Geospatial Combined Heat and Power Opportunity Mapping and Smart Power Electronics Potential for Smart Grid Integration

AMO Strategic Analysis (StA) Team

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Overview

- The multi-laboratory (Argonne National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, and Oak Ridge National Laboratory) AMO Strategic Analysis (StA) Team provides independent, objective, and credible information to inform decision-making.
- The StA team submitted 6 posters for this year's Program Review; the research topics are ongoing and do not follow the typical poster format
- This poster, **"Geospatial Combined Heat and Power Opportunity Mapping and Smart Power Electronics Potential for Smart Grid Integration"** includes information on three example projects in Combined Heat and Power (CHP):
    1. Geospatial CHP Potential Analysis Using the Industrial Geospatial Analysis Tool for Energy Evaluations (IGATE-E) CHP Tool,
    2. Modeling the Impact of Advanced CHP on the Future Electric Grid and
    3. Power Electronics Potential for Grid Integration

Geospatial CHP Potential Analysis Using the Industrial Geospatial Analysis Tool for Energy Evaluations (IGATE-E) CHP Tool

- IGATE-E tool:
  - Evaluates CHP feasibility (using statistical and engineering models) at the manufacturing plant level
  - Projects CHP penetration potential & energy impacts across U.S. manufacturing sector
  - Able to aggregate analysis results by zip code, state, and national level by industrial subsector (NAICS/SIC)
  - Has evaluated CHP potential for other sectors (e.g., commercial buildings (hospitals))
- Expanding to commercial and institutional buildings will be made available to the public through a web-based geospatial visualization tool without any underlying proprietary data used for regression analysis

Modeling the Impact of Advanced CHP on the Future Electric Grid: California Market

Updated Analysis Nearly Complete

<u>Objective</u>: Estimate value of added flexible CHP at California **industrial and institutional sites** due to increased revenue from grid services and lower CHP costs.

<u>Three scenarios modeled</u> for adding flexible CHP systems to CA grid in 2024

- ***Baseline:*** 33% renewables on grid, 3,385 MW existing CHP for site loads
- ***Traditional CHP:*** Serves site loads + 10% capacity for grid services <500 hr/yr
- ***Advanced CHP:*** Serves site loads + large flexible capacity for grid services
- ***Combined Scenario:*** Selects most profitable option (between traditional and advanced) at each site

<u>Key Preliminary Findings</u>:

- ***Reduced Grid Operating Costs***:

  All scenarios reduce grid operations by $1 Billion or more
- ***Increased Generation Capacity***: Alleviates need for new centralized power plants.
- ***Lowers Site Energy Costs and Provides Additional Revenue Stream***:

  Sites average additional revenue of receive $40,000 - $780,000/ megawatt (MW) surplus capacity
- ***Reduction in Grid Stress:***

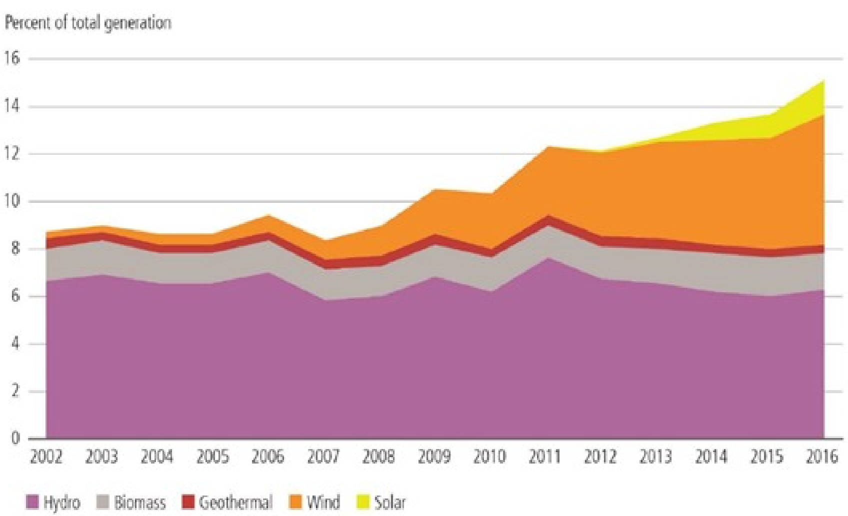
  Eliminates hours when reserves may not be met or transmission ratings exceeded

Power Electronics Potential for Grid Integration

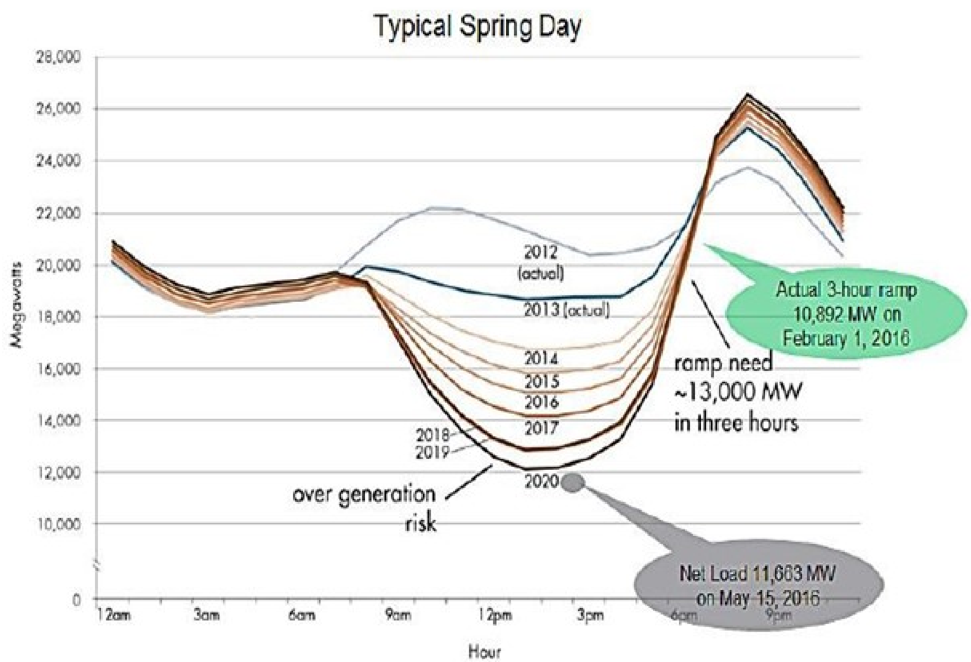
- Study analyzing smart grid interconnection technology for industrial CHP facilities
- **Goals:** Examine cost (including equipment, installation, and other hidden costs), grid integration requirements, equipment, manufacturers, and suppliers for distributed energy resources (DERs), and any barriers in connecting DERs to the grid
- Included in the study (and reflected on the poster):
  - Typical interconnection equipment required for the CHP prime movers (also referred to as DERs); depending on the CHP configuration, the level of interconnection equipment needed will vary greatly, based on the CHP system size, and the state guidelines and standards.
  - Summary of grid integration equipment cost (includes estimates for a 2,000 kilowatt (kW) CHP plant)
  - Information on regulatory barriers, standards, and guidelines on capacity limits on DER

