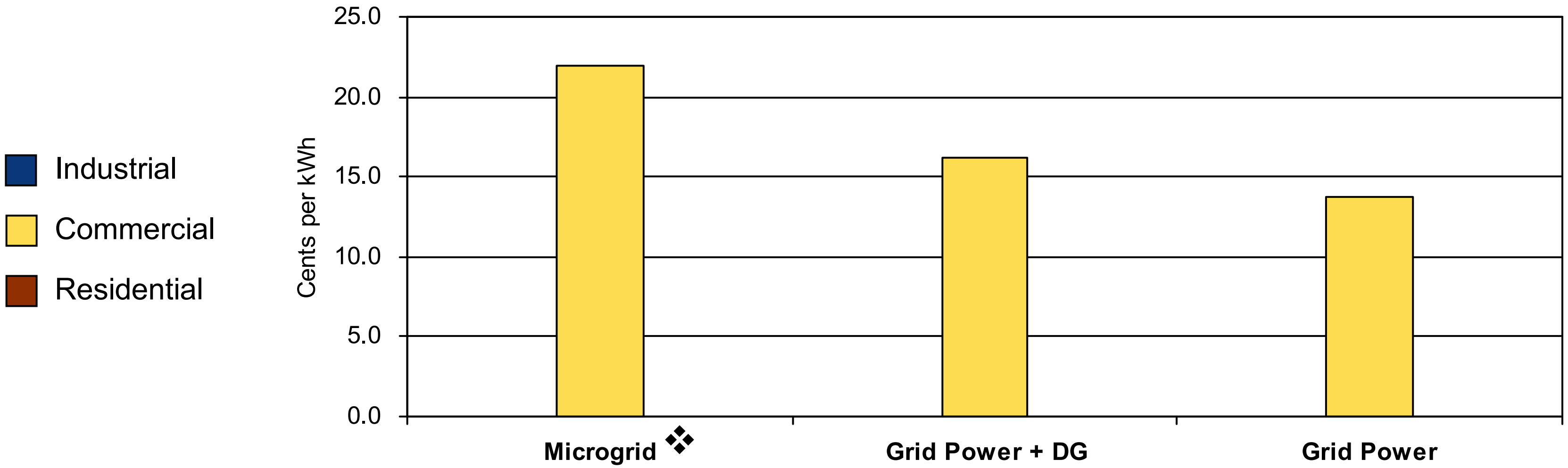
Microgrid

Technology	Number of Units	Size (each)
Microturbines (with cogeneration)	3	60 kW

DG + Grid

Market Segment	Technology	Number of Units	Size (each)
Commercial	Recip engines (with cogeneration)	1	180 kW

The Single-Facility Landlord microgrid does not prove to be very economical due to the inefficiency of having 3 relatively small DG units.



Availability	I	n/a	n/a	99.9%
	C	99.99328%	99.99025%	99.9%
	R	n/a	n/a	99.9%
Energy Efficiency	I	n/a	n/a	33%
	C	76.8%	75.4%	33%
	R	n/a	n/a	33%

❖ Landlord Aggregator: *Single-Facility*

The Landlord/Aggregator model is attractive compared to the Grid and Grid+DG alternatives.

