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Microgrid Techno-Economic Assessment

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IRED Conference, Niagara Falls

10/25/2016

Outline

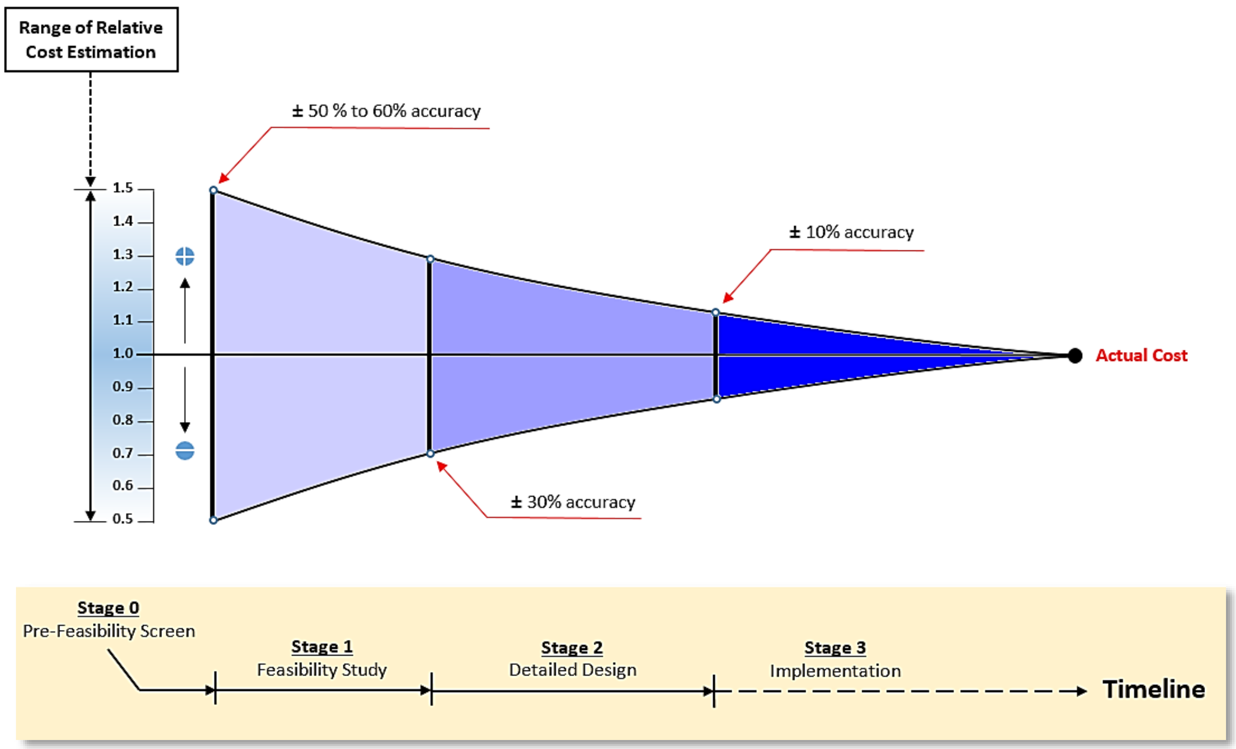
- **What is Techno-Economic Analysis & Why It's Needed**

- **EPRI Study Process**
  1. Site Assessment, Defining Objectives, Data Collection
  2. Modeling Tools & Process
  3. Cost-Benefit Framework

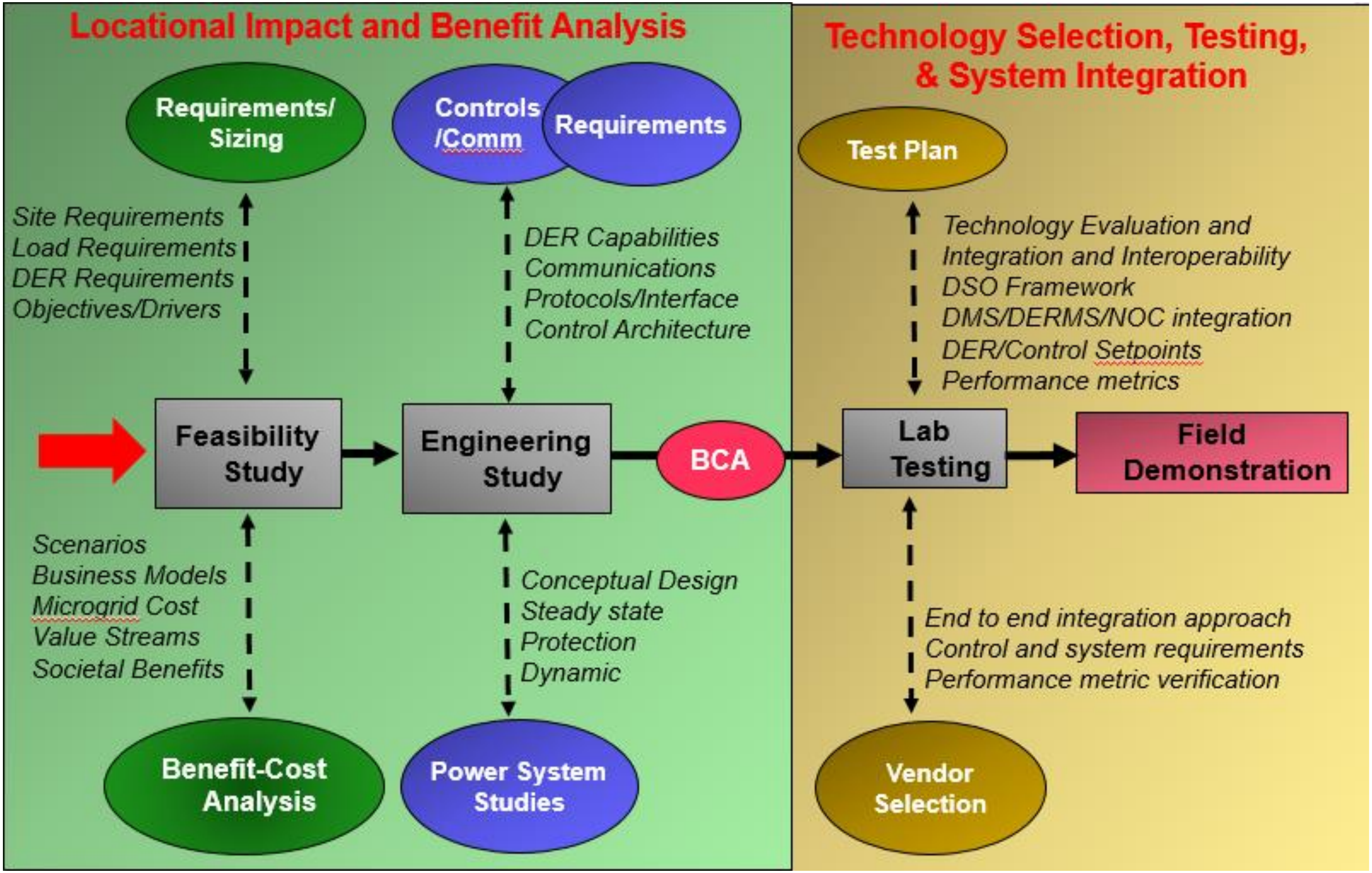
- **Case Studies & Results**

- **Lessons Learned & Challenges**

What is Feasibility (Techno-Economic) Assessment?

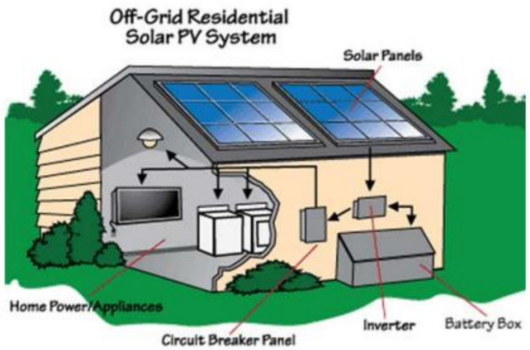


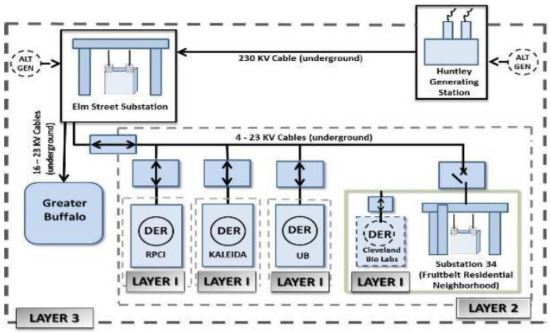
- Evaluate use cases for Microgrid & DERs
- Microgrid design
- DER sizing
- DER dispatch
- First-order analysis of Costs & Benefits


Locational Impact and Benefit Analysis
Requirements/ Sizing
Controls /Comm
Requirements
Site Requirements
Load Requirements
DER Requirements
Objectives/Drivers
DER Capabilities
Communications
Protocols/Interface
Control Architecture
Feasibility Study
Engineering Study
BCA
Scenarios
Business Models
Microgrid Cost
Value Streams
Societal Benefits
Conceptual Design
Steady state
Protection
Dynamic
Benefit-Cost Analysis
Power System Studies
Technology Selection, Testing, & System Integration
Test Plan
Technology Evaluation and
Integration and Interoperability
DSO Framework
DMS/DERMS/NOC integration
DER/Control Setpoints
Performance metrics
Lab Testing
Field Demonstration
End to end integration approach
Control and system requirements
Performance metric verification
Vendor Selection

Sample Projects Types

- Islands
  - *Examination of PV + ES system in the Spanish Canary Islands*
- Off-Grid vs On-Grid
  - *A Case Study Comparison of On-Grid and Off-Grid Power for Residential Consumers*
- Microgrid
  - Characterized as being grid-connected >99%
  - Islanded during emergency (e.g. snow storm, grid failure)
- DER Grid Parity





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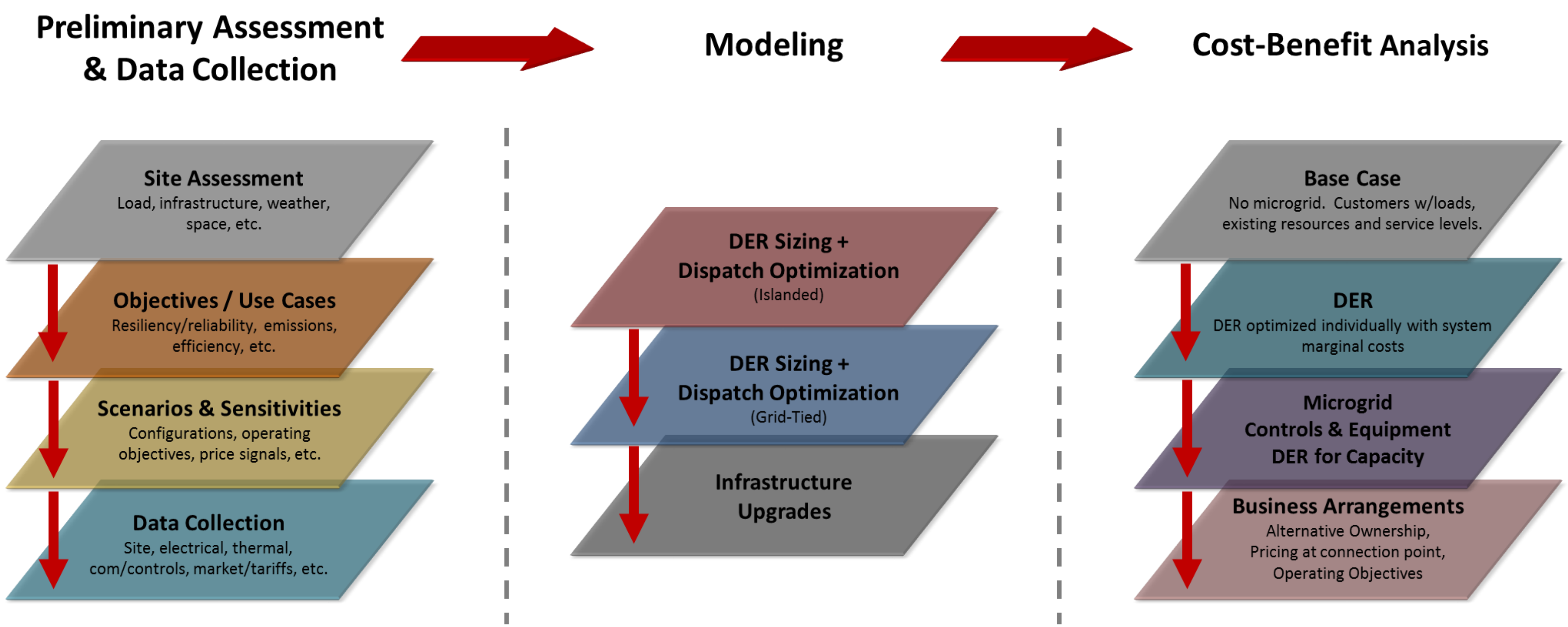
Study Process



