# Potential Impact of Flexible CHP on the Future Electric Grid in California

Flexible CHP Portfolio Meeting – October 16, 2019

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# Published Analysis

Desai, Jal, Ruth, Mark, Lemar, Paul, Bhandari, Mahabir S., Storey, John, Srivastava, Kiran, Rogers, Jonathan, and Schwartz, Harrison. “Modeling the Impact of Flexible CHP on the Future Electric Grid In California.” United States: N. p., 2020. Web. doi:10.2172/1649545. https://www.osti.gov/biblio/1649545-modeling-impact-flexible-chp-future-electric-grid-california and https://info.ornl.gov/sites/publications/Files/Pub129588.pdf

# Analysis Background

## Hypothesis

- Advanced CHP technologies can efficiently and cost-effectively provide flexibility the grid needs.

## Objective

- Cost-benefit analysis to quantify opportunity and guide R&D decisions.
- Compare the cost of operating the grid in California without and with advanced CHP.

# Motivation to CHP Generators

| Market Parameter | Source |
|---|---|
| 85 Percent of All CHP Economic Potential Offers 5-10 year Payback | AGA 2013[1] |
| 89 Percent of Industrial CHP Economic Potential Offers 5-10 Year Payback | EPRI 2014[2] |
| Average Payback Period for Industrial Sector is 7.4 Years | EPRI 2014[2] |

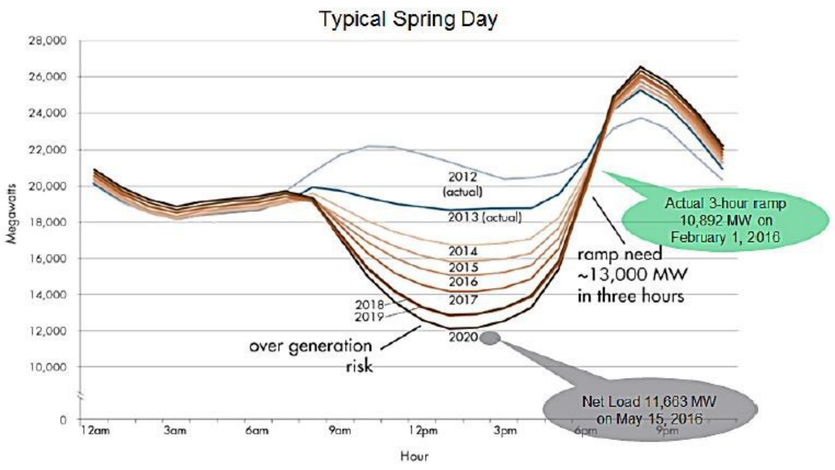
- Significant share of potential projects with longer term paybacks, market potential for new CHP constrained
- More CHP activity in states with incentives, effective at reducing payback periods
- Uncertainty around incentives creates stop/start market disruptions

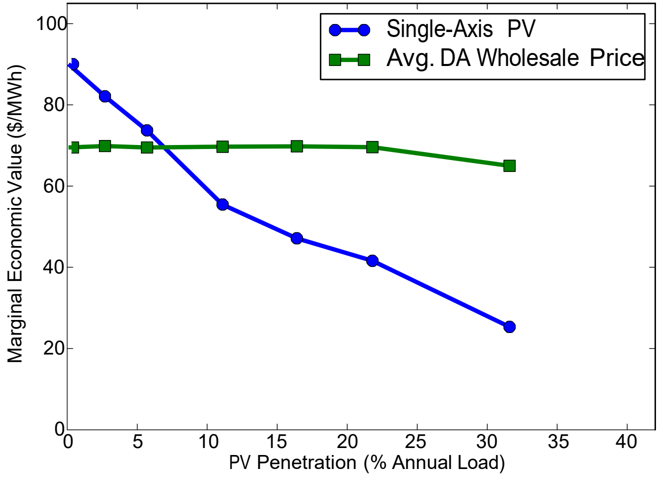
[1]American Gas Association, The Opportunity for CHP in the United States, Washington, DC, May 2013.
[2] Program on Technical Innovation: Natural Gas Distribution Generation Options: Cost and Market Benchmarking Assessment. EPRI, Palo Alto, CA: 2014. 3002004191.

# Motivation for Grid

As renewable penetration increases, overgeneration and transients become larger concerns.

The economic value of renewable electricity generation decreases significantly with increasing penetration. Causes risk of RE deployment being limited.