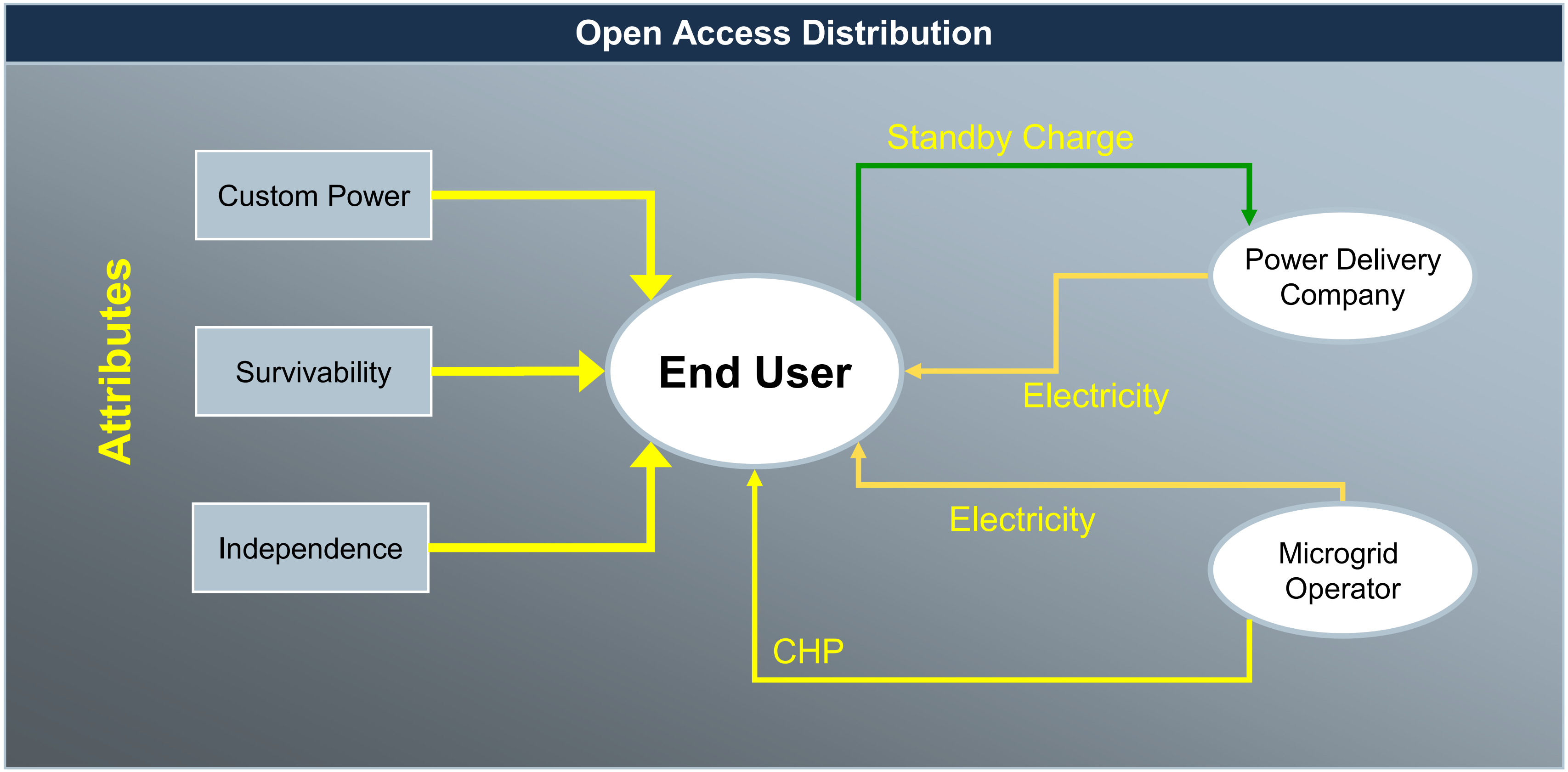
- Multi-facility Case Study
  - The savings from the commercial customers, whose costs are lower than grid-supplied electricity, would have to subsidize the other customers whose costs are slightly less competitive.
  - We need to better understand what price customers would be willing to pay for higher reliability.
  - This microgrid would have better efficiency than the grid-only option.
  - This Microgrid is better than the Grid + DG option, offering lower costs, higher reliability and greater efficiency.

- Single facility Case Study
  - The microgrid would have higher reliability and efficiency than the Grid Power or DG Options.
  - However it would be substantially more expensive for the customer

The Open Access Distribution business case allow individuals or small groups to build into a microgrid infrastructure with plug and play features.