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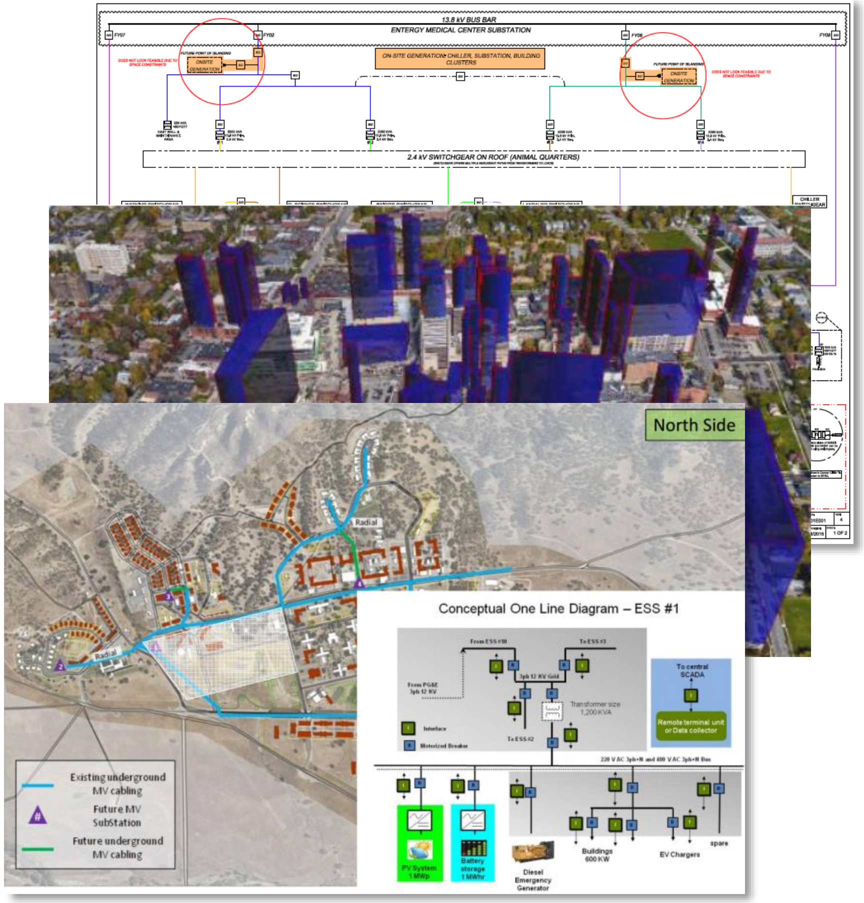
Site Assessment

- Infrastructure
- Current reliability/resiliency
- Load
- Current Operations
- Existing Assets
- DER interconnection points
- Available Space for DER



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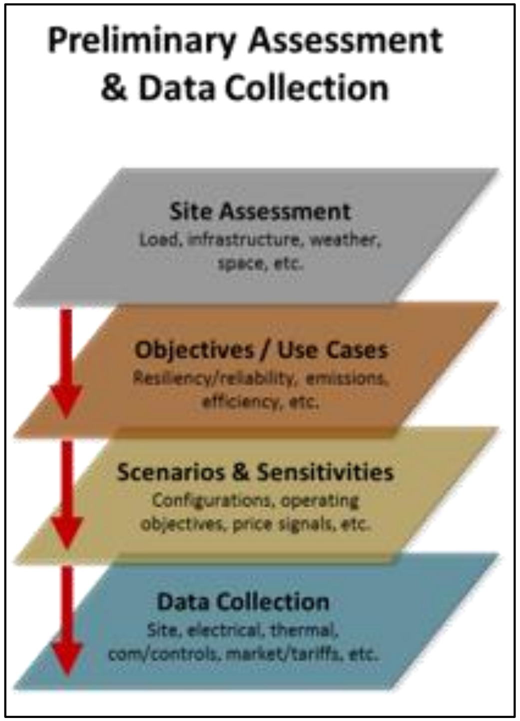
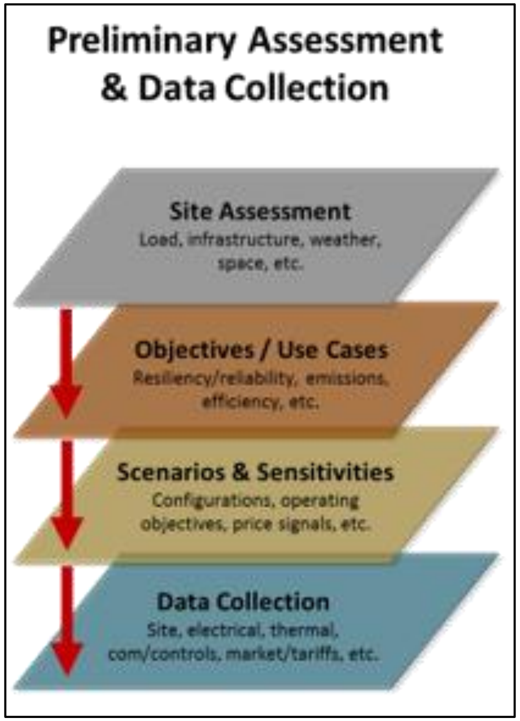
Defining the Study
Importance of Establishing Objectives



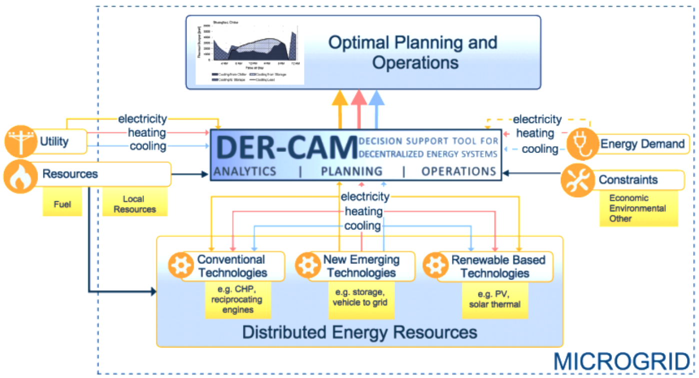
- **Type of Analysis & Level of Detail**
  - Deterministic *vs* Stochastic *vs* Rule-Based
  - "Black Box" approach (energy-in, energy-out)
  - Steady-state power flow
  - Thermal flows
- **Time vs Accuracy**
  - Computation intensity & time
  - Customization (e.g. market participation)
  - Automation (e.g. wrappers)
  - Data collection
- **Analysis constrained by available data**

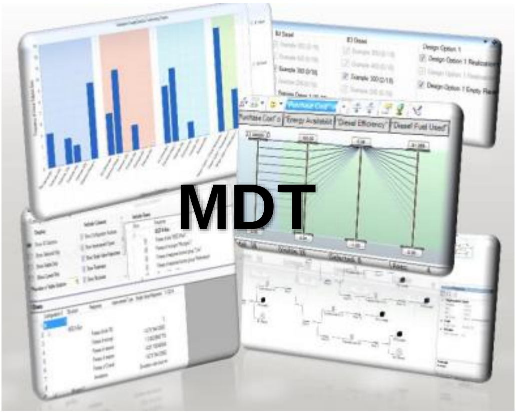
Defining the Study
Importance of Establishing Objectives

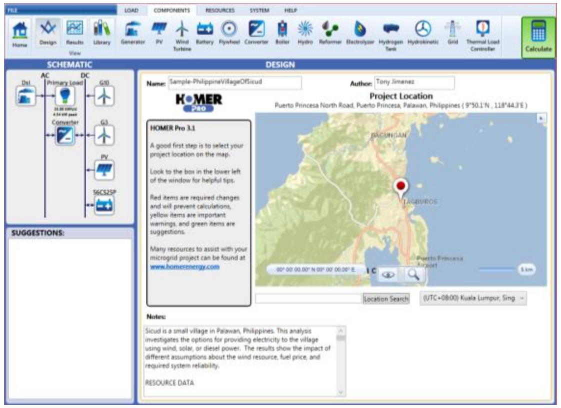


- **Scenarios & Sensitivities:**
  - Load/customer types
  - Critical/Non-critical load, load flexibility
  - Load clustering or microgrid-nesting
  - Rates & Rate Structure
  - Renewable Penetration
  - Environmental Impact
- **Cost-Benefit Perspective?**
  - Customer/Utility/3rd Party/Comomunity/Society
  - What is the economic question(s)?