Two Key Issues and Challenges as Grid Resources Evolve

- Non-dispatchable renewables (particularly wind and solar) are increasing rapidly on the U.S. grid (bottom left figure)
- This rapid increase exacerbates load changes at peak demand periods requiring additional fast-reacting grid resources (example for California show on bottom right)



Renewable Generation as a Percentage of Total U.S. Electricity Generation



California's "Duck Curve"

Grid Modernization Opportunity: Flexible Industrial CHP Systems

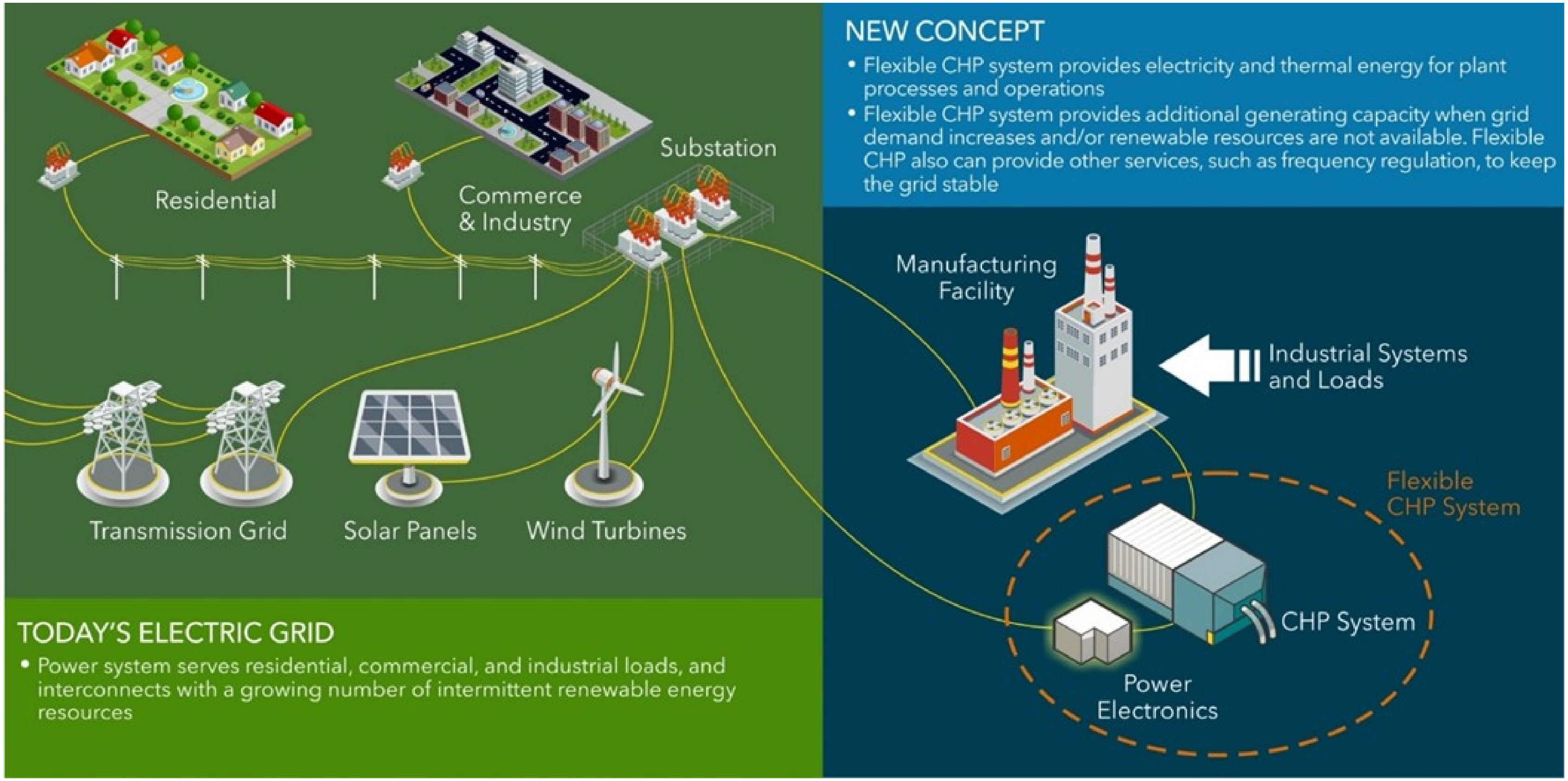
Market Space

- **Large industry:** CHP is now largely saturated (< 20 megawatt (MW) electricity)
  - Recently provide demand reduction to the grid
  - Engineering and operating staff have the needed technical expertise to support cost-effective CHP system installation/operation
  - Considering adding capacity and ancillary services to the grid when needed
- **Small/midsized industrial enterprises (SMEs)**: Represent an important area of "white space" due to substantial electric load (1-20 MW) and familiarity with self-generation
  - **Opportunity:** Electric suppliers in select markets are looking at SME generation for capacity and ancillary services due to variable generation increases
  - **Limitations:** Technology barriers with available technologies and regulatory and business barriers
  - **Needs:** Additional technologies integrate generation resources to the grid