Changes in the Economic Value of Variable Generation at High Penetration Levels: A Pilot Case Study of California Andrew Mills and Ryan Wiser, June 2012, http://eetd.lbl.gov/EA/EMP

# Compensated Services

| Compensated by Most Electricity Markets | Not Compensated by Most Electricity Markets | |
|---|---|---|
| **Bulk power capacity and energy services**<br>• **Energy**<br>• **Generating capacity**<br>**Ancillary services**<br>• **Frequency control**<br>• **Spinning reserves**<br>• **Non-spinning reserves**<br>• **Supplemental reserves**<br>• **Voltage support**<br>• **Black start service** | Indirect system benefits<br>• Reduced overall system electricity production cost<br>• Reduced curtailments of variable generation<br>• Reduced cycling and ramping of conventional generating units<br>• Reduced system emissions (depending on plant mix) | Power system stability services<br>• Inertial response<br>• Governor response<br>Transmission benefits<br>• Transmission congestion relief<br>• Transmission investments deferral<br>Non-energy benefits<br>• Portfolio diversification<br>• Local economic development and job creation<br>• Security of fuel supply<br>• Generation resilience |

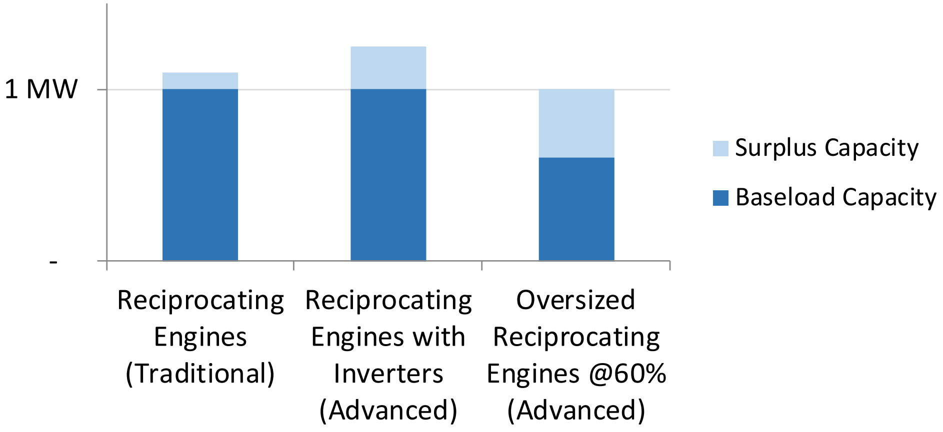
# Performance Requirements

| Market | Requirements to participate |
| --- | --- |
| Energy | Provide energy to the grid based on day-ahead unit commitment per economic dispatch signals |
| Generating Capacity | Generate on-demand at any time during the year |
| Frequency Control | Follow Automatic Generation Control Signal (4 second frequency) – Load-frequency control rate sufficient |
| Spinning Reserves | Ability to respond within 10 minutes to address contingency events |
| Non-Spinning Reserves | Ability to respond within w0 minutes to address contingency and flexibility events |

# Flexible CHP Configurations Analyzed

| Configuration | Grid Support |
|---|---|
| **Traditional: Primarily Serve On-site Electrical Loads and are not ramped to support the grid** | |
| CHP sized to baseload but allowed to operate at 10% overcapacity to provide grid services | Limited to 10% of capacity for 500 hours per year |
| **Advanced: Serve site loads and use surplus capacity to provide a range of services to the grid** | |
| CHP sized between baseload and peak load | More active, limited to 25% and 500 hours per year |
| CHP sized above peak load | Provides up to 40% of the its capacity reserved for grid support, without constraints |

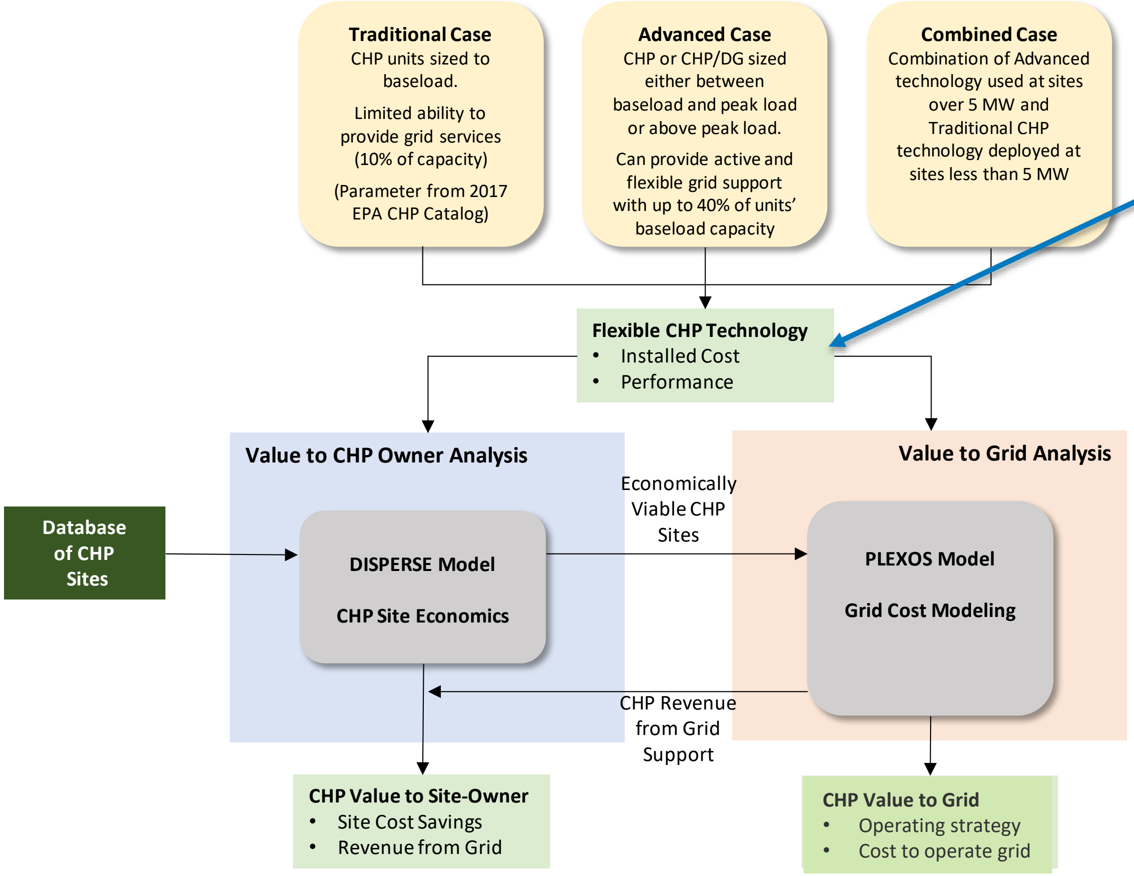
**Operation at 1 MW for Traditional and Advanced CHP Units**