Modeling Tools

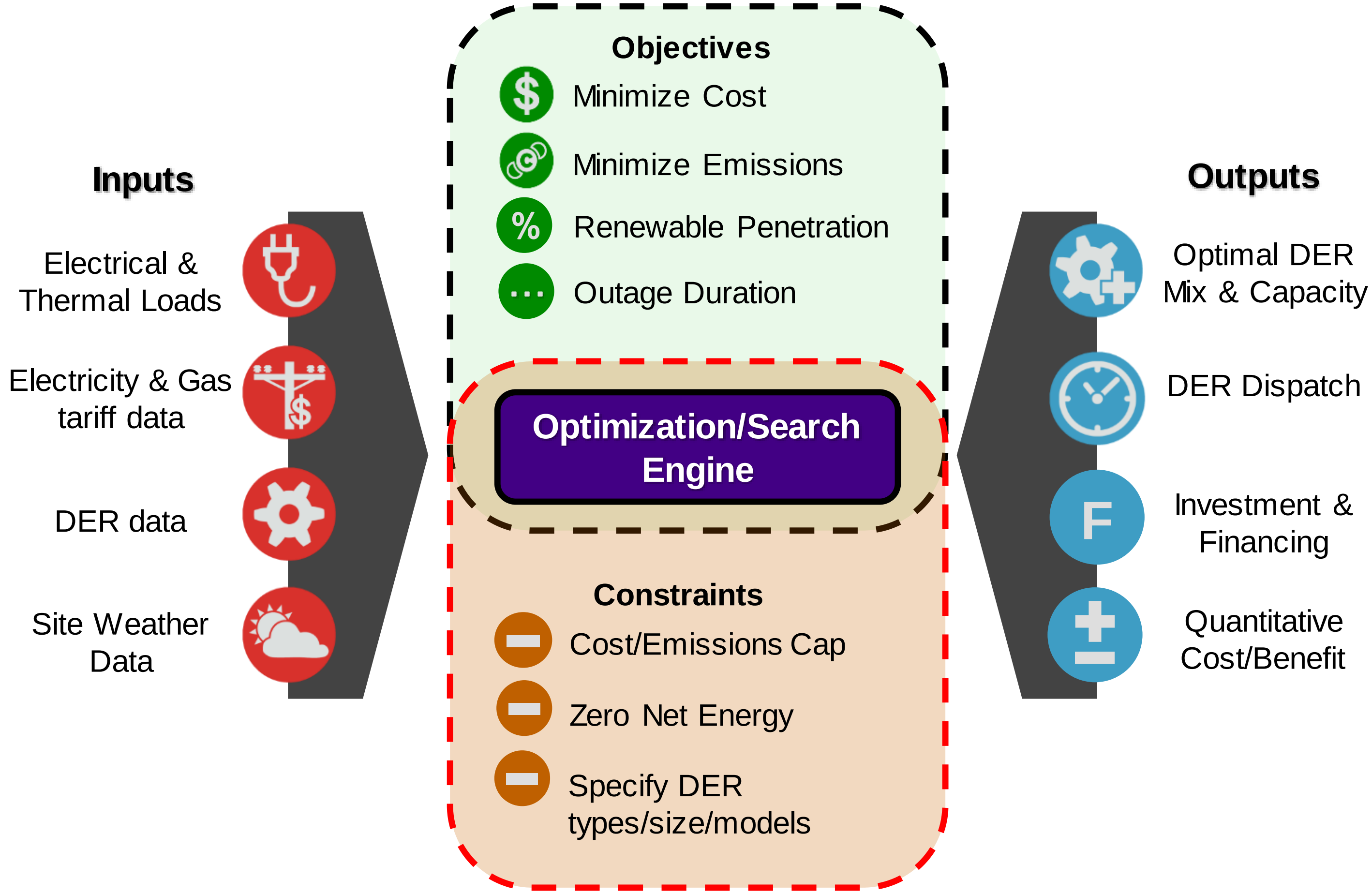




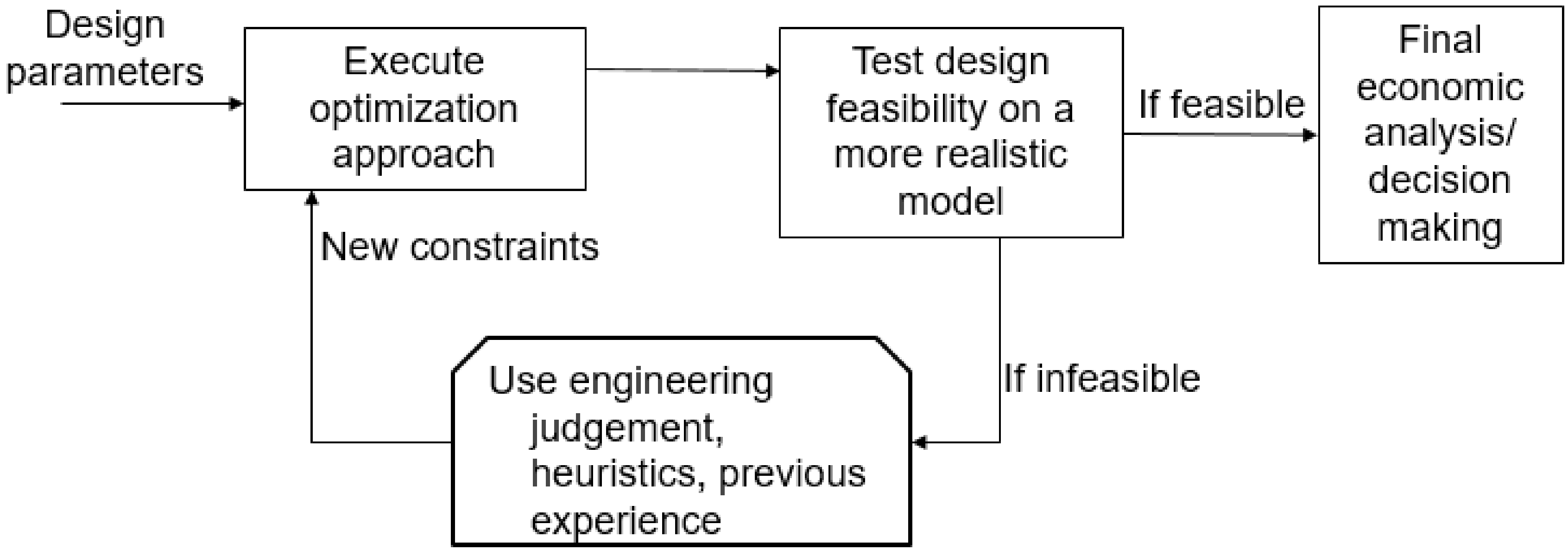


- RETScreen (NRC)
- SAM (NREL)
- Custom

Modeling
Overview



Modeling
Tools



Techno-economic planning tools surveyed

	HOMER ENERGY	DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS ANALYTICS | PLANNING | OPERATIONS
Developer	**National Renewable Energy Laboratory (NREL)**	**Lawrence Berkeley National Laboratory (LBNL)**
Retailer	HOMER Energy LLC	Lawrence Berkeley National Laboratory (LBNL)
Target	Commercial, Industry	Academia
Open source	Customizable for a fee	Yes, with a developers license
Supported OS	Windows	Windows, Unix, Max OS X
Documentation	Extensive	Limited
User support	Forum (user and developer), Sample Models, FAQ	FAQ
Difficulty	Easy	Moderate
Optimization	**Brute force permutations**	**Mixed Integer Linear Program**

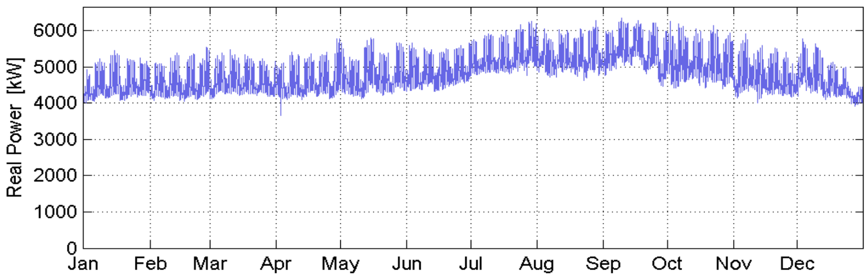
Input differences: Load Models

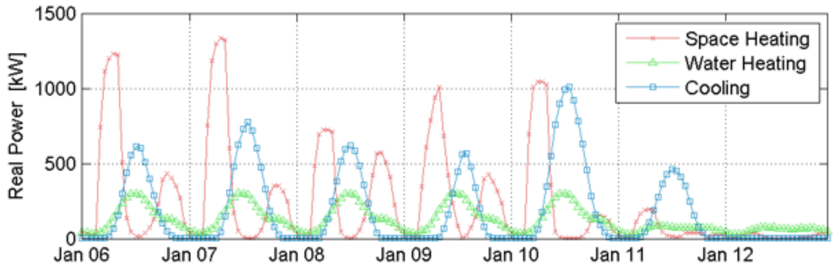
HOMER ENERGY

- Modeled as full time series
- Load diversity
  - Electric
  - Thermal

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

- Modeled as characteristic day type
- Load Diversity
  - Electric
  - Space heating
  - Water heating
  - Cooling
  - Natural gas





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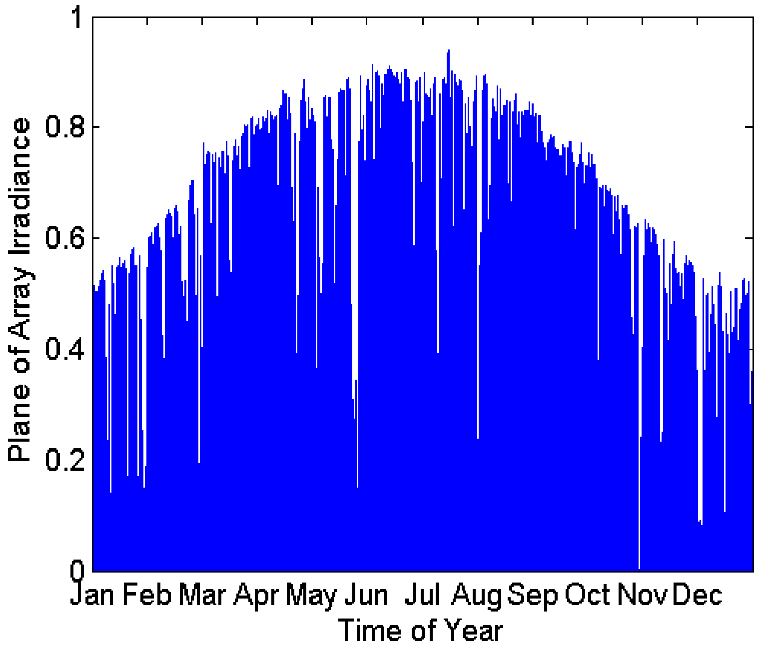
Input differences: Irradiance Models

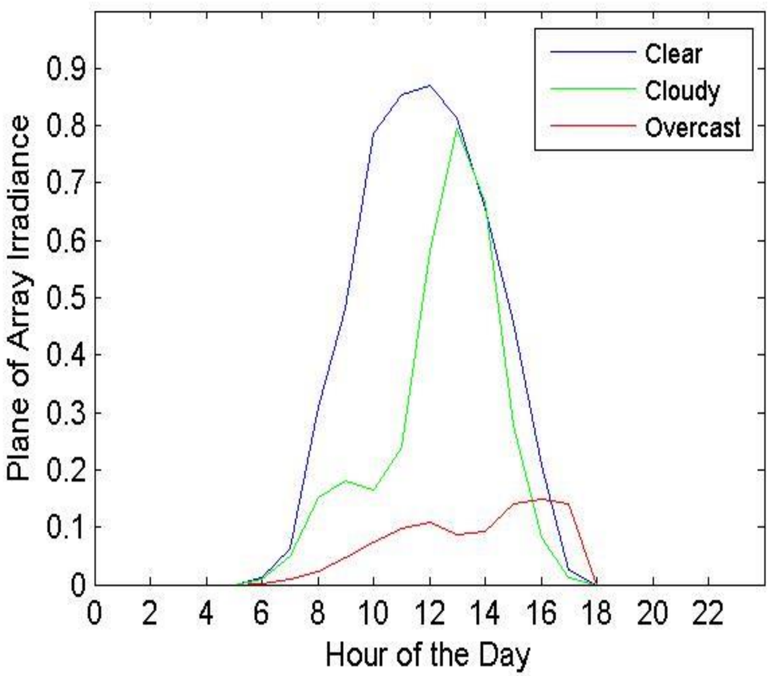
HOMER ENERGY

- Modeled as full time series
- Hour time-step
  - Capture intra-day variability



DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

- Modeled as characteristic day type
- Captures seasonal variability



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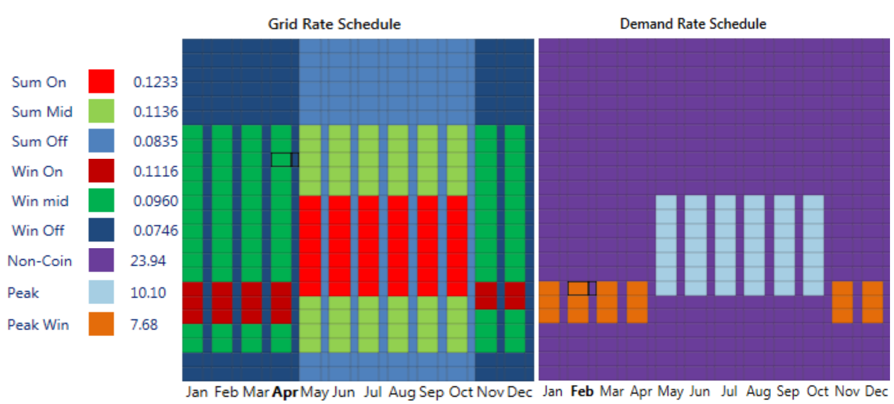
Input differences: Grid cost models

HOMER ENERGY

- Grid rate modeled as hourly price
  - Changes with month
  - Demand charge modeled same way
  - Service fee not considered
  - Volumetric rate not considered

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

- Grid rate Modeled as characteristic periods
  - Changes monthly
  - Demand charge modeled same way
  - Service fee considered
  - Volumetric rates considered