Opportunity

- Traditional CHP systems are sized to match host facility electricity load, yet do not typically meet the thermal needs of the host
- An "oversized" CHP system could generate additional revenue for the host site by providing additional electricity to the grid and other services

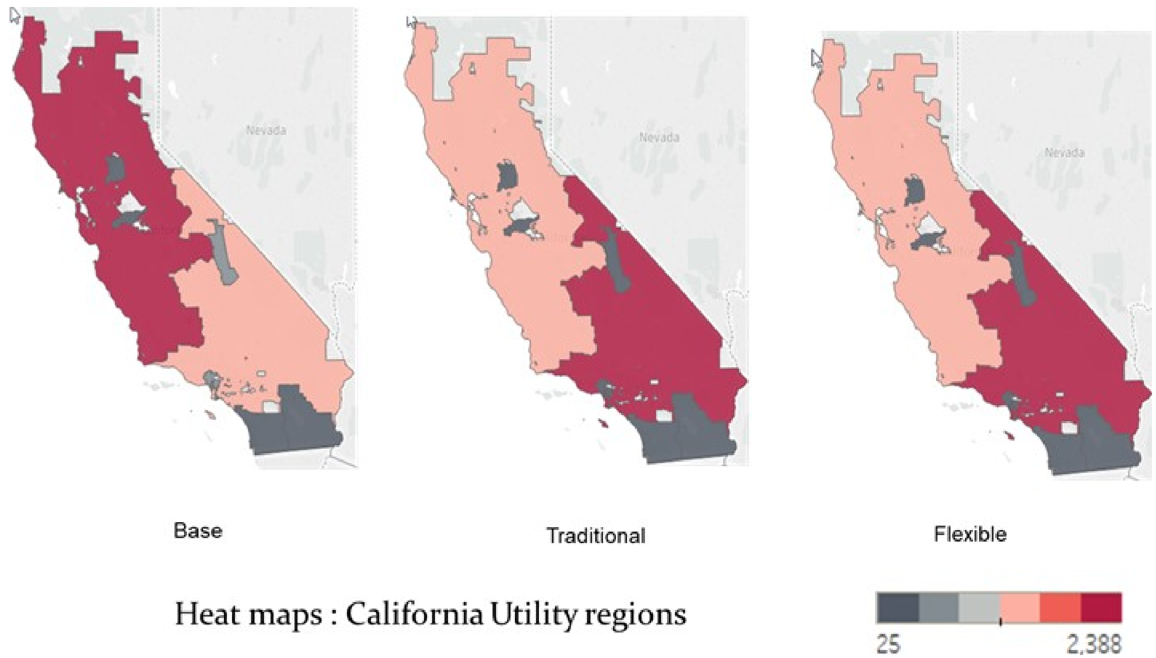
Flexible CHP Systems: Concept Basics



- Concept would improve grid reliability and resiliency & provide economic benefits to manufacturing facilities
- Technology advancements are needed to bring the concept to fruition

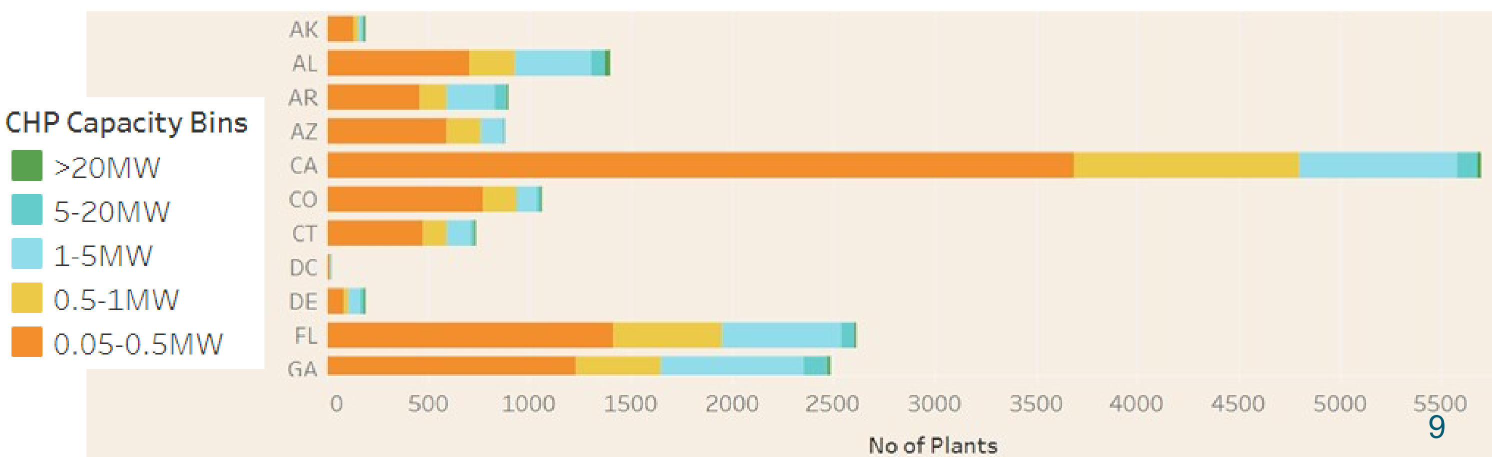
Industrial Geospatial Analysis Tool for Energy Evaluations (IGATE-E) CHP Tool Example: CA CHP Potential impact of flexible industrial sites

- Tool uses data on manufacturing sites in California. Bottom figure shows the largest potential for CA
- Three scenarios assumed for CHP support of the grid
  - ***Baseline:*** Existing 3,385 MW CHP capacity *(left figure)*
  - ***Traditional CHP:*** Baseline CHP capacity plus 4,081 MW of CHP installed (3,722 MW Baseload and 358 MW Surplus) *(middle figure)*
  - ***Advanced CHP:*** Baseline CHP capacity plus 5,046 MW of CHP installed (3,722 MW Baseload and 1,324 MW Surplus)
  - **Combined CHP:** Baseline CHP capacity plus 4,722 MW of CHP installed (3,722 MW Baseload and 1,000 MW Surplus)