# Analysis Scenarios

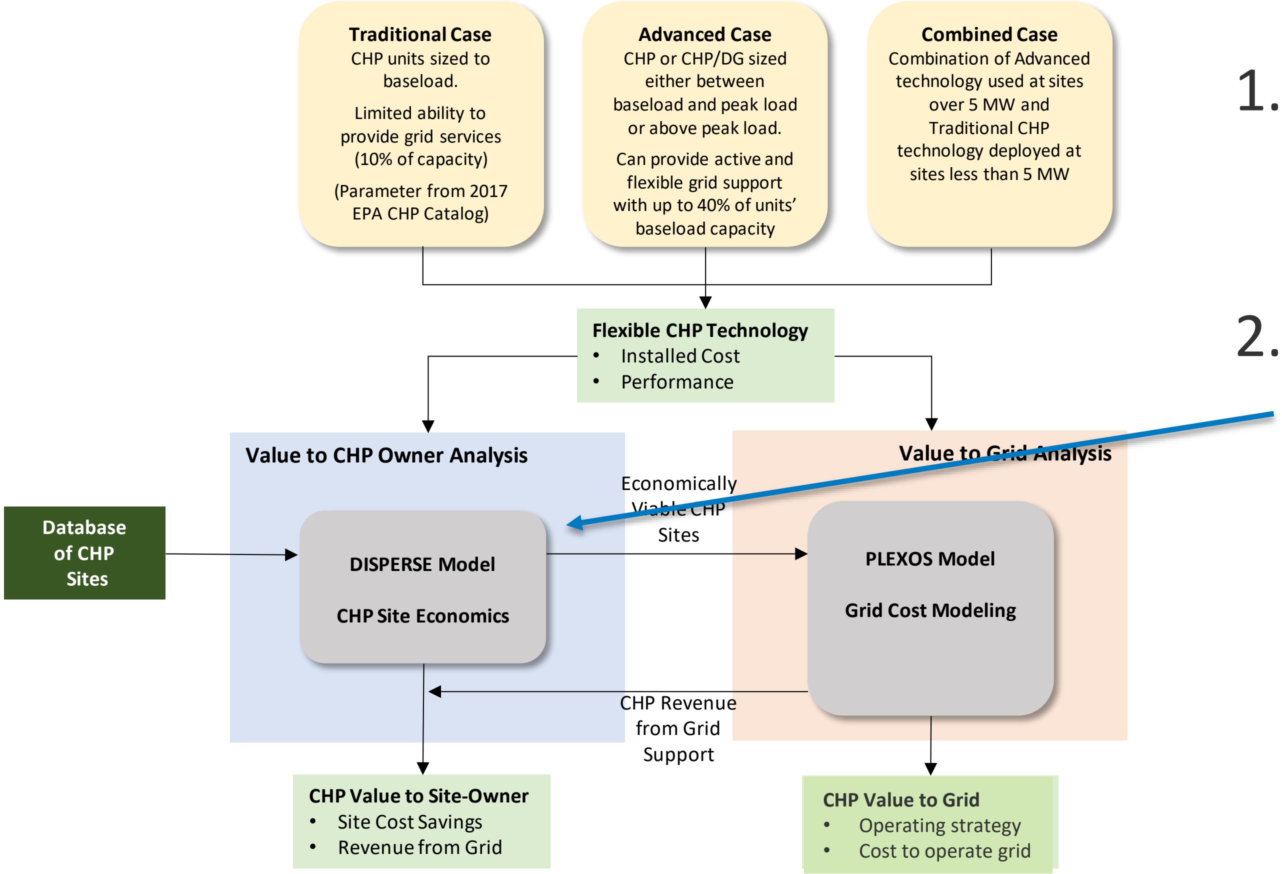
| Scenario | Description |
|---|---|
| **Reference** | CA grid if no additional CHP is added |
| **Traditional** | Grid modeled for all locations where Traditional CHP is economically viable to deploy Traditional CHP<br>• Traditional units are constrained to operate no more than 500 hours per year |
| **Advanced** | Grid modeled such that, in all locations where Traditional CHP is economically viable, Advanced CHP is deployed<br>• The Advanced CHP units have higher up-front capital costs than the traditional units<br>• The scenario determines the value each site-owner would obtain from deploying Advanced CHP units and the associated return on investment.<br>• The results from the Advanced case point to an economically viable set of Advanced CHP deployments that could be modeled with Traditional CHP units at the remaining sites<br>• 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** | Grid modeled such that economically viable Advanced CHP units are deployed, and the remaining suitable sites deploy Traditional CHP |