Hour	Summer week	Summer peak	Summer weekend	Winter peak	Winter week	Winter weekend
1	3	3	3	3	3	3
2	3	3	3	3	3	3
3	3	3	3	3	3	3
4	3	3	3			
5	3	3	3			
6	3	3	3			
7	2	2	3			
8	2	2	3			
9	2	2	3			
10	2	2	3			
11	2	2	3			
12	1	1	3			

	On-peak	Mid-peak	Off-peak
January	0.11157	0.09602	0.0746
February	0.11157	0.09602	0.0746
March	0.11157	0.09602	0.0746
April	0.11157	0.09602	0.0746
May	0.12331	0.11362	0.08287
June	0.12331	0.11362	0.08287
July	0.12331	0.11362	0.08287
August	0.12331	0.11362	0.08287
September	0.12331	0.11362	0.08287
October	0.12331	0.11362	0.08287
November	0.11157	0.09602	0.0746
December	0.11157	0.09602	0.0746

Results: Configuration

HOMER ENERGY

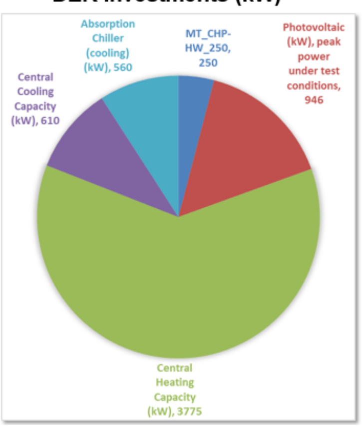
- Optimal mix given for all possible permutations of DER available
  - Optimal: Gas generator, CHP, boiler
  - PV and storage always minimal

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

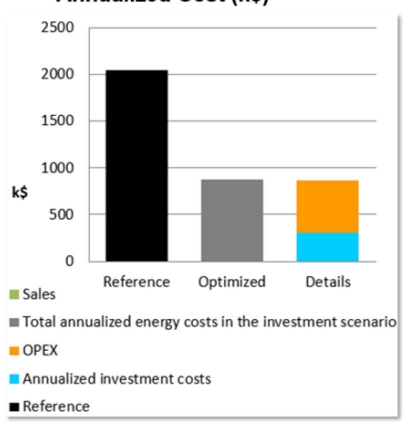
- Single optimal mix choosen
  - Optimal: Gas generator, PV, CHP
  - Storage not selected

Battery	PV	100 kW	200 kW	300 kW	400 kW	500 kW
100kW/200kWh		$xxx				$xxx
200kW/400kWh						
300kW/600kWh						
400kW/800kWh						
500kW/1000kWh						
600kW/1200kWh						
700kW/1400kWh		$xxx				$xxx

DER Investments (kW)



Annualized Cost (k$)



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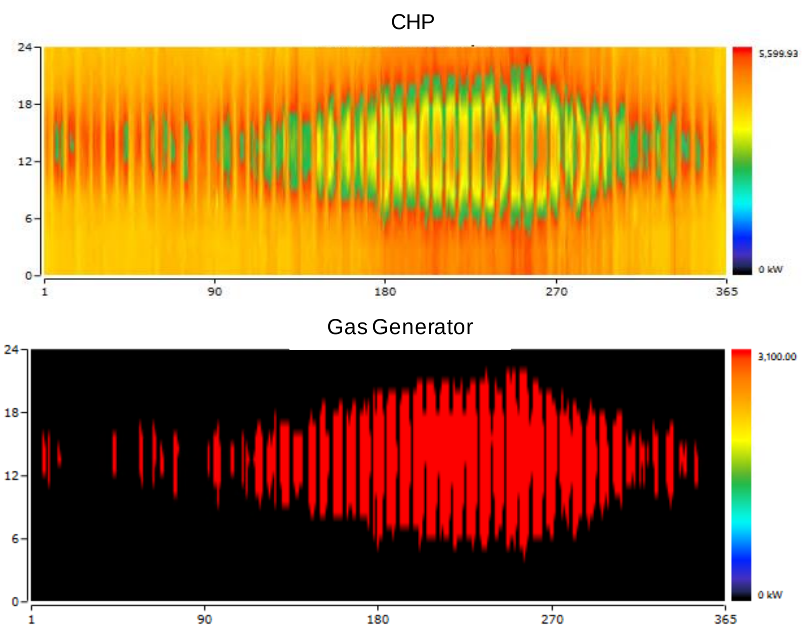
Results: Operation

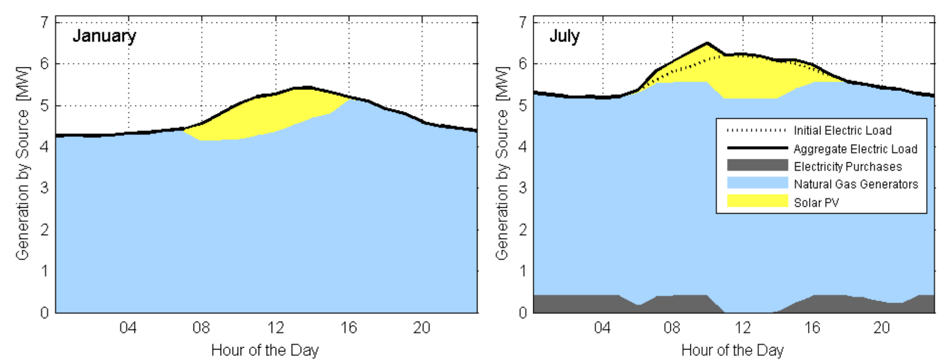
HOMER ENERGY

- Optimal operation given as time series
  - Multiple views available/exportable

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

- Optimal operation given in terms of averaged monthly output
  - Considers load added due to DER (cooling)





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Results: Emissions

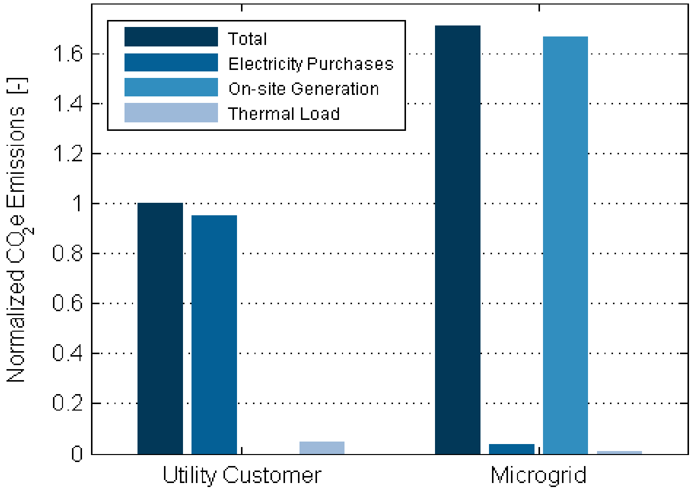
HOMER ENERGY

- Reports emission for both utility customer and microgrid
  - Emission diversity by particle
    - 6 particle types

DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

- Reports emission for both utility customer and microgrid
  - Emission diversity by pollutant
    - Electric purchases
    - On-site generation
    - Thermal load

	Microgrid	Utility	
Quantity	Value	Value	Units
Carbon Dioxide	21,015,846.00	14,440,196.00	kg/yr
Carbon Monoxide	69,507.00	1.57	kg/yr
Unburned Hydrocarbons	7,699.10	0.00	kg/yr
Particulate Matter	5,239.70	0.00	kg/yr
Sulfur Dioxide	55,527.00	124,754.00	kg/yr
Nitrogen Oxides	620,207.00	60,396.00	kg/yr



Results: Cost Breakdown

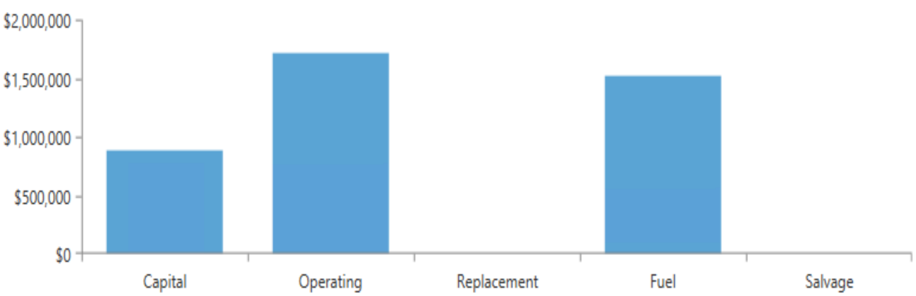
HOMER ENERGY

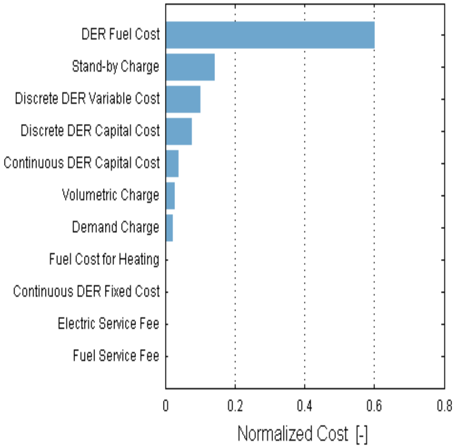
- Cost given for
  - DER type
  - Cost type
- Given for project lifetime

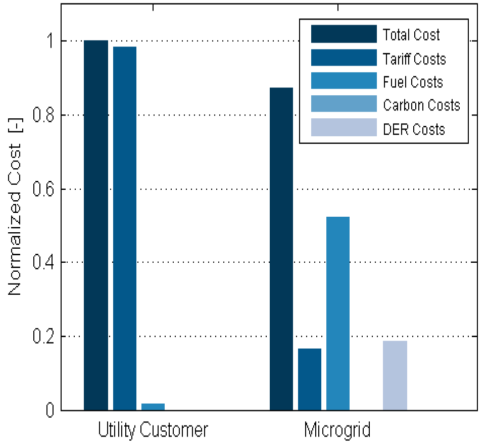
DER-CAM DECISION SUPPORT TOOL FOR DECENTRALIZED ENERGY SYSTEMS
ANALYTICS | PLANNING | OPERATIONS

- Cost given for
  - Cost type
- Large diversity of cost type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic flat plate PV	$35,810.00	$0.00	$50.00	$0.00	$0.00	$35,860.00
Gen	$500,889.00	$0.00	$1,520,736.00	$1,433,616.00	$0.00	$3,455,242.00
CHP	$340,923.00	$0.00	$188,164.00	$63,436.00	$0.00	$592,523.00
Boiler	$0.00	$0.00	$0.00	$28,201.00	$0.00	$28,201.00
Converter	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
System	$877,622.00	$0.00	$1,708,950.00	$1,525,252.00	$0.00	$4,111,825.00







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A complex project can be examined in stages, addressing a series of Cost/Benefit Analysis (CBA) questions

"Stacking Order" for DER and Microgrids

Base Layer w/o Microgrid
Existing system: customers, loads, existing DER, and service levels.

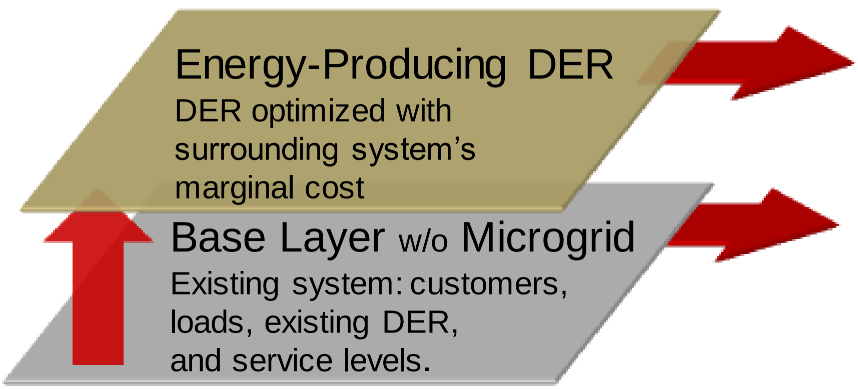
- Reliability
- Power Quality
- Customer Types
- Customer loads
- Expected Upgrades
- Cost of Interruptions
- Cost of PQ Issues
- Expected Growth
- Cost of Energy
- Cost of Capacity
- Cost of Emissions

Cost of Upgrades

Full and specific description of existing system and customers.