Ownership	Flexible ownership includes opportunities for third-party providers
Customer	DG owners
Value Delivered	• End users have increased independence and survivability from the grid, at a lower cost than current rates • CHP can be implemented where it is desired.
Economic Factors	Customers pay for the level of electricity service they seek.
Concerns	• Control and switching without complex high-speed communication system could be very difficult • Assumes emergence of plug and play capabilities • Wider grid needs to be able to tolerate multiple points of interconnection with “microgrid” • Lack of centralized management and decision-making

While the open access distribution concept holds much promise, the concept is difficult to model at this point.



Three of the five business cases have value propositions that warrant further investigation: Custom Power, Municipal Energy and Landlord.

Business Case	Microgrid Owner/ Operator	Customer	Strength of Case Study Microgrid Value Proposition: Versus DG	Strength of Case Study Microgrid Value Proposition: Versus the Grid
Custom Power	Electric Utility (IOU or REC)	End users, customers that want custom energy solutions	●	◑
Municipal Energy	Municipal Utility	Municipality	●	●
Environmental	Municipal Utility, IOU or REC	Regulator – meet regulatory targets	○	○
Landlord/ Aggregator	"Landlord"	Multi-Facility Tenants	●	◑
		Single-Facility Tenant	○	○
Open Access Distribution	Electric Utility (IOU or REC)	DG owners	---	---

● Investigate ◑ Consider ○ Wait

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Appendices

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Interviews

Syed Ahmed
Technical Expert
Southern California Edison

Juan de Bedout
Manager – Electronic Power and Propulsion Systems Group
General Electric Corporation

Bill Glauz
Manager of Distributed Generation
Los Angeles Department of Water and Power

Ward Jewell
Professor
University of Wichita

Ben Kroposki
Chair, Working Group for Distributed Resource Island Systems
National Renewables Energy Laboratory

Bob Lasseter
Emeritus Professor
University of Wisconsin

Jonathan Lynch
Director of Technology
Northern Power

Chris Marnay
Staff Scientist
Lawrence Berkeley National Laboratory

Dave Nichols
Manager – Dolan Technology Center
AEP

Kjell Ostensen
Manager of Fuel Cells and New Technologies
Los Angeles Department of Water and Power

Bob Panora
President
Tecogen

Richard Smith
Transportation Crosscut Manager
Oak Ridge National Laboratory

John Stevens
Principal Member of the Technical Staff
Sandia National Laboratory

Randy West
Director of New Product Development
Encorp

Keith White
Business Development Manager
General Electric Corporation

Published Microgrid Concepts

CERTS
The CERTS Microgrid.
Recorded on: October 2004.
http://certs.lbl.gov/DER_H1.html
Integration of Distributed Energy Resources. The CERTS Microgrid Concept, October 2003. Recorded on: October 2004.
http://certs.lbl.gov/pdf/LBNL_50829.pdf

DTE Energy Solutions
Energy|now Microgrid Systems.
Recorded on: October 2004.
http://www.dtetech.com/energynow/microgrids

EPRI
Distributed Renewable Energy Generation Impacts on Microgrid Operation and Reliability, February 2002.
Recorded on: October 2004.
http://www.epri.com/OrderableitemDesc.asp?product_id=000000000001004045&targetnid=267825&value=04T084.0&marketnid%20=267715&oitype=1&searchdate=2/6/2002

European Research Project Cluster
Microgrids.
Recorded on: October 2004.
http://microgrids.power.ece.ntua.gr/

Northern Power
Northern Power Systems' MicroGrid® Power Network to Address Risk of Power Outages. Recorded on: October 2004.
http://www.northernpower.com/pdf/pr_microgrid.pdf

PSERC
Lasseter, Robert and Paolo Piagi. Microgrid: A Conceptual Solution, June 2004.
Recorded on: October 2004.
http://www.pserc.wisc.edu/ecow/get/publicatio/2004public/lasseterpesc04us.pdf