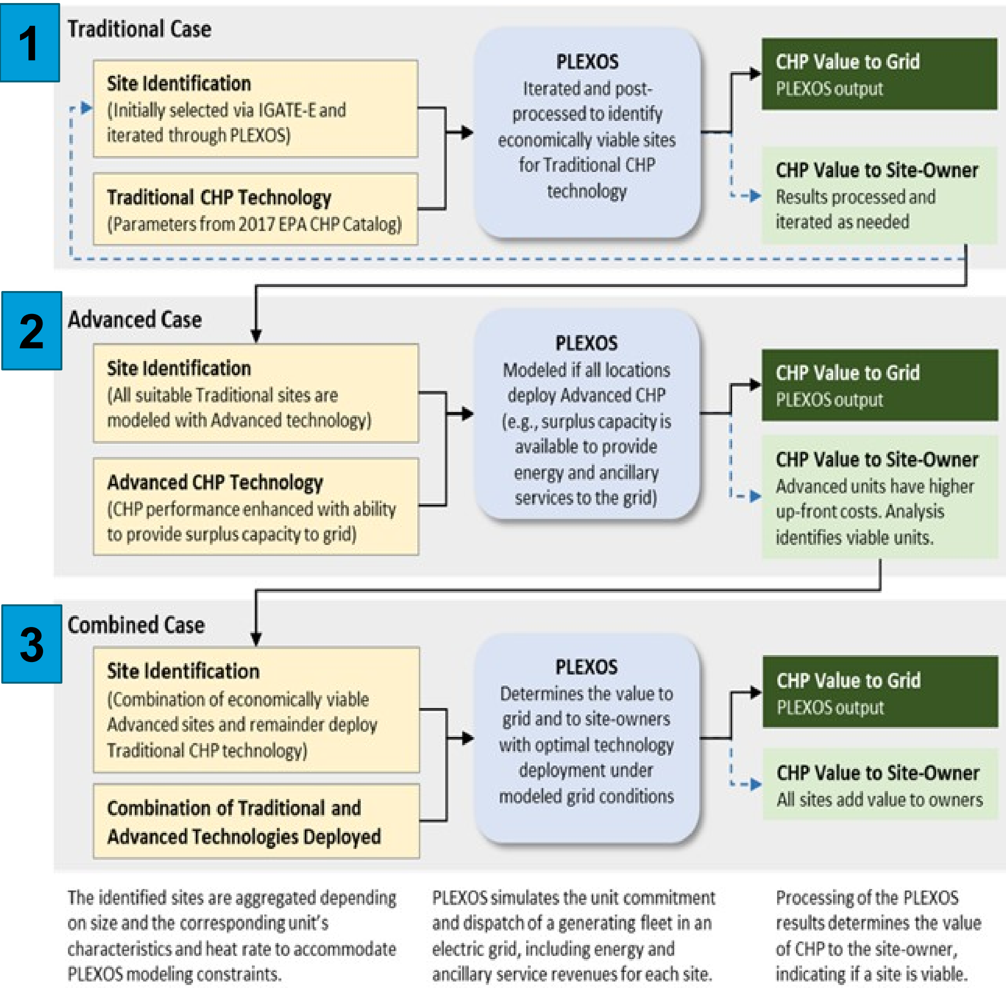


Heat maps : California Utility regions

CHP Estimated Potential by Region/State/Industry Type



High Level Modeling flow for the CHP Deployment Scenarios



**Sites identified using IGATE-E to identify those as being cost-effective using traditional CHP technology*

Case	Description
Base Scenario	California (CA) grid if no additional CHP is added
Traditional 1	Grid modeled if all locations where Traditional CHP is cost-effective deploy Traditional CHP • Traditional units: constrained to operate <500 hours per year
Advanced 2	Grid modeled if all locations where Traditional CHP is cost-effective deploy Advanced CHP • Advanced CHP units come with additional up-front capital costs • Scenario determines the value each site-owner would obtain from deploying Advanced CHP units & associated return on investment • Results: suggest an economically viable set of Advanced CHP deployments that could be modeled with Traditional CHP units at remaining sites • Advanced CHP units may become more economically viable with increased research and development to lower costs, or the addition of capacity payments in CA markets
Combined 3	Grid modeled if economically viable Advanced CHP units are deployed and the remaining suitable sites deploy Traditional CHP