A complex project can be examined in stages, addressing a series of Cost/Benefit Analysis (CBA) questions

"Stacking Order" for DER and Microgrids



- **Reliability (unchanged)**
- **Avoided Energy**
- **Avoided Capacity**
- **Avoided Emissions**
- **Avoided/Incurred Upgrades**

Full and specific description of existing system and customers.

CBA1

CBA 1: What is the net value of the energy-producing DER?

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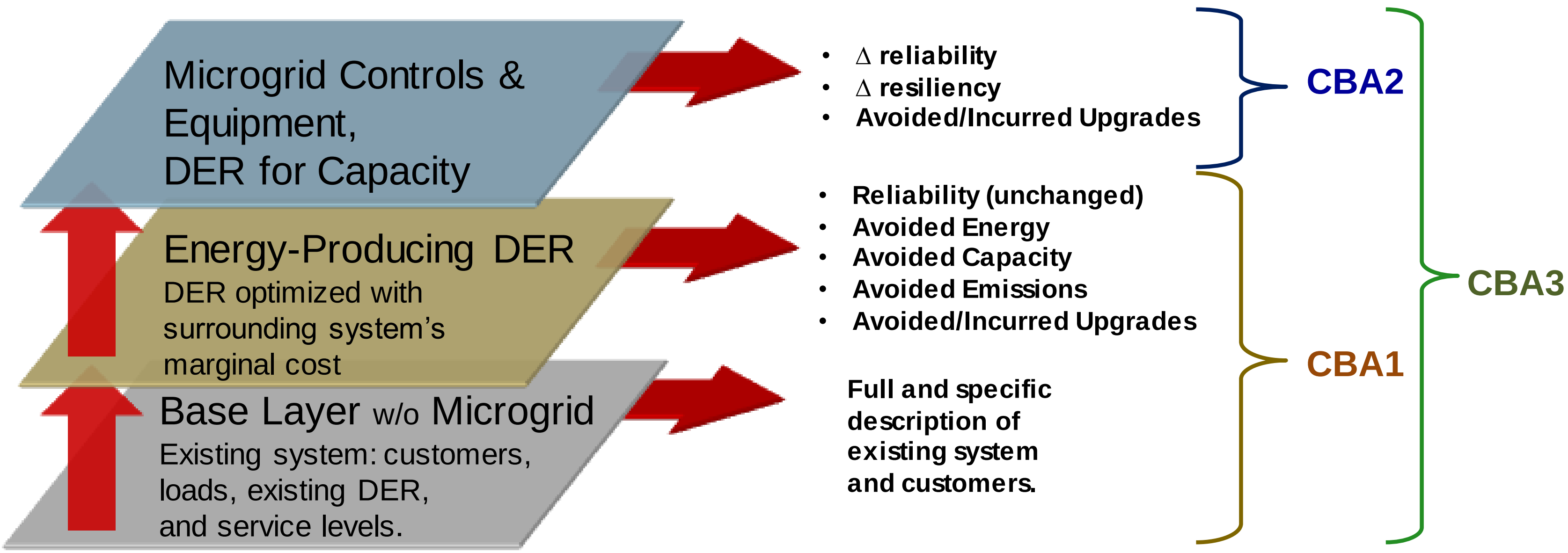
“Stacking Order” for DER and Microgrids



CBA 1: What is the net value of the energy-producing DER?

CBA 2: Does the value of incremental reliability/ resiliency outweigh the incremental cost?

CBA 3: Does the total value of the microgrid outweigh its cost?

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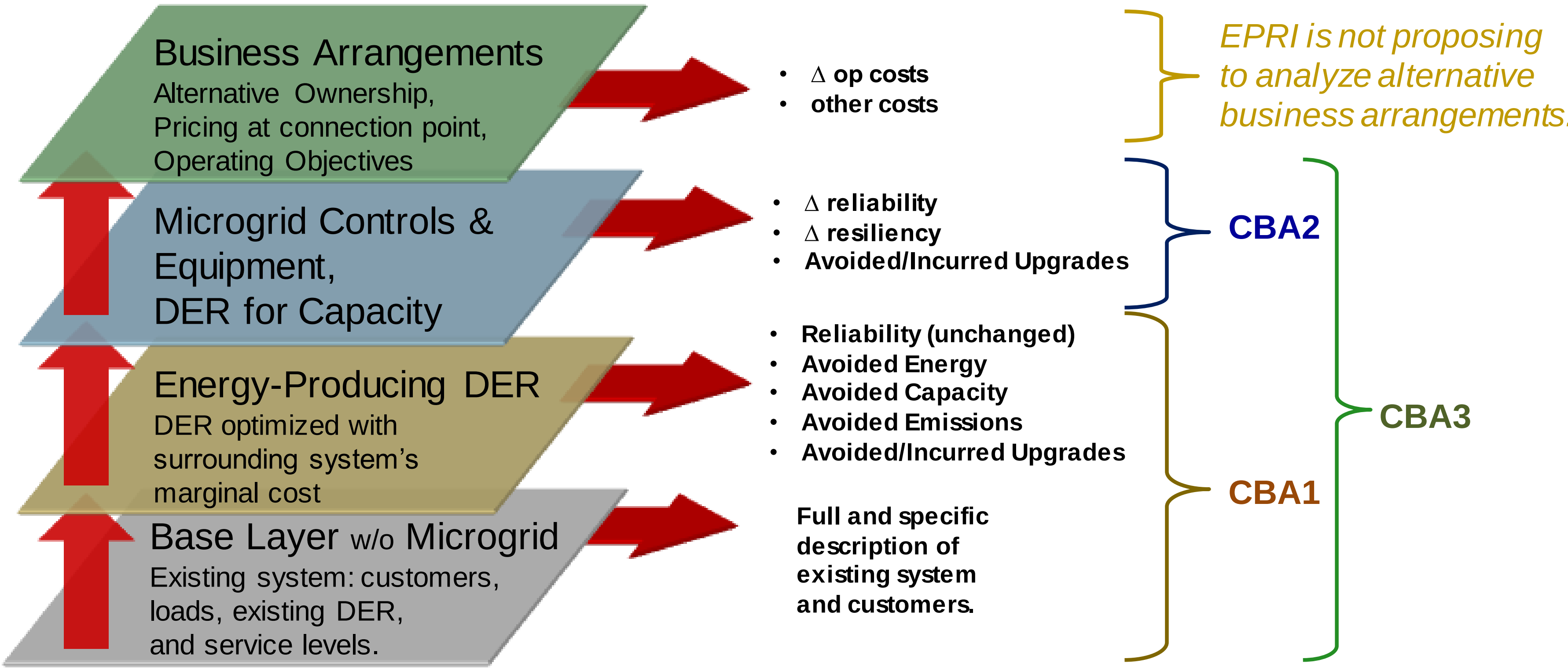
"Stacking Order" for DER and Microgrids



CBA 1: What is the net value of the energy-producing DER?

CBA 2: Does the value of incremental reliability/ resiliency outweigh the incremental cost?

CBA 3: Does the total value of the microgrid outweigh its cost?

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Microgrids

- Optimization of microgrid design is challenging and inherently contains **<u>many</u>** unknowns…

Regulatory Issues

Value of Resiliency

Costs

Microgrids

Who pays for the microgrid?
- Microgrid Customers?
- Community?
- Ratepayers?
- Government?

Business Model
- IOU?
- Integrated?
- Public Utility?
- Self-Regulated?
- Third Party (SPE)?
- IPP?

Regulatory Issues

Energy Transactions
- Rate Structure?
- Net Metering?
- Wheeling/Backup charges?
- Market Participation?
- Grid Support?

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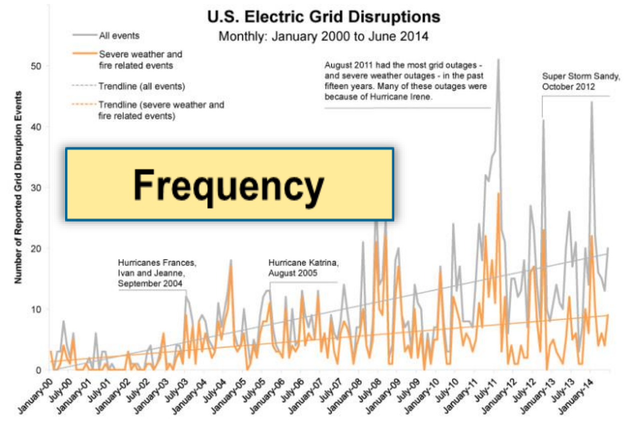
Microgrids

Location?

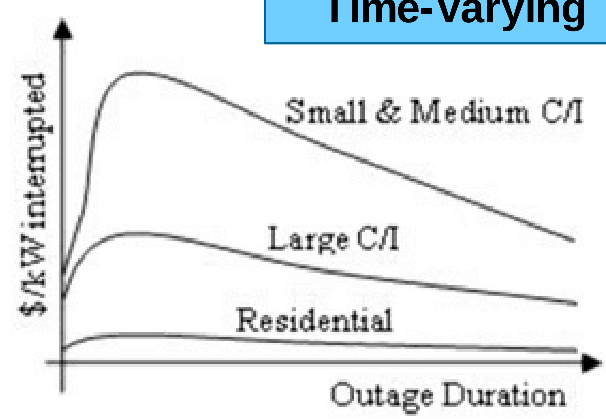


Frequency

Value of Resiliency

Customer Type?

Time-Varying



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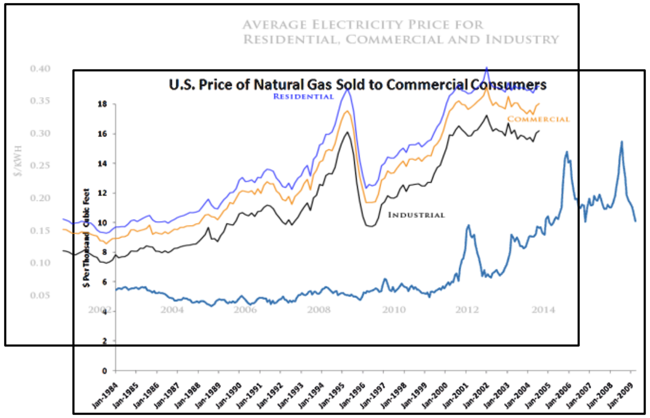
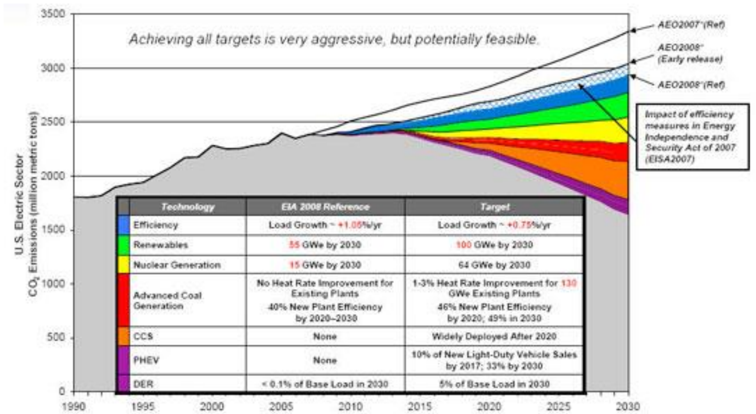
Microgrids