Microgrid Research Projects

CERTS
Recorded on: October 2004.
http://certs.lbl.gov/DER_H1.html

Distributed Utility Integration Test
Iannucci, Joseph. Distributed Power Integration Needs Assessment and Testing, April 2001.
Recorded on: October 2004.
http://www.energy.ca.gov/distgen_oii/documents/dgwg/R+D-17.pdf
Distributed Utility Integration Test, Subcontractor Report, August 2003.
Recorded on: October 2004.
http://www.nrel.gov/docs/fy03osti/34389.pdf
Press release: November 19, 2003.
Recorded on: October 2004.
http://www.dtetech.com/pressroom/releases/4_1_111903.asp

Encorp
Meyer, Joshua and Jim Peeden. "A Microgrid Worth 'Bragging' About," Power Engineering, May 2003.
Recorded on: October 2004.
http://www.encorp.com/dwnld/pdf/awd-art/Power_Engineering_magazine_Ft_Bragg_color.pdf
http://www.encorp.com/content.asp?cmsID=76

European Research Project Cluster
Recorded on: October 2004.
http://microgrids.power.ece.ntua.gr/index.htm

Lawrence Berkeley National Laboratory
Recorded on: October 2004.
http://der.lbl.gov/dercam.html

National Renewables Energy Laboratory
Kroposki, Ben. "Interconnection Testing at NREL," October 28-30, 2003.
Recorded on: October 2004.
http://www.eere.energy.gov/distributedpower/pdfs/reviewannual03pres/dertf_2003.pdf

Northern Power
Press release: March 23, 2004.
Recorded on: October 2004.
http://www.northernpower.com/company/whats-new/press-releases.html?news_id=16756&year=2004&month=8&superstep=6

Palmdale Water District
Surles, Terry. "CEC's Energy R&D Program and the Potential for Storage Technologies
APEC Energy Storage Workshop," May 11, 2004.
Recorded on: October 2004.
http://www.energy.ca.gov/pier/papers_presentations/2004-05-11_APEC_STORAGE.PDF

PSERC
Recorded on: October 2004.
http://eppe.tamu.edu/pserc/summary/grid.pdf

DTE Energy Solutions

Energy|now microgrids are small-scale energy supply and delivery systems that generate and store electricity on site for the multiple users and facilities they serve. The basic components of the microgrid system include multiple on-site generators in a variety of sizes and types, an underground delivery network and an interconnection to the grid (optional).

(Source: http://www.dtetech.com/energynow/microgrids/)

CERTS

A microgrid involves large numbers of small DER (less than one-megawatt each) located on the low-voltage distribution system. At the heart of CERTS' microgrid concept is the notion of a flexible, controllable interface between the microgrid and the wider power system. This interface can isolate the microgrid's internal electrical operations from those of the surrounding distribution system while maintaining the economic connection between the two. The conditions and quality of service within the microgrid are determined by the needs of the customers involved; flows across the interface between the microgrid and the distribution system are determined by the needs of the wider power system.

(Source: http://certs.lbl.gov/DER_H1.html and http://certs.lbl.gov/pdf/LBNL_50829.pdf)

EPRI

Distributed generation (DG) refers broadly to the use of on-site generators that can operate independently of a central station power plant. DG may be owned by either a consumer or supplier of electricity and can operate either independently or interconnected with the grid. In the context of this report, renewable energy technologies can be considered a subset of DG fueled by renewable energy sources such as solar, wind, hydro, or biomass power. Microgrids extend the DG concept to encompass several DG resources linked together in an industrial park, commercial complex, residential neighborhood, or university campus. A microgrid would most often generate enough electricity to meet its own internal demand, though most microgrid concepts also call for connection to a utility for backup power.

(Source: http://www.epri.com/OrderableitemDesc.asp?product_id=000000000001004045&targetnid=267825&value=04T084.0&marketnid=267715&oitype=1&searchdate=2/6/2002 and “Investigation of the Technical and Economic Feasibility of Micro-Grid-Based Power Systems”, December 2001)

Published Microgrid Concept

Northern Power

A MicroGrid power network is defined as two or more distributed generation or storage assets configured in a network and capable of operating either in parallel with, or independent from, a larger electric grid, while providing continuous power to one or more end users. The assets may be combinations of power generation and energy storage devices, depending on the requirements of a specific application.