CHP Capacity by Scenarios for California

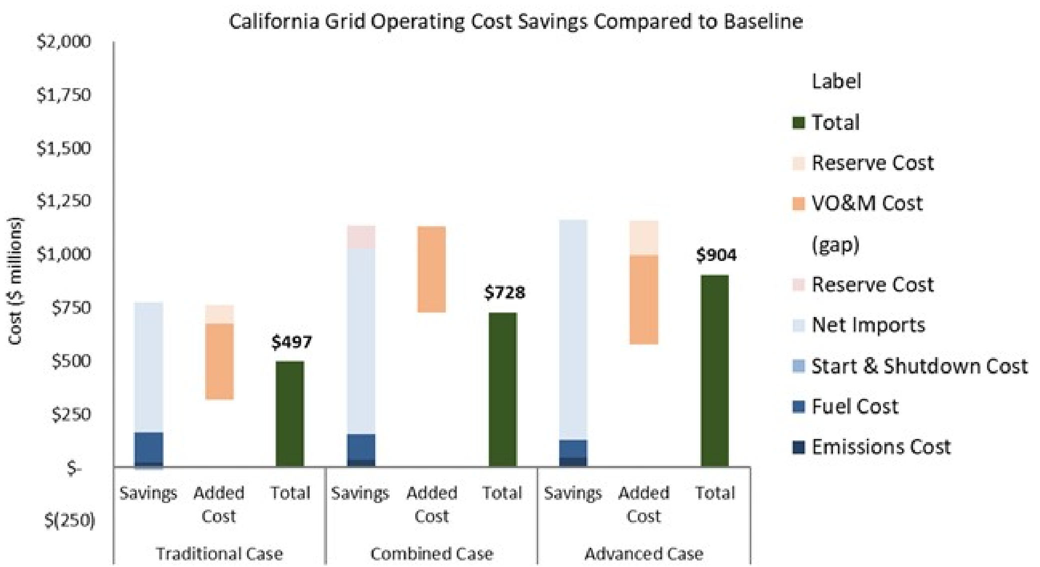
Scenario and CHP unit size grouping	Baseload (megawatts)		Surplus (megawatts)		Total (megawatts)
	Heat Rate	Capacity	Heat Rate	Capacity	Capacity
Base		**1,855**		**1,530**	**3,385**
Traditional		**3,722**		**358**	**4,081**
5+ MW	5,300	1,655	6,040	165	1,820
1-5 MW	5,150	1,787	6,080	172	1,959
Under 1 MW	5,400	281	6,815	21	302
Advanced		**3,722**		**1,324**	**5,046**
5+ MW	5,610	1,655	4,900	808	2,463
2-5 MW	5,130	1,032	6,540	258	1,290
Under 2 MW	5,680	1,035	6,800	259	1,294
Combined		**3,722**		**1,000**	**4,722**
5+ MW (Advanced - HR4920)	5,610	1,642	4,900	799	2,441
5+ MW (Traditional-Recip)	5,500	13	6,040	1	14
1-5 MW (Traditional-Recip)	5,150	1,787	6,080	179	1,965
Under 1 MW (Traditional-Recip)	5,400	209	6,815	21	230
0-2 MW (Traditional-Microturbine)	6,940	72	n/a	0	72

Value to the Grid: 8 Different Utility Regions Modelled in CA

Revenue (thousands)			
Case	Energy	Ancillary Service	Total
Traditional (total)	$1,182	$12,820	$14,002
5+ MW (HR 6040)	$1,059	$9,336	$10,394
1-5 MW (HR 6080)	$121	$3,175	$3,296
Under 1 MW (HR 6815)	$2	$309	$312
Advanced (total)	$759,303	$7,748	$767,051
5+ MW (HR 4900)	$759,144	$3,707	$762,851
2-5 MW (HR 6540)	$122	$2,006	$2,128
Under 2 MW (HR 6800)	$37	$2,035	$2,073
Combined (total)	$763,828	$16,934	$780,762
5+ MW (Advanced - HR4900)	$763,737	$14,805	$778,543
5+ MW (Traditional-Recip HR 6040)	$4	$0	$4
1-5 MW (Traditional-Recip HR 6080)	$83	$1,922	$2,006
Under 1 MW (Traditional-Recip HR 6815)	$3	$206	$209
0-2 MW (Traditional-Microturbine)	n/a	n/a	n/a

Region	PLEXOS* Code	Name
IID	IID	Imperial Irrigation District
TIDC	TIDC	Turlock Irrigation District
SMUD	BANC	Sacramento Municipal Utility District
SCE	CISC	Southern California Edison
SDGE	CISD	San Diego Gas and Electric
LDWP	LDWP	Los Angeles Department of Water and Power
PG&E_BAY	CIPB	Pacific Gas & Electric - Bay
PG&E_VLY	CIPV	Pacific Gas & Electric – Valley