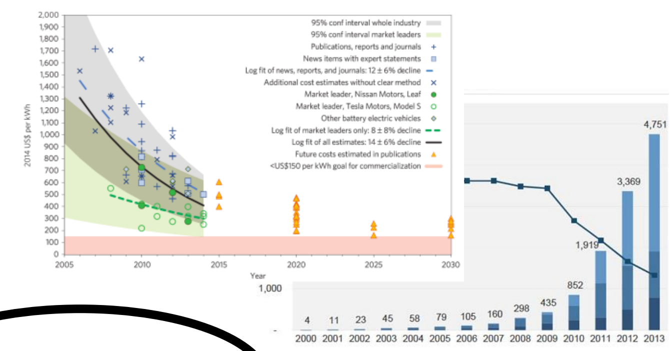
Gas/Electricity Price



Cost of Emissions



DER Costs



Costs

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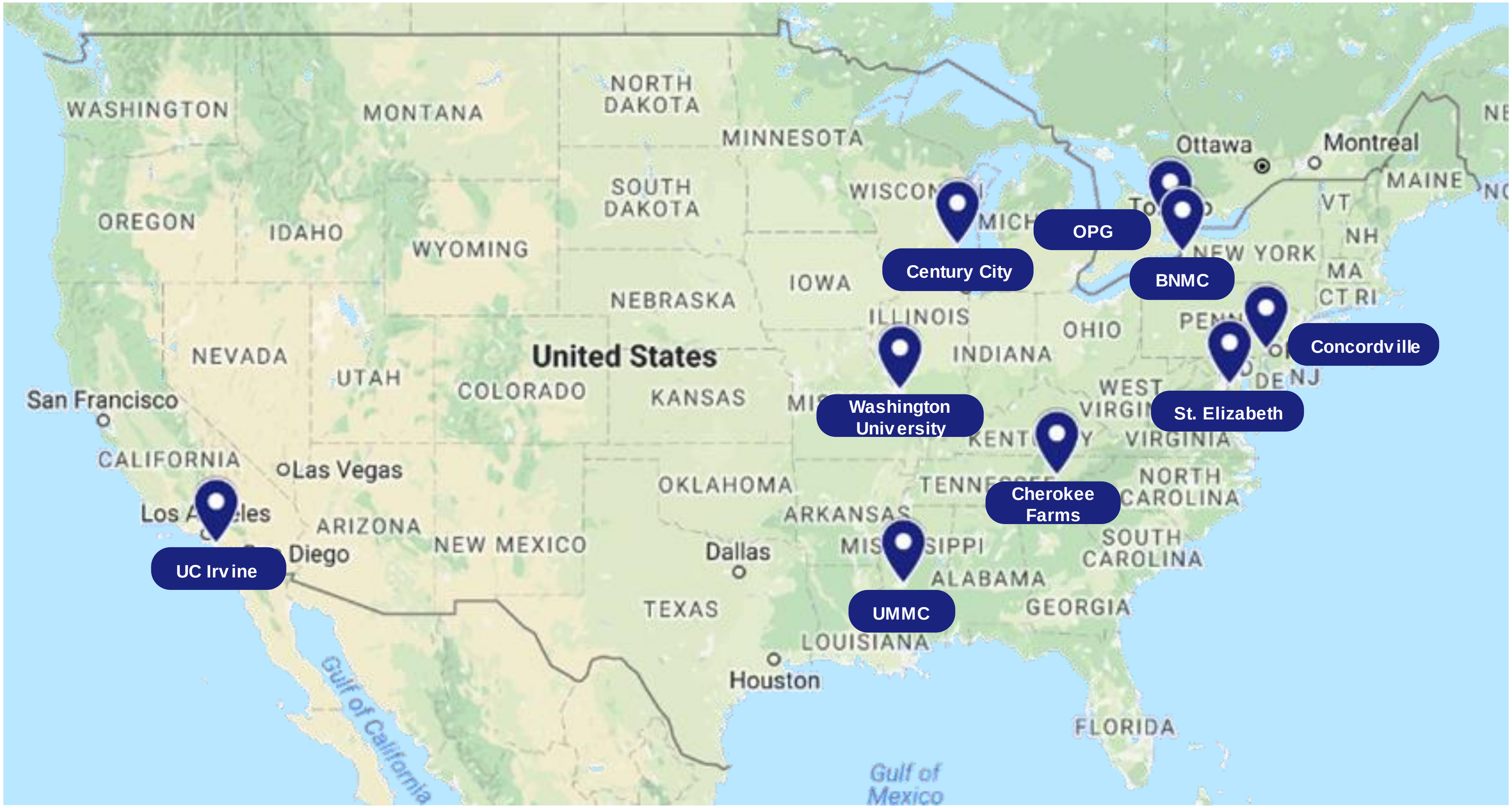
EPRI Microgrid Feasibility Projects



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EPRI Microgrid Feasibility Projects

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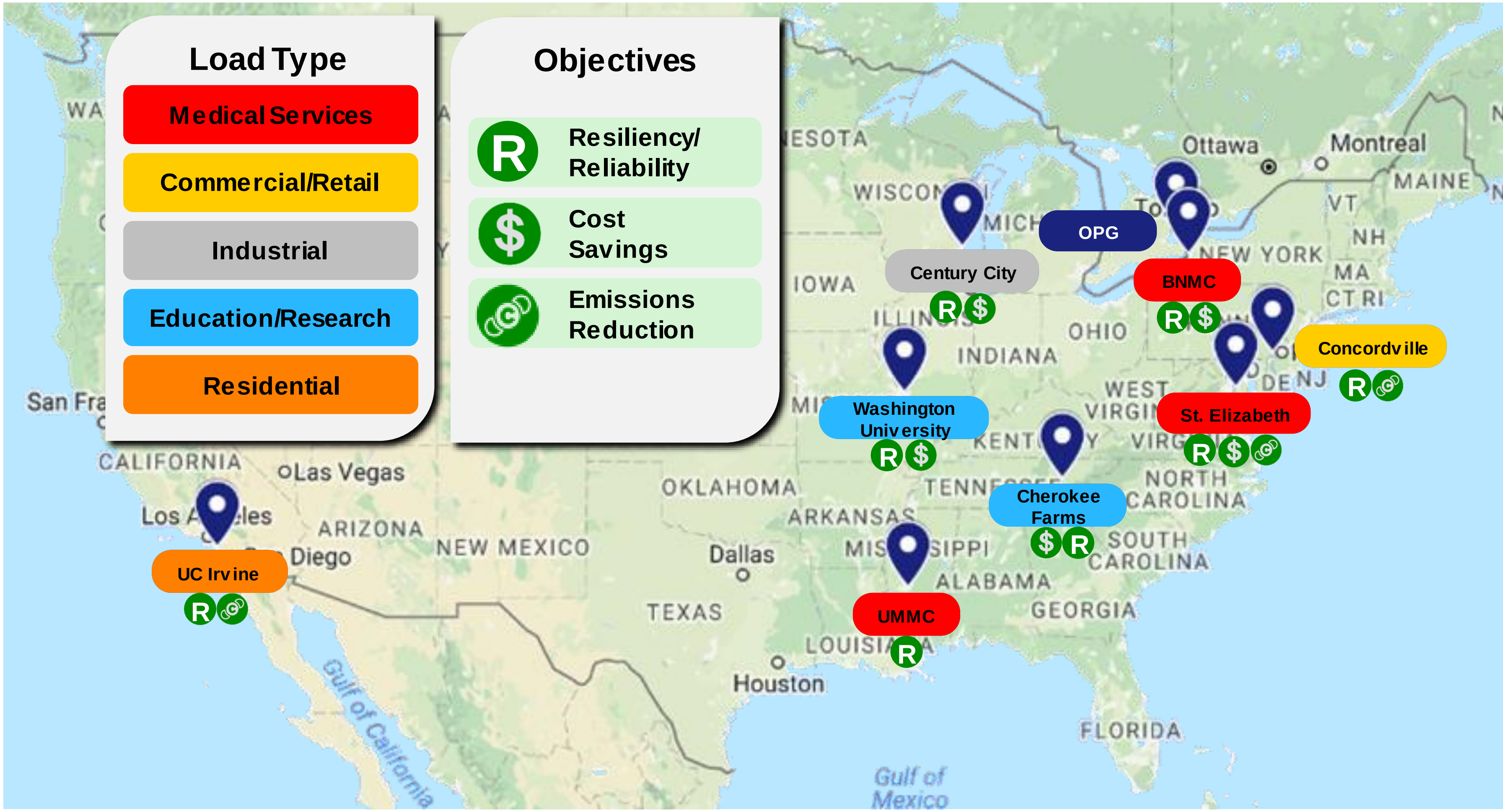

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EPRI Microgrid Feasibility Projects

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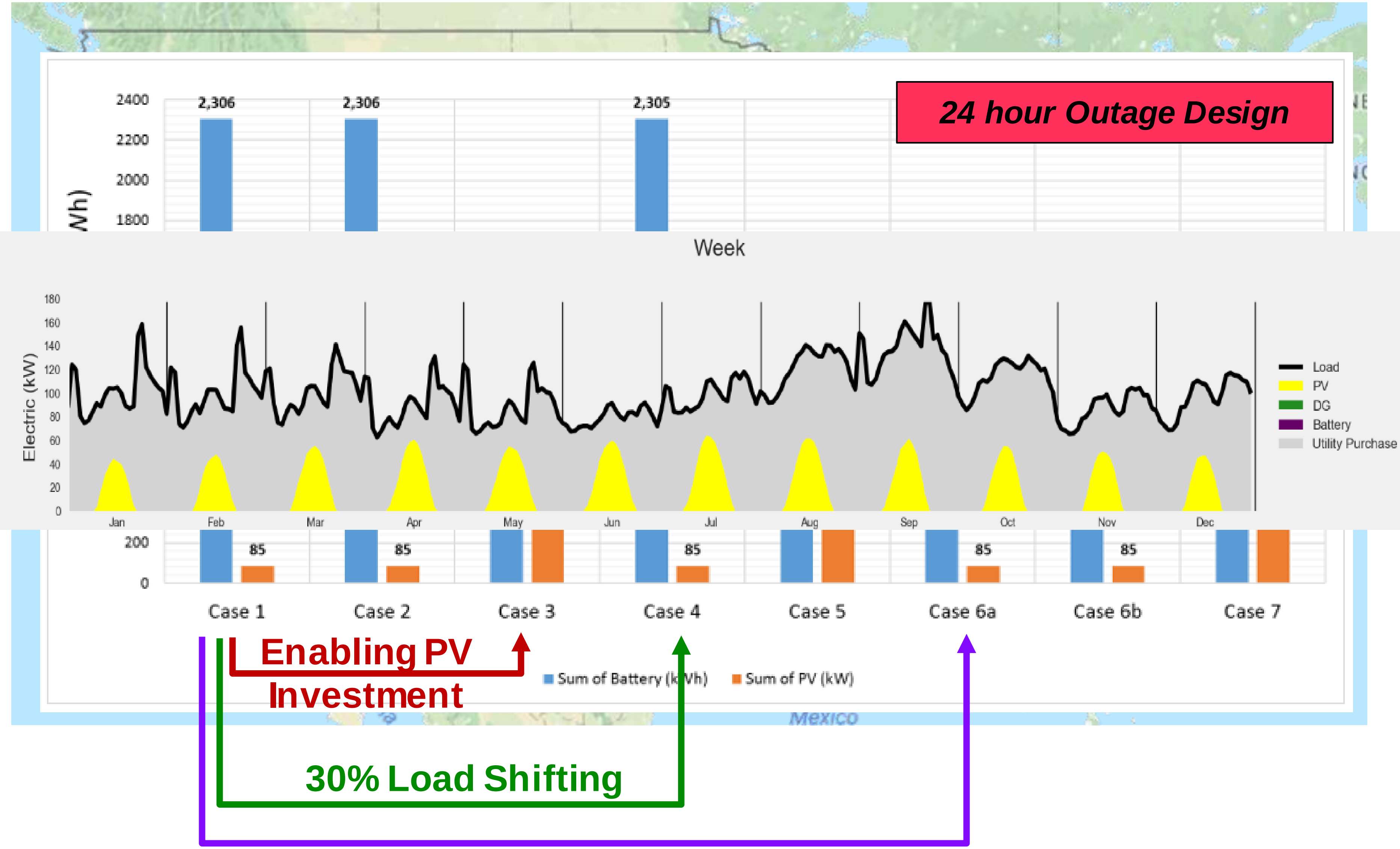