(Source: http://www.northernpower.com/pdf/pr_microgrid.pdf)

Bob Lasseter PSERC

During disturbances, the generation and corresponding loads can separate from the distribution system to isolate the microgrid's load from the disturbance (and thereby maintaining service) without harming the transmission grid's integrity.

It is assumed that there is sufficient generation to meet the loads' demand.

There is a single point of connection to the utility called point of common coupling.

(Source: http://www.pserc.wisc.edu/ecow/get/publicatio/2004public/lasseterpesc04us.pdf)

European Research Project Cluster "Integration of RES + DG"

The interconnection of small, modular generation sources to low voltage distribution systems can form a new type of power system, the MicroGrid. MicroGrids can be connected to the main power network or be operated autonomously, if they are isolated from the power grid, in a similar manner to the power systems of physical islands.

(Source: http://microgrids.power.ece.ntua.gr/)

Interview Highlights

John Stevens, Sandia

For the purposes of the survey project, we have two key criteria [that define a microgrid]:

1. A system with a group of sources (at least two) and loads where the sources are not co-connected to the same electrical bus so that there's some impedance between units, requiring voltage controls. Essentially, you need more than one building, more than one generation source and at least one interconnection point to the grid.
2. High speed disconnect from the grid so you don't drop off critical load.

Chris Marnay, Lawrence Berkeley Laboratory

As a general concept, a microgrid has to have a control mechanism autonomous from the grid. In other words, it has to have some self-control. If a customer has a certain number of customers at a site and he set up an operating schedule, it is a microgrid in my view.

In my mind, a microgrid could be comprised of only a single generator, although it is rare and others may disagree. With a microgrid, there is no two-way power flow. From an upstream-perspective, it looks like any other customer. Being able to tap into the grid in some way is still going to be economically beneficial. I would say that access to the grid is a necessary requirement for a microgrid.

Ben Kroproski, NREL

We have defined a Distributed Resource Islanding System as one of the following (loosely):

1. A system that is located at one facility (one customer), with one generation source and one point of interconnection with the grid
2. A system with multiple generation sources, but still one customer and one point of interconnection with the grid
3. A system with multiple generation sources and customers, but again, with one point of interconnection with the grid

Jonathan Lynch, Northern Power

- We internally define systems as microgrid when they start to have multiple energy sources. A customer needs to have a collection of end user customers or widely separated such as on military bases. We need to see multiple load users. If the microgrid is connected with a utility, it needs to be able to seamlessly disconnect from the utility, but 100% of the load does not need to be picked up. Seamless switchover from grid to DG supplied power needs to be possible.
- Isolated islanded power may also be microgrids. Village power or an actual island in the Pacific may be considered a microgrid.
- Industrial parks, government facilities, and military facilities are considered good customers for microgrids. The part that defines a microgrid is the diversity in the load structure. Microgrids are essentially a local area network of DG systems.
- Storage is not a must have, but it is valuable for high function systems. New technologies may not have the same load-following capabilities as traditional technologies, making storage very good to have. CHP allows us to make the systems more economical. There's generally a CHP component in our installations.
- What we would not consider a microgrid would be something like an industrial facility with two generators connected next to each other with interconnection to the grid or a simple DG unit with an isolating switch.

Randy West, ENCORP

- A microgrid must have local generation, local loads, and some way of getting the generation to the load. It must be capable of operating independent or in parallel with the grid. I think a system with one building with one DG can be viewed as a microgrid, but that is not the predominantly held view. Most people want to see multiple separate loads. As long as the DG system enhances the security, reliability, and survivability of the grid, it's a microgrid.
- A microgrid doesn't have to be able to meet the full load requirement of the facility it serves since if you have too much generation capacity in your system, you're not using your equipment efficiently.