* Integrated energy modeling software

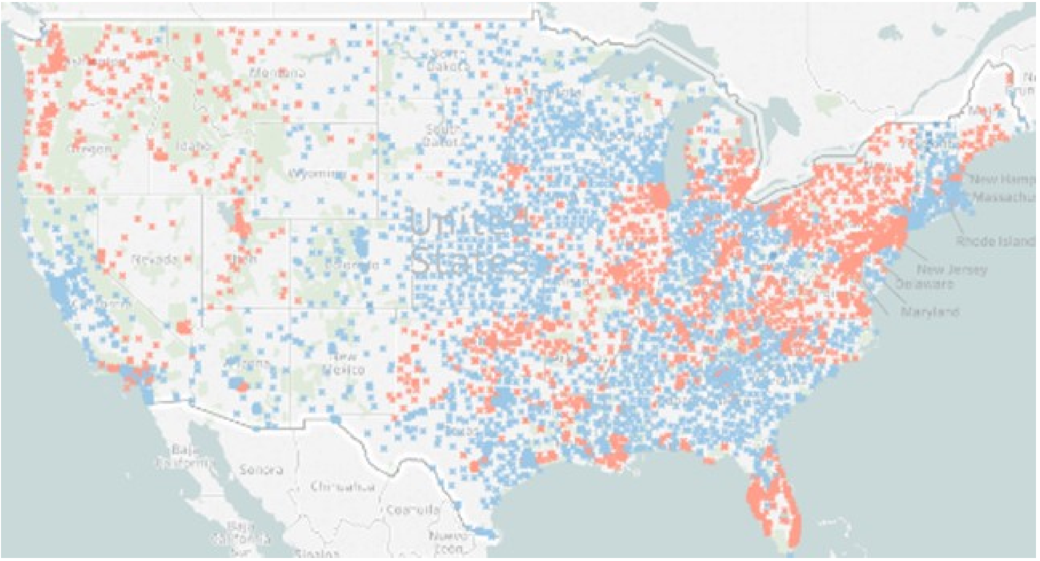


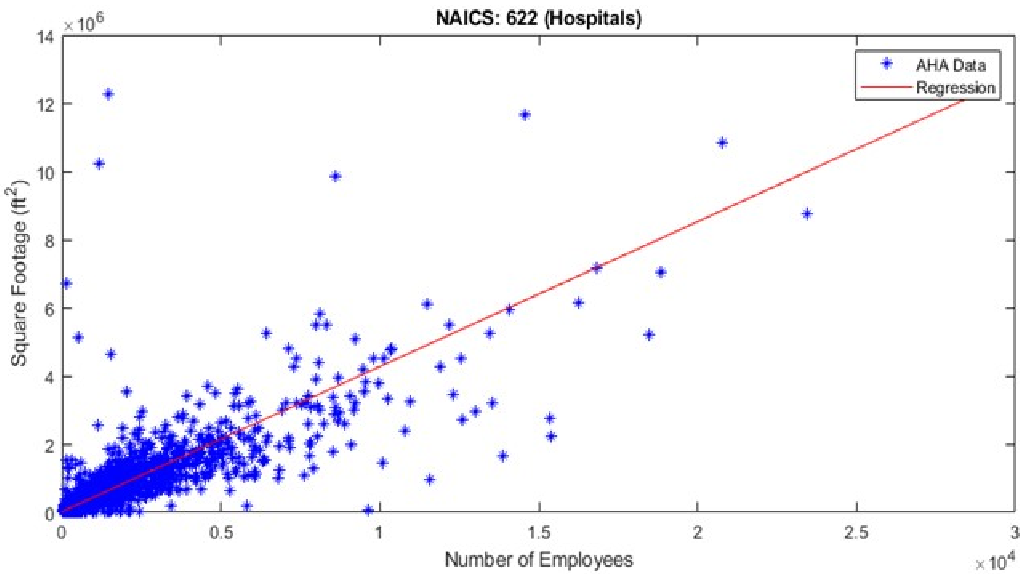
High-grid-stress hours by region

Region	Baseline (hours)
PG&E Bay	22
PG&E Valley	22
SCE	11
SDG&E	10
BANC	23
IID	10
LDWP	4
TIDC	23
Total	125

Grid Stress hours reduced to zero for all three cases that were modeled

IGATE-E Methodology Expanded to Commercial Buildings (e.g. Hospitals)

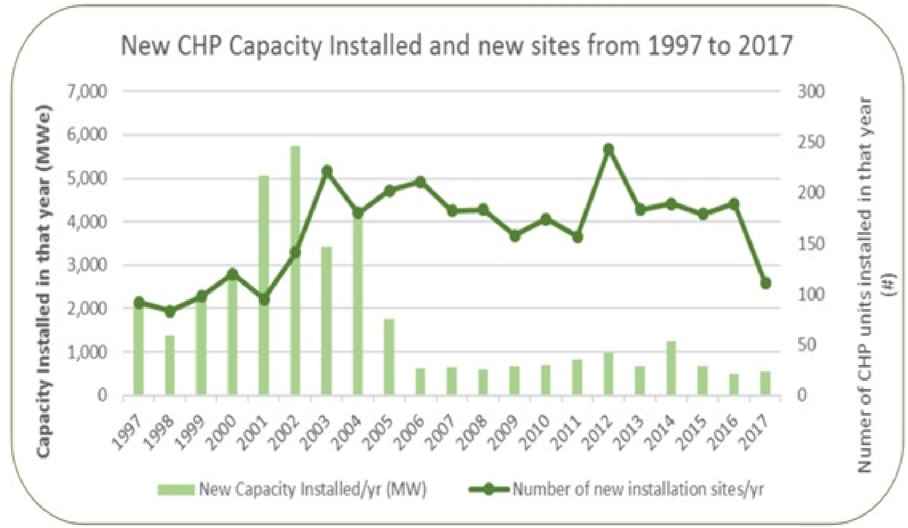


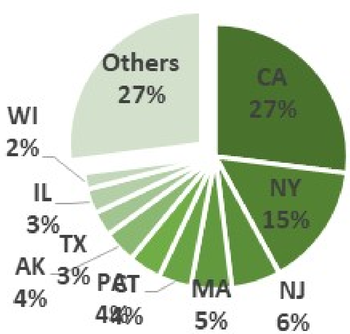


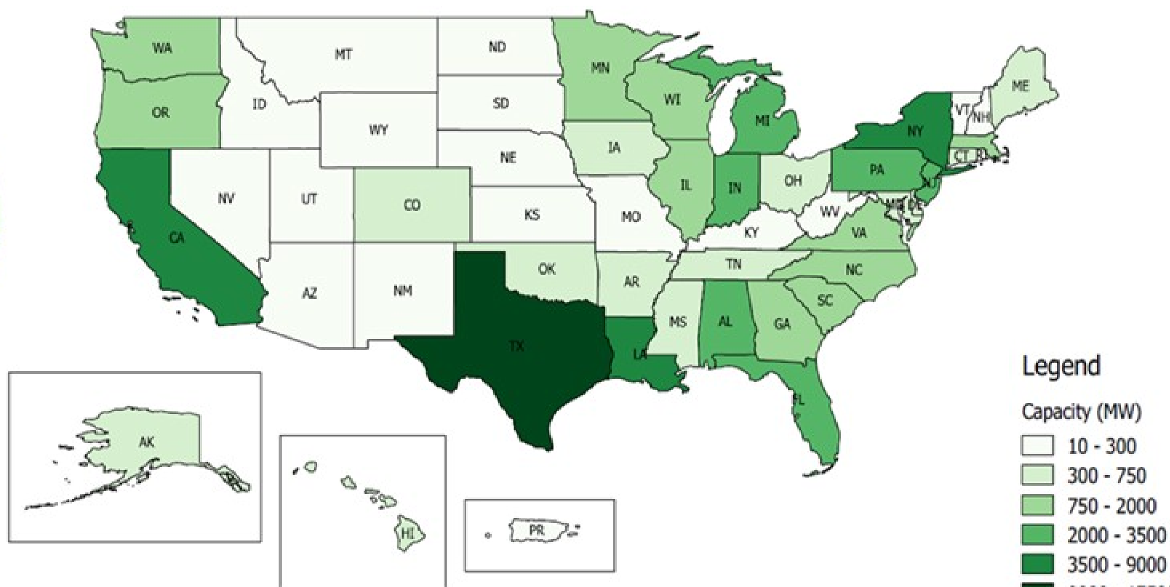
1. Regressions of energy per sq. ft. vs. # of employees developed using American Hospital Association (AHA) database (private) (*see bottom figure)*
2. Energy consumption estimated for each location based on energy intensity estimates from the 2012 Commercial Buildings Energy Consumption Survey (CBECS)
3. Load factors and thermal to electric ratios estimated by climate zone using EnergyPlus building energy modeling (using the DOE Commercial Prototype Building models)
4. CHP potential evaluated at the facility-level using methodology developed by CHP Technical Assistance Partnerships (CHP TAPs)