30% Load Curtailment

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EPRI Microgrid Feasibility Projects

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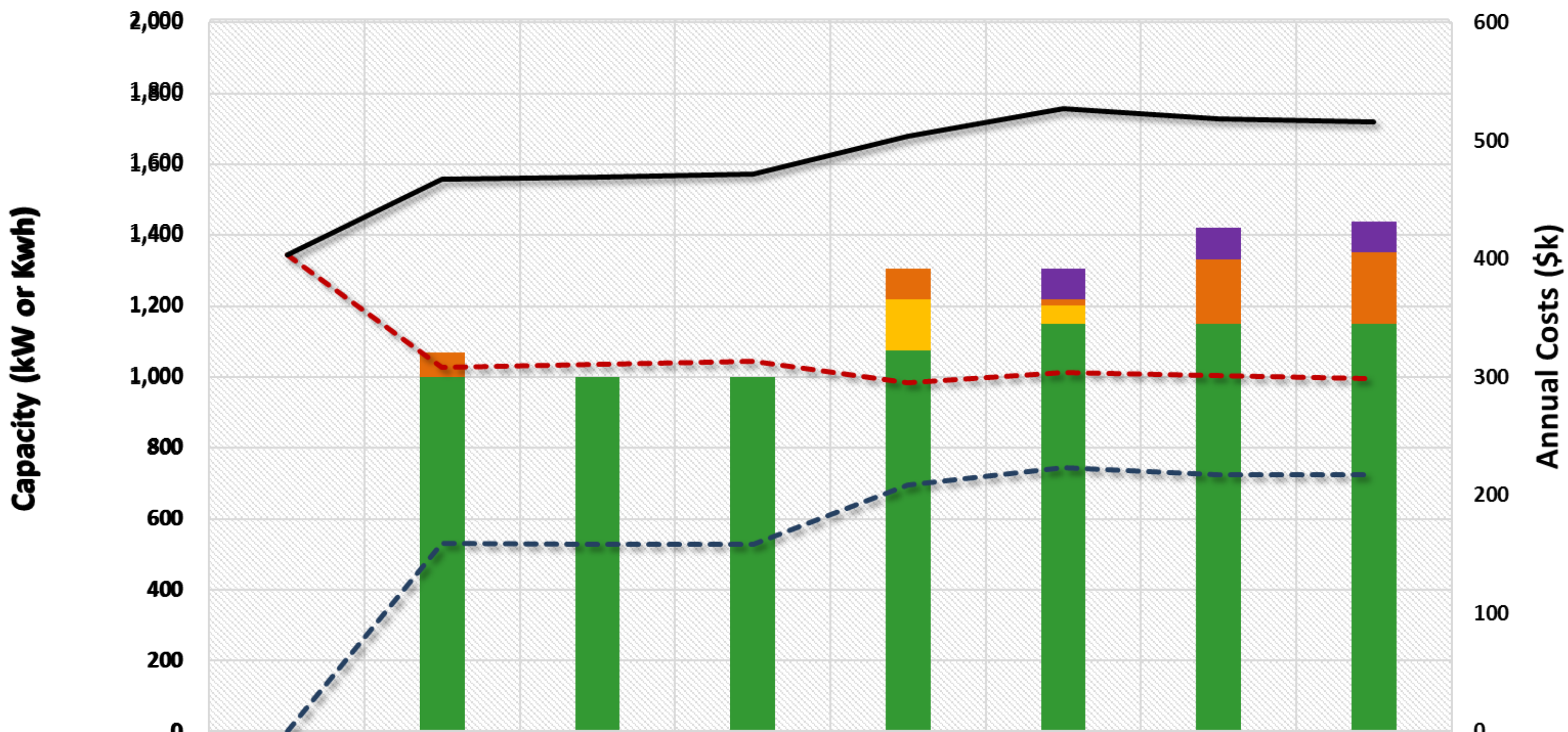
Century City Business Park
Outage Duration vs Capacity & Cost



Outage Duration	0	1	3	6	12	24	72	168
Abs Chiller Capacity (kW)	0	0	0	0	0	0	0	0
ES Capacity (kWh)	0	0	0	0	0	85	88	88
Thermal Storage Capacity (kWh)	0	70	0	0	86	19	182	201
PV Capacity (kW)	0	0	0	0	144	51	0	0
Generator Capacity (kW)	0	1,000	1,000	1,000	1,075	1,150	1,150	1,150
Annual Operating Cost ($)	403,601	308,086	311,003	313,513	295,146	304,196	301,434	298,749
Total Annualized Capital Cost ($)	0	159,231	158,427	158,427	208,910	223,010	217,064	217,274
Total Annual Costs ($)	403,601	467,316	469,430	471,941	504,056	527,206	518,498	516,023

What drives Microgrid DER Size & Type?

- **Outage Duration**

- **Climate & Load**
  - Thermal load requirements

- **Rates & Rate Structure**
  - Energy/Capacity demand
  - Flat, TOU, real-time
  - Demand charge

- **Existing DER assets & Infrastructure**
  - Renewables based microgrid
  - Gas infrastructure resiliency

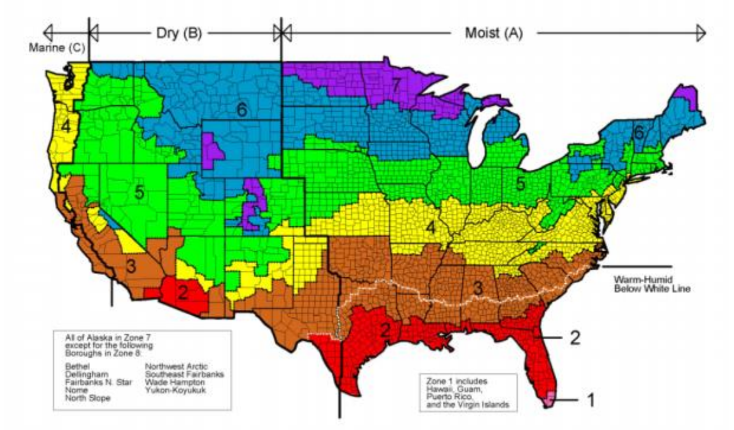
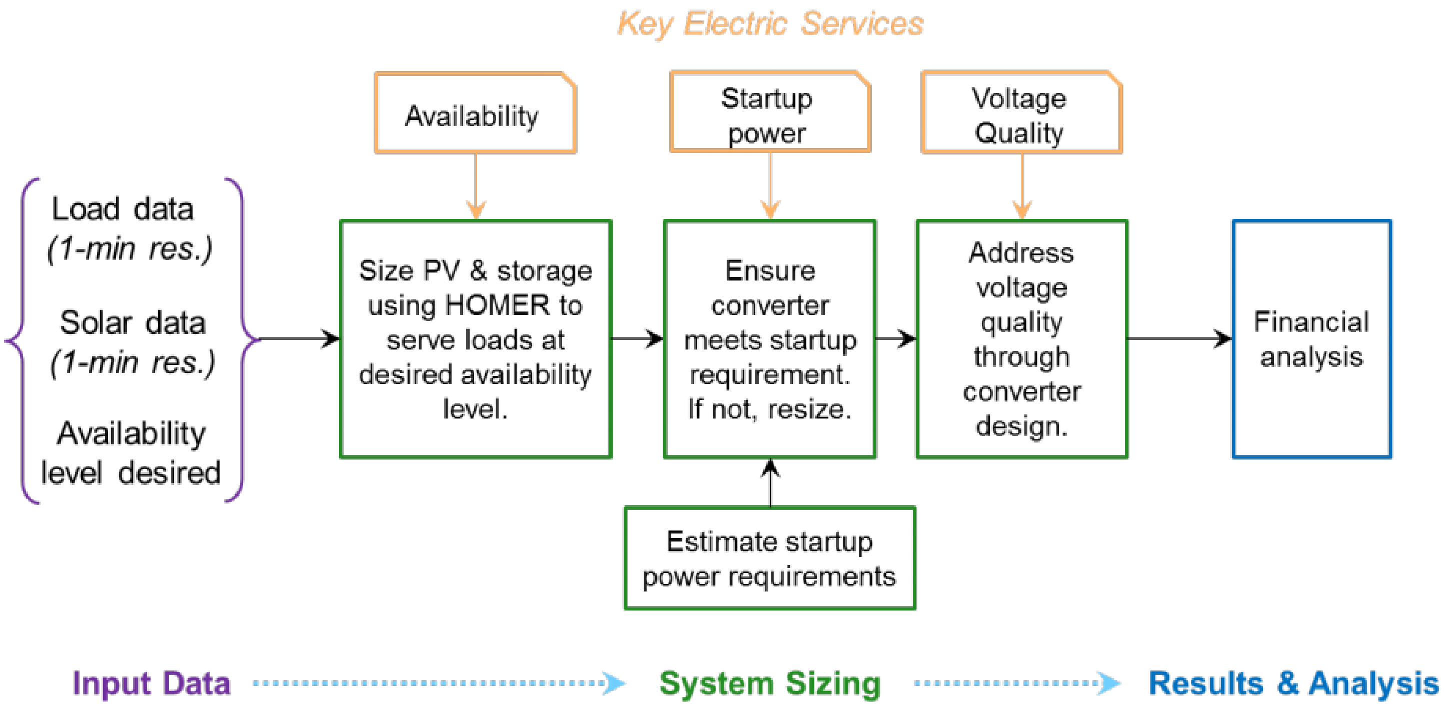
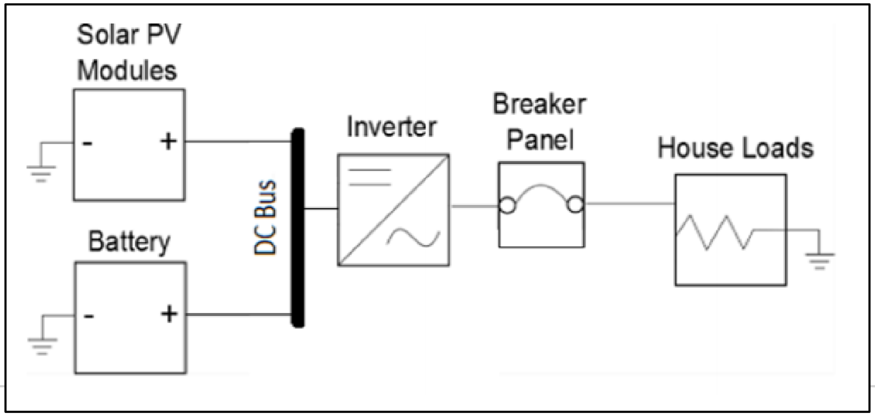


Figure 1 Climate zone classification
(Credit: Briggs et al. [2003]; DOE [2005])