PSERC – Microgrid Protection and Control (T-18)

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
The focus of this work is on protection and control of the MicroGrid from internal faults. This work will look at less traditional protection methods coupled with the microsource controls to create an effective MicroGrid control and protection system.	•Do we understand DER's impact on the grid? •Can microgrids be utilized effectively? •Can the power system or the expansion thereof be built around microgrids?	• Develop design guidelines for microgrids • Demonstrate aggregation and control of DER	This effort should lead to ractical control and protection options for Microgrids

Funding/Source	Participants	Point of Contact
$50,000 per year for three years (June 1, 2002-Jun 30, 2005)	University of Wisconsin, Texas A&M University, Duke Power, and American Electric Power	Robert Lasseter University of Wisconsin/PSERC lasseter@engr.wisc.edu (608) 262-0186

Project Area	Project Focus	Technology Characteristic	Project Type
Interconnection ?	Microgrids	Key	Research

Source: http://eppe.tamu.edu/pserc/summary/grid.pdf

CERTS – Microgrids

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
CERTS is concentrating on DER solutions that can meet the twin goals of delivering more reliable service to specific customers and enhancing the performance of the interconnected grid. They are developing data on the dynamic performance of microsources (e.g., microturbines); creating new modeling tools and collecting relevant data to study microgrids; and planning microgrid field demonstrations.	•Can the power system or the expansion thereof be built around microgrids? •Do we understand microgrids impact to the grid?	• Demonstrate and test microgrids • Model and analyze microgrids • Develop design guidelines for microgrids	CERTS is currently working to demonstrate a full-scale microgrid utilizing three 60kW microturbines. The results of this effort would help validate the conceptual work that has been completed.

Funding/Source	Participants	Point of Contact
DOE and CEC	CERTS: PSERC, Sandia National Laboratories, Pacific Northwest National Laboratories, Lawrence Berkeley Laboratory	Robert Lasseter University of Wisconsin/PSERC lasseter@engr.wisc.edu (608) 262-0186

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects	Microgrids	Key	Research / Demonstration

Source: http://certs.lbl.gov/DER_H1.html

LBNL – DER Customer Adoption Model

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
The DER Customer Adoption Model (DER CAM) helps quantify the economic benefits of DER applications, including microgrids. Its thermal energy modeling capability allows it to quantify the benefit of CHP installations. The objective of the model is to minimize the cost of operating on-site generation and combined heat and power (CHP) systems, either for individual customer sites or a microgrid.	•Can the power system or the expansion thereof be built around microgrids? •Do we understand microgrids impact to the grid?	• Model and analyze microgrids • Develop design guidelines for microgrids	Users of the model can identify the appropriate capacities of DG and CHP technology or combination of technologies to be installed, when and how much of the capacity installed will be running, and the total cost of supplying the electric and heat loads

Funding/Source	Participants	Point of Contact
DOE and CEC	Lawrence Berkeley National Lab	Chris Marnay Lawrence Berkeley National Lab c_marnay@lbl.gov (510) 486-7028

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects/ Market Integration	Microgrids	Base	Research/Demonstration

Source: http://der.lbl.gov/dercam.html

Palmdale Water District – Energy Storage Enabled Renewable MicroGrid Power Network

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
Project will integrate a 950kW wind turbine, 250 kW hydro and 250kW natural gas generator into a MicroGrid using 450kW ultra-capacitor. Ultracapacitor storage technology is used as an energy bridge to enable the smooth transfer of renewables and DG technologies.	•Can the power system or the expansion thereof be built around microgrids? •Do we understand microgrids impact to the grid?	• Demonstrate and test microgrids • Model and analyze microgrids • Develop design guidelines for microgrids	The renewable microgrid would enhance DG and renewable use by utilities and end customers and support: • T&D congestion relief for utilities, ISO and ESPs • End customer reliability • Demand response for end customers and utilities • Back-up power and power quality for end customers.