# Analysis Methodology



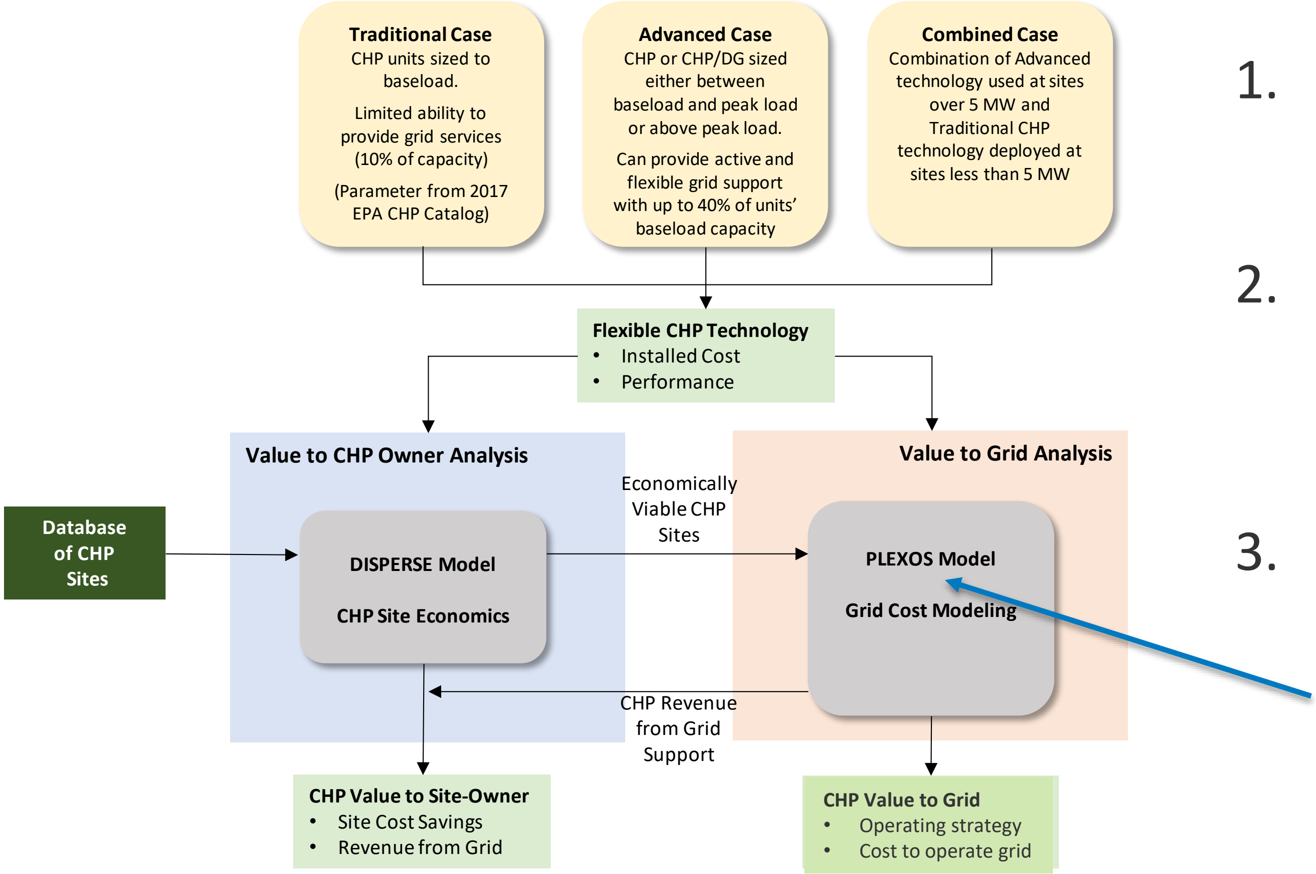

1. Estimate potential improvements to CHP technologies,

# Analysis Methodology