Overview of the U.S. CHP market

- December 2017: U.S. installed CHP capacity of approximately 81.3 GWe (DOE EERE 2017)
    - Represents nearly 8% of the total U.S. generation capacity (Global CCS Institute 2018)
    - Top 10 states comprise 73% of installed U.S. CHP sites *(see bottom left)*
- 2008-2017: Average new CHP installed capacity approximately 741-MWe/yr; 177 sites per year installing CHP *(see right)*





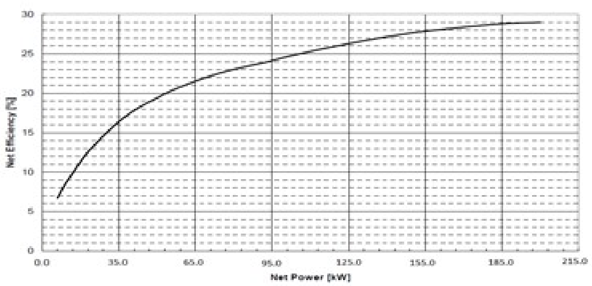


CHP installed capacity distribution across the country (DOE EERE 2017)

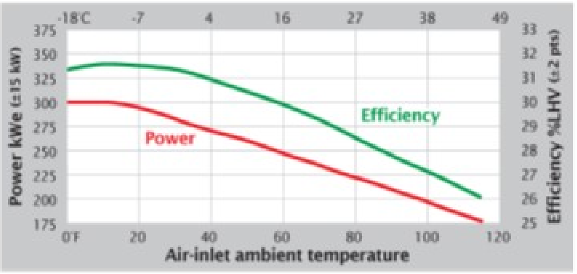
Distributed Energy Resources (DER) Capable Modular Microturbines

Distributed Energy resources (DERs): Variety of small, modular electricity-generating or storage technologies located close to the load they serve (Friedman 2002)

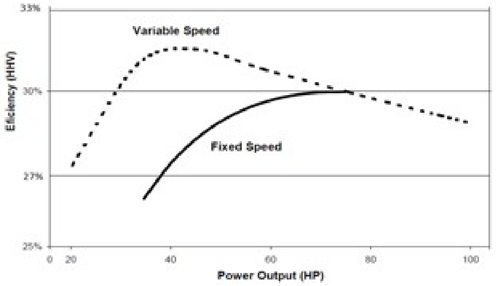
Capstone C200S
Capacity: 200kW



FlexEnergy MT/GT250
Capacity: 250kW



TecoGen InVerde INV100 e+
Capacity: 100kW



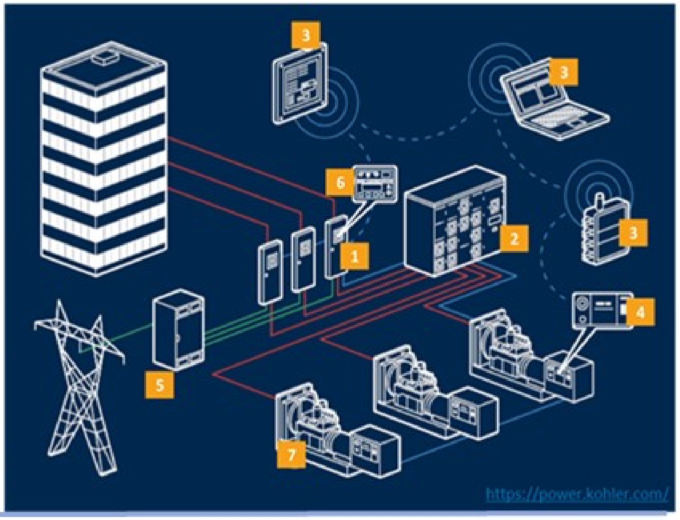
Cost estimates for DER microturbines

Microturbine	Capstone C30*	Capstone C200 *	Capstone 200s**	FlexEnergy MT250**	FlexEnergy MT330*	TecoGen InVerde INV100 e+**
Gen Set Package	$53,100	$359,300	$402,000	$441,200	$566,400	$165,000
Heat Recovery	$13,500	$0	$70,000	included	included	included
Fuel Gas Compression	$8,700	$42,600	$0	$0	$0	$0
Total Equipment ($)	**$75,300**	**$401,900**	**$472,000**	**$441,200**	**$566,400**	**$165,000**
Unit Cost ($/kW)	**$2,689**	**$2,010**	**$2,360**	**$1,765**	**$1,716**	**$1,650**
Controller Cost	N/A	N/A	$50,000	N/A	N/A	N/A
Installation Cost	$45,100	$196,600	$167,500	$167,500	$167,500	$65,000
Total Installed Cost ($)	**$120,400**	**$598,500**	**$689,500**	**$608,700**	**$733,900**	**$230,000**
Total Unit Cost ($)	**$4,300**	**$2,993**	**$3,448**	**$2,435**	**$2,224**	**$2,300**

CHP Grid Connection Equipment & Cost

- Successful integration of any CHP system into the Area electric power system (EPS) on a dispatchable basis depends on what is installed in the interconnection system
- Estimated cost of interconnection equipment ranges for different system size *(see middle table)*
- Potential costs that could be added for the interconnection of a CHP system to a local grid or EPS operated by a California utility like Pacific Gas and electric (PG&E) or Southern California Edison (SCE) *(see bottom table)*

1	Transfer Switch =	$1,000 -	$14,000
2	Paralleling Switchgear =	$13,000 -	$25,000
3	Dispatch, Communication & Control =	$15,000 -	$80,000
4	DER Controls =	$5,000 -	$26,000
5	Power Conversion =	$40,000 -	$170,000
6	Metering & Monitoring =	$5,000 -	$19,000
UP*	Wiring and Cables =	$15,000 -	$60,000
	TOTAL =	$94,000 -	$ 394,000
7	CHP Unit (Microturbine /Steam Turbine)		



Equipment Description	Cost ($) SCE 2018	Cost ($) PG&E 2018
12/16,000V 480 V transformer	$35k – $173k	$35k – $173k
Overhead to Underground (UG)	$30k – $40k	$30k – $40k
Overhead (OH) Service	$16k + $120/ft	$16k + $120/ft
Underground to Underground	$15k – $36k	$15,000 – $36,000
Metering	$5k – $108k	$5k – $108k
Telemetry	$56k – $140k	$130k – $200k
System Equipment	$12.5k – $274k	$12.5k – $300k

CHP Plant Case Studies: (1) 2,000-kW vs (2) 200-kW

- The results of case 1 (2,000-kW) and case 2 (200-kW) showed:
  - unit cost of 2,000-kW system ***(2,502 $/kW)*** is smaller than the unit of 200-kw system ***(3,920 $/kW)*** *on the grid side*.