Funding/Source	Participants	Point of Contact
California Energy Commission: $987K (22% of $4,376K Total Project Costs)	Southern California Edison, Palmdale Water District	David Chambers California Energy Commission dchambers@energy.state.ca.us (916) 653-7067

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects	Microgrids	Pacing	Demonstration

Source: http://www.energy.ca.gov/pier/papers_presentations/2004-05-11_APEC_STORAGE.PDF

Distributed Utility Integration Test

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
DUIT is a large scale effort to examine DER technology and impacts through laboratory testing and demonstration of varying levels of DER on distribution systems. DUIT is seeking to provide answers on microgrid performance in a real world setting.	• Do we understand DER's impact on the grid? • Do we understand how DER will interact with other DER and the grid in real-time? • Is there a limit to the level of DER that the system can absorb without adverse impacts?	•Model and analyze the grid with varying levels of DER penetration •Develop models to understand system impacts	Increased understanding of electrical issues, control systems, modeling techniques, utility distribution system benefits, and outreach/cooperation.

Funding/Source	Participants	Point of Contact
CEC and DOE	Distributed Utility Associates, California Energy Commission, Endecon Engineering, Caterpillar, Solar Turbines, Encorp, Pacific Gas and Electric Co., Exelon (Philadelphia Electric Co.), On-Site Energy, Gas Research Institute	Distributed Utility Associates dua@ix.netcom.com 925-447-0624

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects	Power Quality, Power Reliability, Congestion, Grid Impacts	Pacing	Research

Source: www.energy.ca.gov/distgen_oii/documents/dgwg/R+D-17.pdf
http://www.nrel.gov/docs/fy03osti/34389.pdf

ENCORP – Fort Bragg Microgrid

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
ENCORP and Honeywell collaborated at Fort Bragg to aggregated 15 diesel generators, one 5kW fuel cell and will soon install one 5 MW gas turbine on its microgrid. Using a full parallel interface that allows seamless power flows, the generators use the post's distribution system to export power to various loads	• Can microgrids be utilized effectively? • Can the power system or the expansion thereof be built around microgrids? •Can we aggregate and remotely operate and control DER to better respond to market signals (e.g., energy capacity, ancillary services, and transmission and congestion)?	• Demonstrate and test microgrids • Develop design guidelines for microgrids • Demonstrate aggregation and control of DER	The Fort Bragg microgrid was completed in May 2003. The facility's performance would be measured and help clarify the feasibility of the microgrid concept and enabling technology.

Funding/Source	Participants	Point of Contact
Demonstration project for DOE's Integrated Energy Services Award	ENCORP Honeywell Carolina Light and Power	Joshua Meyer ENCORP 9351 Eastman Park Drive Windsor, Colorado 80550 joshua.meyer@encorp.com

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects, *Interconnection, Market Integration*	Microgrids	Key	Demonstration

Source: http://www.encorp.com/dwnld/pdf/awd-art/Power_Engineering_magazine_Ft_Bragg_color.pdf
http://www.encorp.com/content.asp?cmsID=76

NREL – Electric Distribution Transformation Program: Interconnection Testing

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
NREL is conducting a large scale interconnection project to test and demonstrate advanced technologies for interconnection, integration, and control of DR. The project will also conduct Intentional Islanding (microgrid) component and system testing and examine issues with interconnection of multiple DGs	• Are their safe, reliable and cost-effective interconnection solutions for microgrids? •Do we understand microgrid's impact to the grid	•Model and analyze microgrids •Develop and test interconnect designs •Demonstrate and test microgrids •Understand impact of new interconnection requirement; identify best practices for interconnection	FY 2004: • Conduct Hardware characterization on GE UI and ENCORP controller • Conduct exploratory testing on impacts of multiple DR on single feeder • Conduct a Technical Workshop on modeling • Develop targeted solicitation on distribution modeling

Funding/Source	Participants	Point of Contact
DOE $13.6M over 4 years	DOE, NREL, CEC, GE, Northern Power, University of Wisconsin, DUIT, PG&E, ENCORP, DTE Energy	Ben Kroposki NREL 1617 Cole Blvd Golden, CO 80401-3393 303-275-2979 ben_kroposki@nrel.gov

Project Area	Project Focus	Technology Characteristic	Project Type
Interconnection, *Grid Effects*	Microgrids	Key	Research / Demonstration