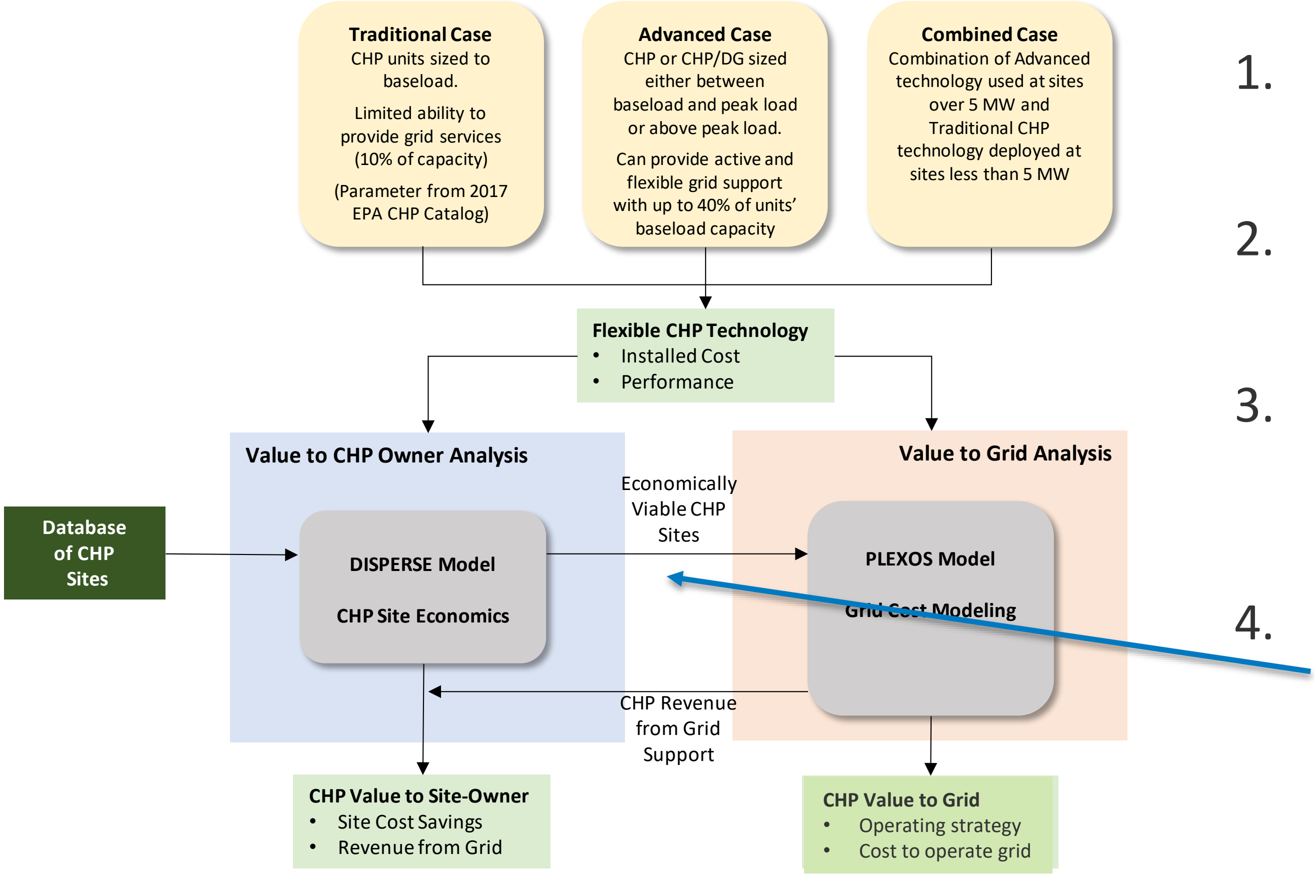

1. Estimate potential improvements to CHP technologies,
2. Identify locations where those technologies reduce owner costs,