- However, the unit cost of interconnection is more expensive ***(1,270 $/kW)*** for a small system when compared to a bigger system (***470 $/kW)*** a big system.

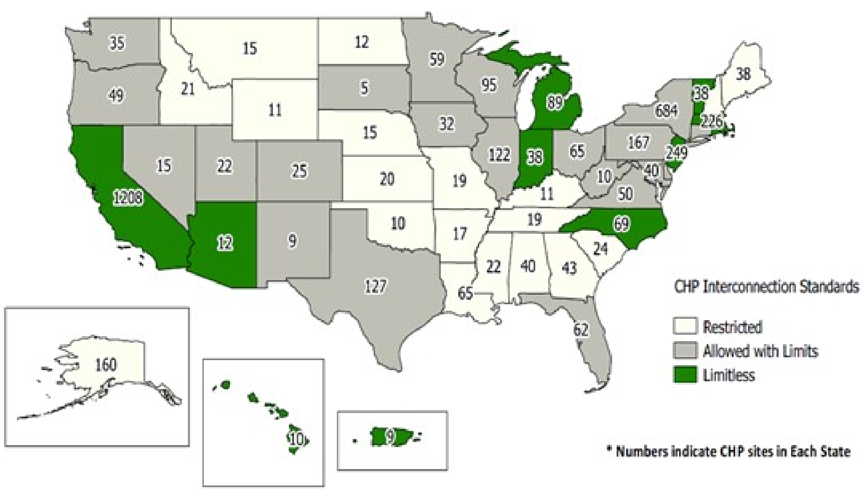
2,000 kW CHP System (case 1)		
Equipment Cost ($/kW)	**$/kW**	**$**
Generator Set Package	$369	$738,000
Heat Recovery	$495	$990,000
Exhaust Gas Treatment	$401	$802,000
Total Equipment Cost ($/kW)	**$1,265**	**$2,530,000**
Labor/Materials	$310	$620,000
Project Management and Construction	$200	$400,000
Engineering and Fees	$126	$252,000
Project Contingency	$68	$136,000
Project Financing	$63	$126,000
System Cost w/o Interconnection ($/kW)	**$2,032**	**$4,064,000**
Interconnection Equipment	$70	$140,000
Distribution Upgrades	$400	$800,000
Total System Cost w/ Interconnection ($/kW)	**$2,502**	**$5,004,000**

200 kW CHP System (case 2)		
Equipment Cost ($/kW)	**$/kW**	**$**
Generator Set Package	$1,400	$280,000
Heat Recovery	$250	$50,000
Exhaust Gas Treatment	$0	$0
Total Equipment Cost ($/kW)	**$1,650**	**$330,000**
Labor/Materials	$500	$100,000
Project Management and Construction	$125	$25,000
Engineering and Fees	$250	$50,000
Project Contingency	$95	$19,000
Project Financing	$30	$6,000
System Cost w/o Interconnection ($/kW)	**$2,650**	**$530,000**
Interconnection Equipment	$550	$110,000
Distribution Upgrades	$720	$144,000
Total System Cost w/ Interconnection ($/kW)	**$3,920**	**$784,000**

Grid integration cost on the grid side (PG&E 2018)

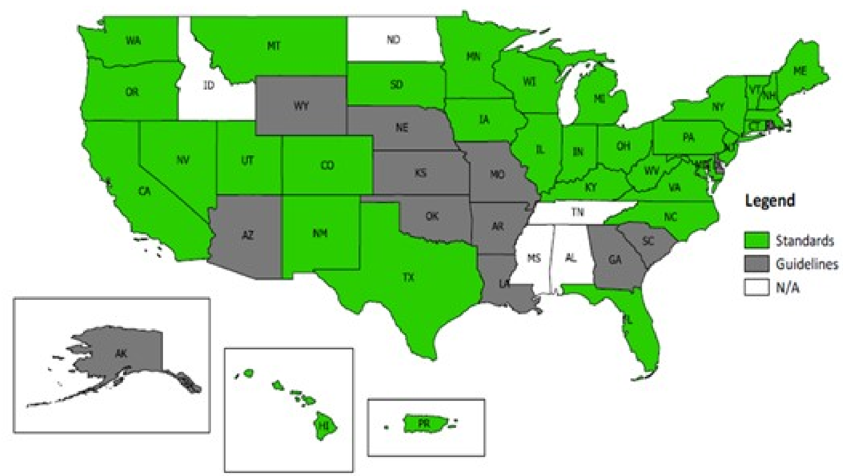
Interconnection Codes, Standards, and Guidelines

- CHP interconnection to area electric power system (EPS) transmission and distribution system is regulated by codes and standards (set requirements for CHP interconnection equipment manufacture, installation and operation)
- 32 states & District of Columbia have interconnection standards (see right)
    - 13 states provide guidelines for some or all distributed generation interconnections



CHP interconnection capacity restrictions overlain by number CHP sites in the U.S

DER guidelines and standards by State



- **Institute of Electrical and Electronical Engineers (IEEE)**
    - ***IEEE 1547***
- **Underwriter Laboratories (UL)**
    - ***UL 1741***
- **American National Standards Institute (ANSI)**
    - ***ANSI C84.1***
- **National Fire Protection Association (NFPA)**
    - ***NFPA 70***