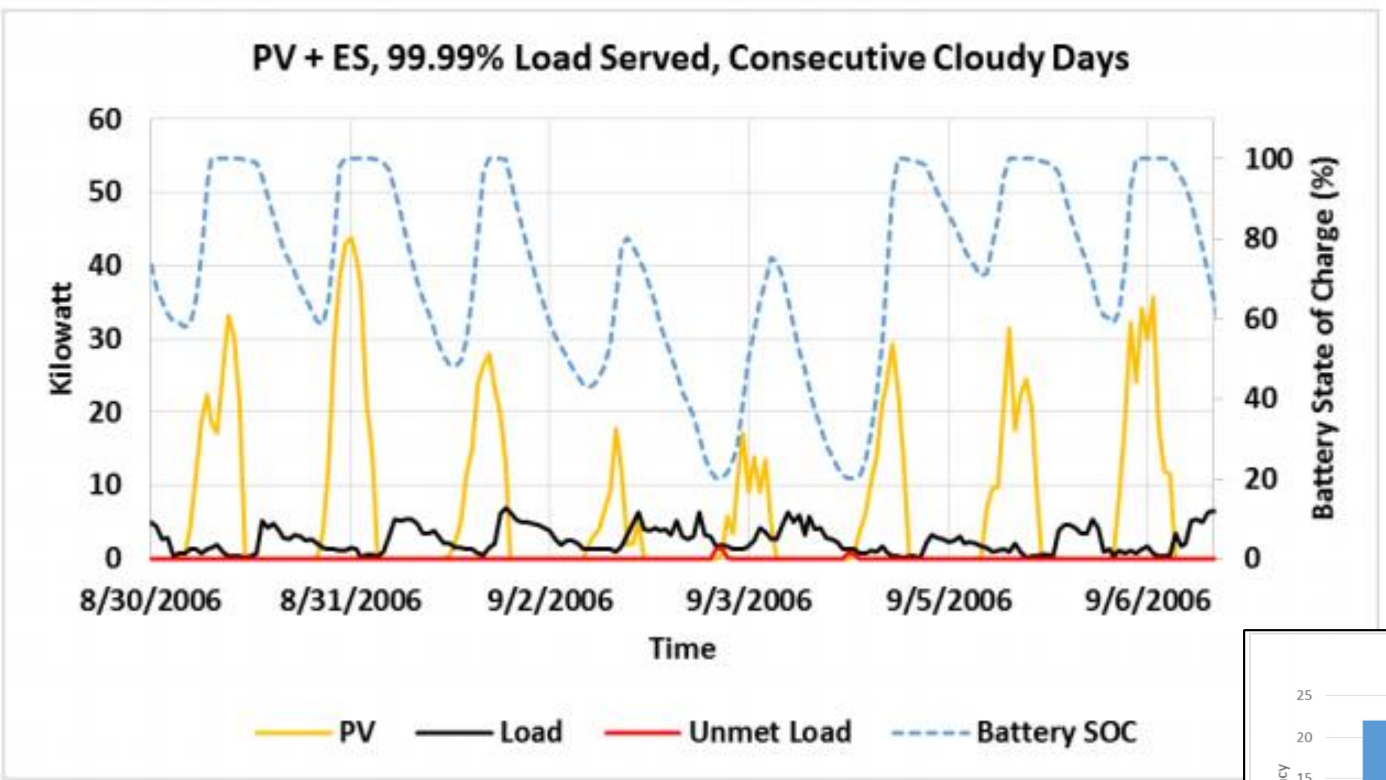
Study Results
Off-Grid vs On-Grid Residential PV + ES Systems

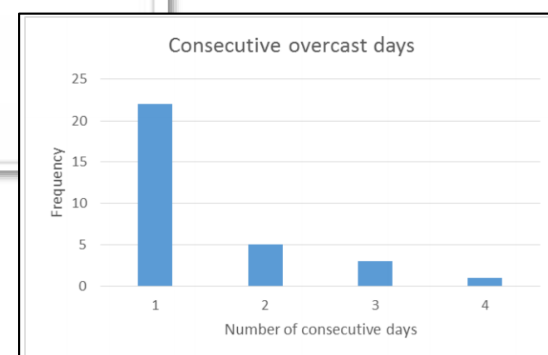




Study Results
Off-Grid vs On-Grid Residential PV + ES Systems

- Overall system size driven by consecutive cloudy days





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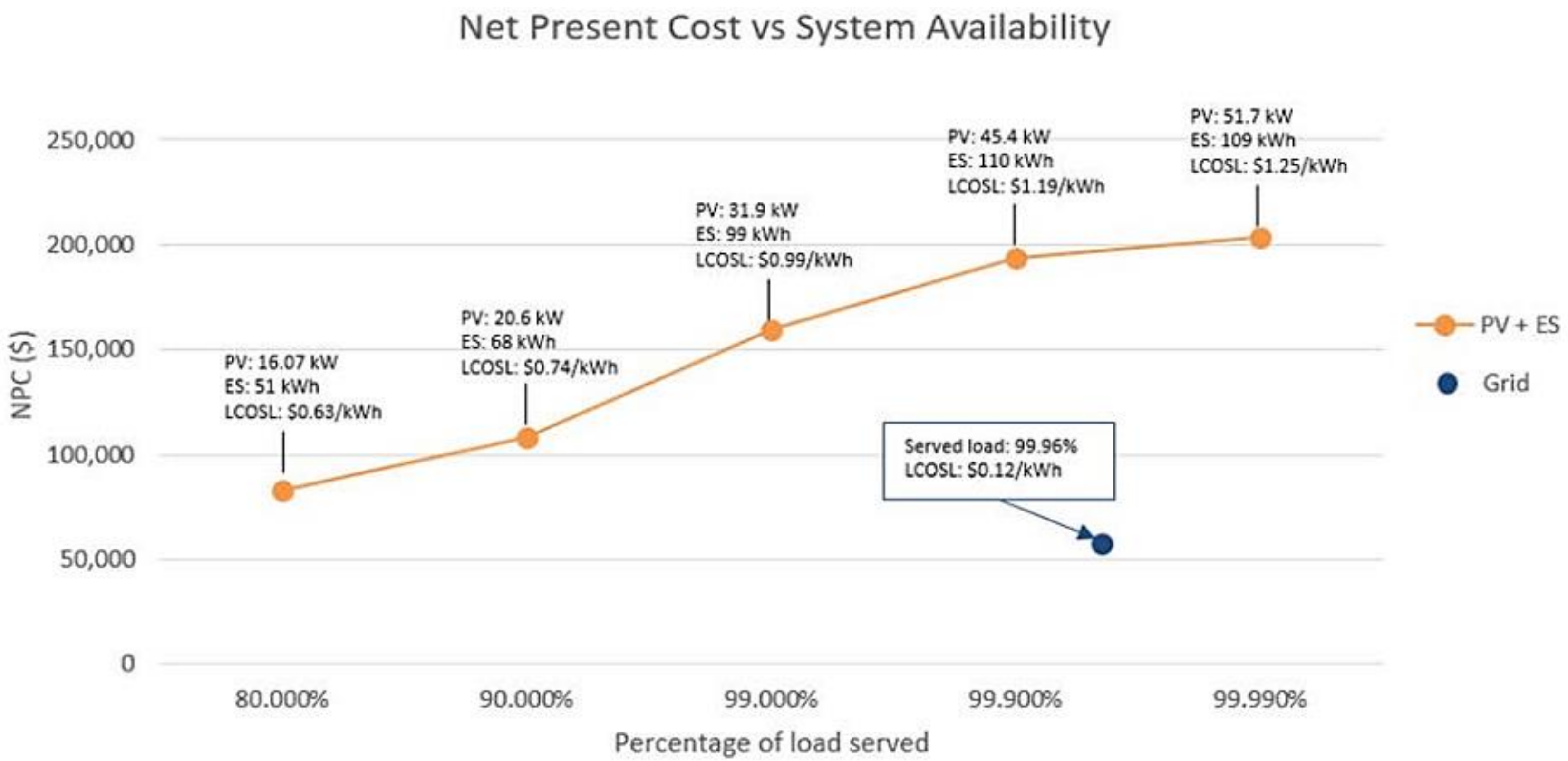
Study Results
Off-Grid vs On-Grid Residential PV + ES Systems



- To achieve the same level of reliability as the typical grid (~99.96%)
- Off-grid PV + Battery system would require:

PV = 45-52 kW, ES = 109-110 kWh

- **Off-Grid System ~10x more expensive** (0.12 vs 1.20 $/kWh)

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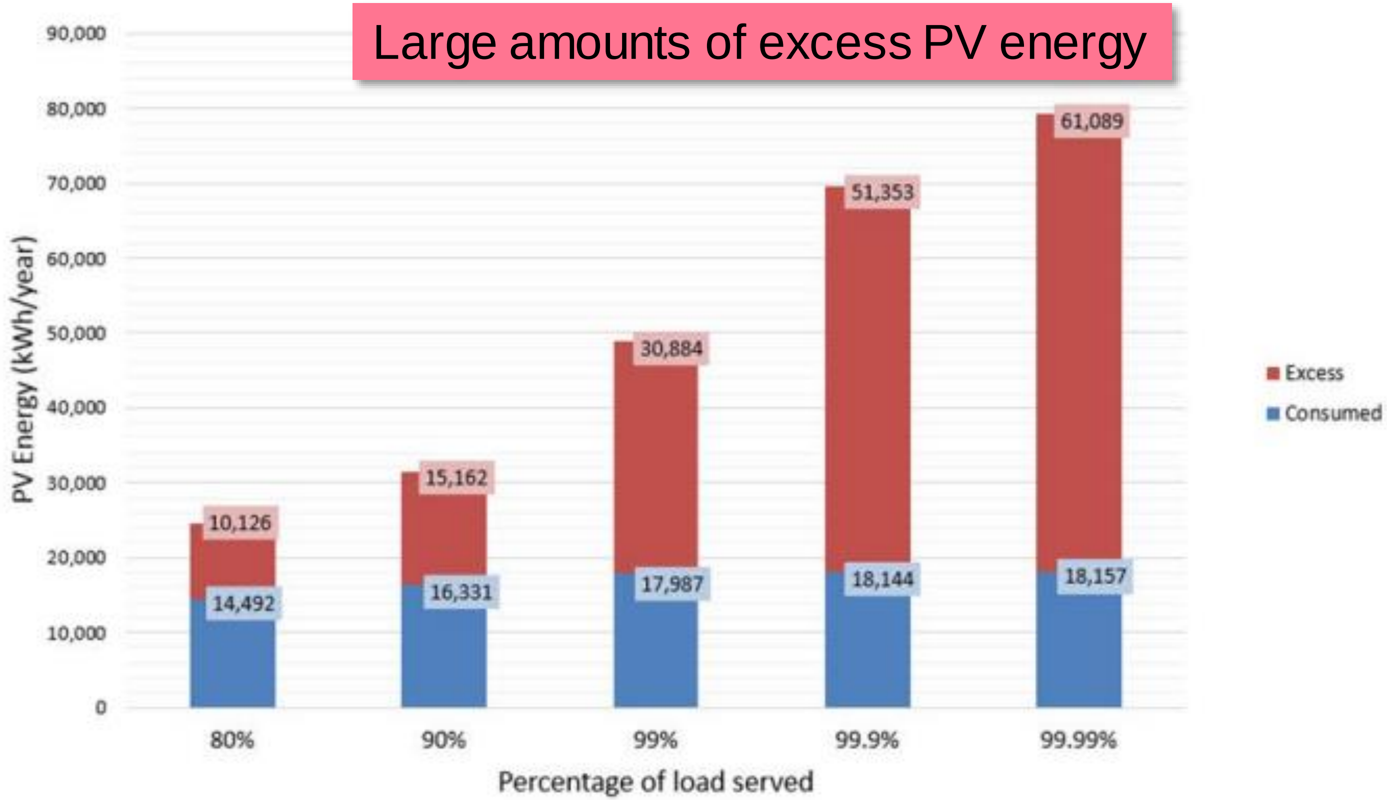
Study Results
Off-Grid vs On-Grid Residential PV + ES Systems



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Study Results
Off-Grid vs On-Grid Residential PV + ES Systems

- **Video**: https://www.youtube.com/watch?v=2P9EHWg850w
- **Whitepaper**: www.epri.com (*ID: 000000003002009150)*

Lessons Learned

- **Objectives**
  – Needs to be defined upfront otherwise # of scenarios can become unmanageable
- **Analysis tools**
  – Which model to use is dependent on situation, no model is catch all
  – Most problems have specific constraints/parameters that requires tweaking models
  – Trade-off between time (i.e. simplified assumptions) and accuracy (e.g. requires lots of data)
- **Data**
  – Missing or unavailable data
  – Available data – understanding data and formatting are non-trivial
- **Modeling**
  – Model formulation requires engineering experience and judgement
  – Design problem is often complex and with many unknowns, requiring many iterations/sensitivities
  – Non-linear nature of most problems are computationally expensive
- **Cost/Benefit Analysis**
  – Value of Resiliency methodology/framework/studies are lacking
  – Requires defining perspectives, ownership, etc.
  – Definitive cost/benefit answers are rare due to future unknowns

Together…Shaping the Future of Electricity