# Analysis Methodology



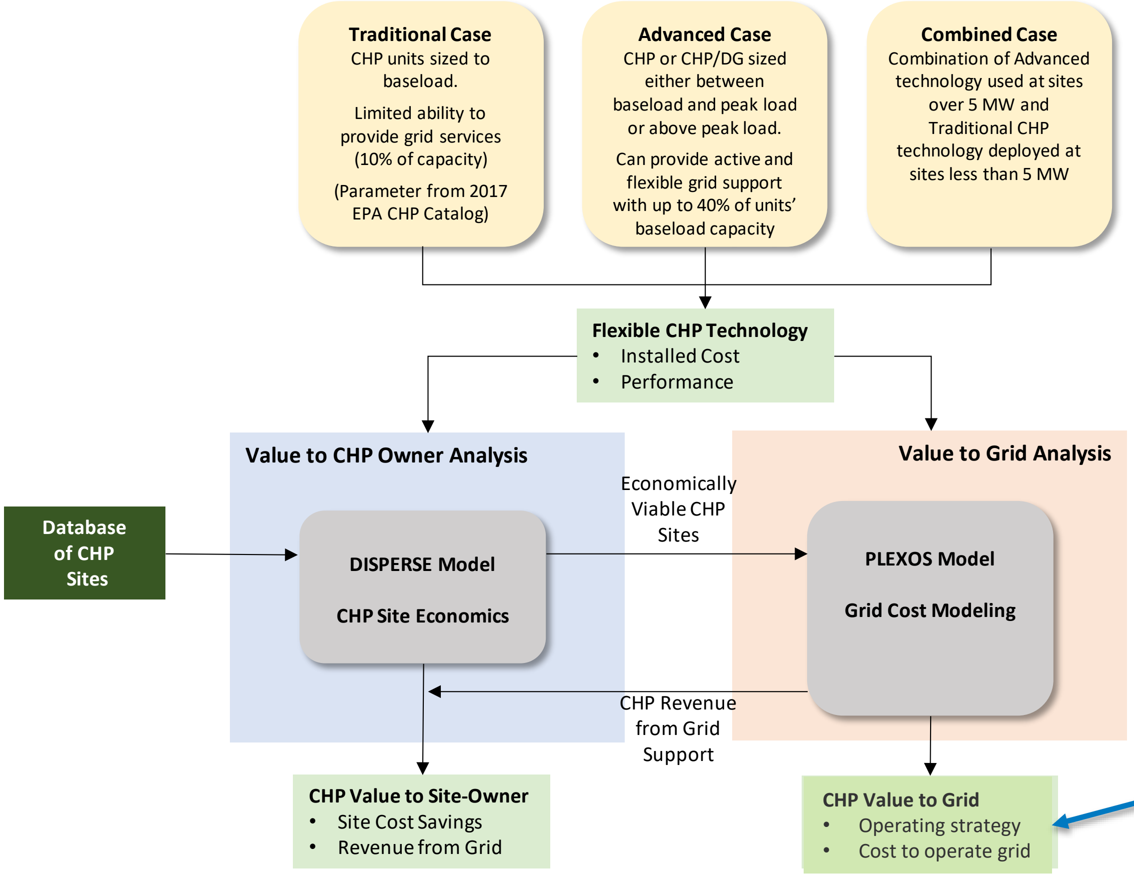

1. Estimate potential improvements to CHP technologies,
2. Identify locations where those technologies reduce owner costs,
3. Run electricity system production cost model without adding the technologies,

# Analysis Methodology



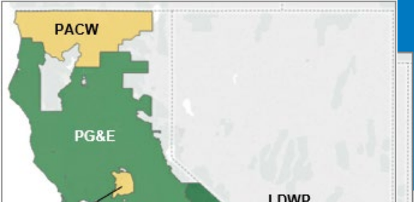

1. Estimate potential improvements to CHP technologies,
2. Identify locations where those technologies reduce owner costs,
3. Run electricity system production cost model without adding the technologies,
4. Add the technologies to production cost model and run it again,

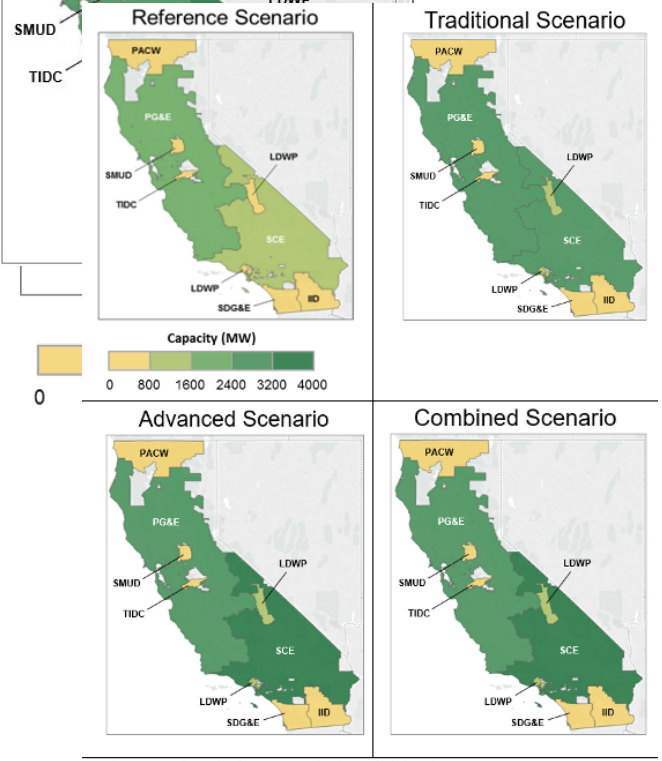
# Analysis Methodology




1. Estimate potential improvements to CHP technologies,
2. Identify locations where those technologies reduce owner costs,
3. Run electricity system production cost model without adding the technologies,
4. Add the technologies to production cost model and run it again,
5. Compare results