Source: http://www.eere.energy.gov/distributedpower/pdfs/reviewannual03pres/dertf_2003.pdf

Appendix C – Research Project Details

Northern Power – Mad River Park

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
Northern Power is building an advanced power network solution that incorporates distributed generation, energy storage, and load management subsystems into a highly reliable, efficient, and robust power systems. The Mad River Park MicroGrid power network will serve customers residing in the park -- approximately five businesses and 12 residential power users, including Northern Power's new headquarters.	•Can microgrids be utilized effectively? • Can the power system or the expansion thereof be built around microgrids? •Do we understand what benefits DER can provide to the power system?	• Demonstrate and test microgrids • Develop design guidelines for microgrids • Demonstrate aggregation and control of DER	With construction expected to be complete by summer 2005, Northern Power will monitor the systems performance and economic feasibility.

Funding/Source	Participants	Point of Contact
DOE ($600K over two years) and Northern Power	Northern Power Systems Washington Electric Cooperative VT Department of Public Service	Jonathan Lynch Northern Power Systems jlynch@northernpower.com 802-496-2955

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects, *Interconnections*	Microgrids	Key	Demonstration / Commercialization

Source: http://www.northernpower.com/company/whats-new/press-releases.html?news_id=16756&year=2004&month=8&superstep=6

DTE Energy Technologies – NextEnergy Microgrid

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
DTE Energy Technologies is installing a microgrid at the NextEnergy site in Michigan. The project, fueled by hydrogen, natural gas and sunlight will include the use of several emerging on-site energy technologies including fuel cells, internal and external combustion engines, miniturbine technology and photovoltaic (solar) cells.	•Can microgrids be utilized effectively? •Can the power system or the expansion thereof be built around microgrids?	• Demonstrate and test microgrids • Develop design guidelines for microgrids • Demonstrate aggregation and control of DER	The facility is expected to be complete by the end of the year. Monitoring the performance of the microgrid should yield meaningful insights into the feasibility and challenges of microgrid operation.

Funding/Source	Participants	Point of Contact
$5.4M from NextEnergy and partially by a grant from the Michigan Public Service Commission	DTE Energy Technologies NextEnergy	Jim Croce President and Chief Executive Officer NextEnergy 3011 W. Grand Blvd., 320 Fisher Bldg., Detroit, MI 48202 (313) 873-9260 jimc@nextenergy.org

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects	Microgrids	Key	Demonstration

Source: http://www.dtetech.com/pressroom/releases/4_1_111903.asp

Appendix C – Research Project Details

EU – Cluster "Integration of RES + DG"

Project/Technology Development/Product	Issues	Research Initiatives	Expected Results
The project will investigate, develop and demonstrate the operation, control, protection, safety and telecommunication infrastructure of MicroGrids and will determine and quantify their economic benefits. Operation and Control concepts in both stand-alone and interconnected mode on Laboratory MicroGrids will be demonstrated.	•Do we understand what benefits DER can provide to the power system? •Can microgrids be utilized effectively? •Can the power system or the expansion thereof be built around microgrids? •Should standards for communications/control be developed?	• Model and analyze microgrids • Demonstrate and test microgrids • Develop design guidelines for microgrids • Demonstrate aggregation and control of DER	This EU-Cluster project is seeking to increase the penetration of renewable energy sources and other micro sources by 15%, reduce annual losses by 10%, increase reliability levels by 30%, and reduce energy cost for the end-user by 10%.

Funding/Source	Participants	Point of Contact
European Union €4.4M	EPRI, EMFORCE, Electricite de France, National Technical University of Athens, Electricidade de Portugal, Ecole Nationale Supérieure des Mines de Paris, University of Manchester, and URENCO Power Technologies Ltd.	Prof. Dr. J. Schmid ISET e.V. Königstor 59 D-34119 Kassel, Germany +49 561 7294 304

Project Area	Project Focus	Technology Characteristic	Project Type
Grid Effects	Microgrids	Key	Research / Demonstration

Source: http://microgrids.power.ece.ntua.gr/index.htm