# Potential CHP Sites



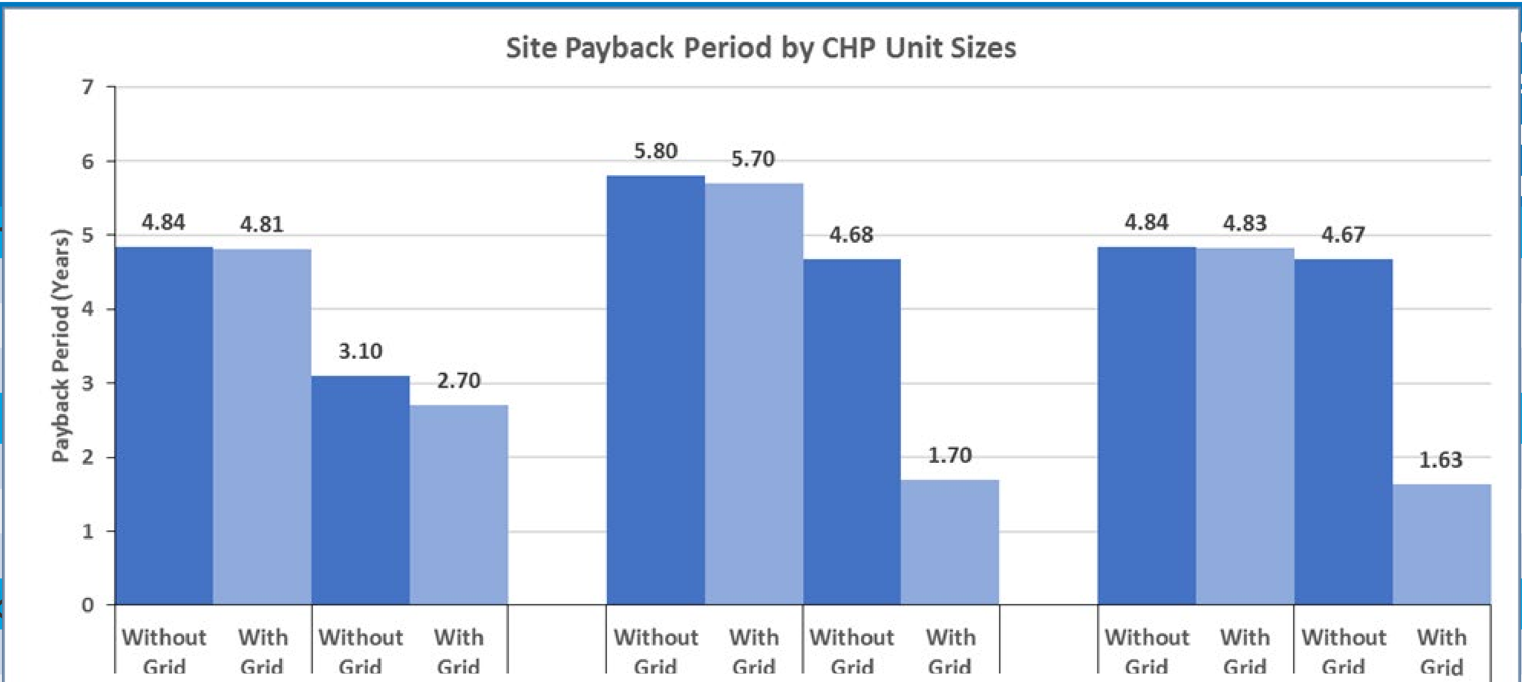

Maximum capacity = (Reference+Baseload+surplus) (MW)
Region names as follows: Imperial Irrigation District (IID); Turlock Irrigation District (TIDC); PacifiCorp West (PACW); Sacramento Municipal Utility District (SMUD); Southern California Edison (SCE); San Diego Gas and Electric (SDG&E); Los Angeles Department of Water and Power (LDWP); Pacific Gas & Electric–Bay (PG&E_BAY); Pacific Gas & Electric–Valley (PG&E_VLY)

| Region | Reference capacity (MW) | Model sites | Traditional max capacity (MW) | Advanced max capacity (MW) | Combined max capacity (MW) |
|---|---|---|---|---|---|
| IID | – | 6 | 17 | 25 | 24 |
| TIDC | – | 12 | 36 | 46 | 42 |
| PACW | – | 12 | 25 | 34 | 25 |
| SMUD | 70 | 102 | 354 | 418 | 393 |
| SCE | 1,053 | 641 | 2,987 | 3,442 | 3,292 |
| SDG&E | 47 | 119 | 365 | 429 | 404 |
| LDWP | 562 | 72 | 840 | 909 | 891 |
| PG&E_BAY | 449 | 241 | 1,064 | 1,205 | 1,152 |
| PG&E_VLY | 1,203 | 204 | 1,778 | 1,924 | 1,883 |
| **Total** | **3,385** | **1,409** | **7,466** | **8,432** | **8,108** |

- Many opportunities across the California Independent System Operator (CA-ISO) territory
- Potential increase of up to 150% over projected installations
- SCE Balancing Authority has the greatest potential

# Energy and Ancillary Service Revenues to CHP Owner

| Case | …venue …sands …r MW …rplus) |
|---|---|
| Tradi… | $39 |
| Adva… | $583 |
| Comb… | $781 |




Advanced CHP technology can increase the revenue to site owners by $760M. Focusing that advanced technology increases benefits.

# Energy and Ancillary Service Revenues to CHP Owner

| Case | Revenue ($ thousands) Energy | Ancillary Service | Total | Hours operating at surplus | Surplus capacity (MW) | Revenue ($ thousands per MW surplus) |
|---|---|---|---|---|---|---|
| **Traditional** | $1,182 | $12,820 | $14,002 | 3,418 | 358 | $39 |
| 5+ MW (T6040) | $1,059 | $9,336 | $10,394 | 2,964 | 165 | $63 |
| 1-5 MW (T6080) | $121 | $3,175 | $3,296 | 333 | 172 | $19 |
| Under 1 MW (T6815) | $2 | $309 | $312 | 121 | 21 | $15 |
| **Advanced** | $759,303 | $13,212 | $772,515 | 45,696 | 1,324 | $583 |
| 5+ MW (A4900) | $759,144 | $8972 | $768,116 | 45,269 | 808 | $951 |
| 2-5 MW (A6540) | $122 | $2077 | $2,199 | 205 | 258 | $9 |
| Under 2 MW (A6800) | $37 | $2,163 | $2,200 | 222 | 262 | $9 |
| **Combined** | $763,828 | $16,934 | $780,762 | 45,180 | 1,000 | $781 |
| 5+ MW (A4900) | $763,737 | $14,805 | $778,543 | 44,689 | 799 | $974 |
| 5+ MW (T6040) | $4 | $0 | $4 | 135 | 1 | $3 |
| 1-5 MW (T6080) | $83 | $1,922 | $2,006 | 232 | 179 | $11 |
| Under 1 MW (T6815) | $3 | $206 | $209 | 124 | 21 | $10 |
| 0-2 MW (MT) | n/a | n/a | n/a | n/a | n/a | n/a |

# Energy and Ancillary Service Revenues to CHP Owner

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| **Advanced** | [illegible] | [illegible] | [illegible] | [illegible] | 1,324 | $583 |
| 5+ MW (A4900) | [illegible] | [illegible] | [illegible] | [illegible] | 808 | $951 |
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| 0-2 MW (MT) | n/a | n/a | n/a | n/a | n/a | n/a |

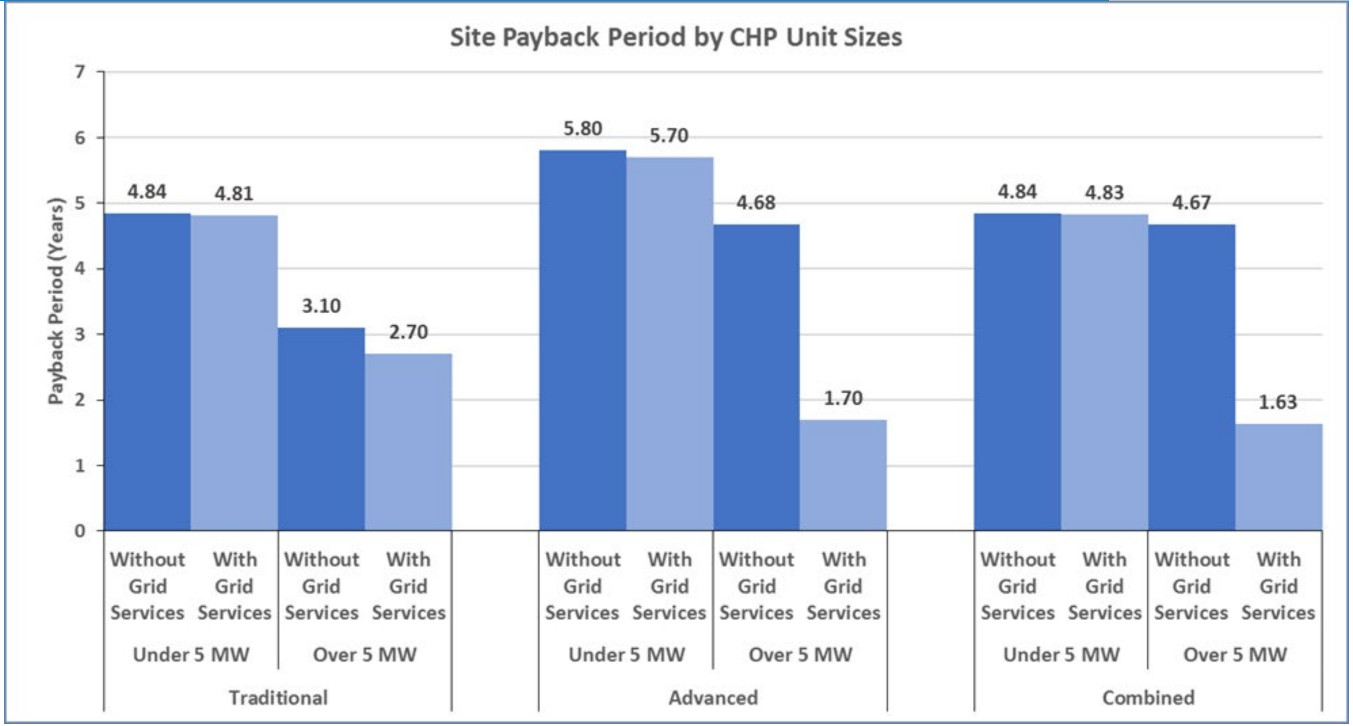
The greatest opportunities are for larger (5+ MW systems)

# Potential Value of Capacity to CHP Owners

Capacity payments could increase the site's income by 20% - 100% if rules and regulations allow for that payment

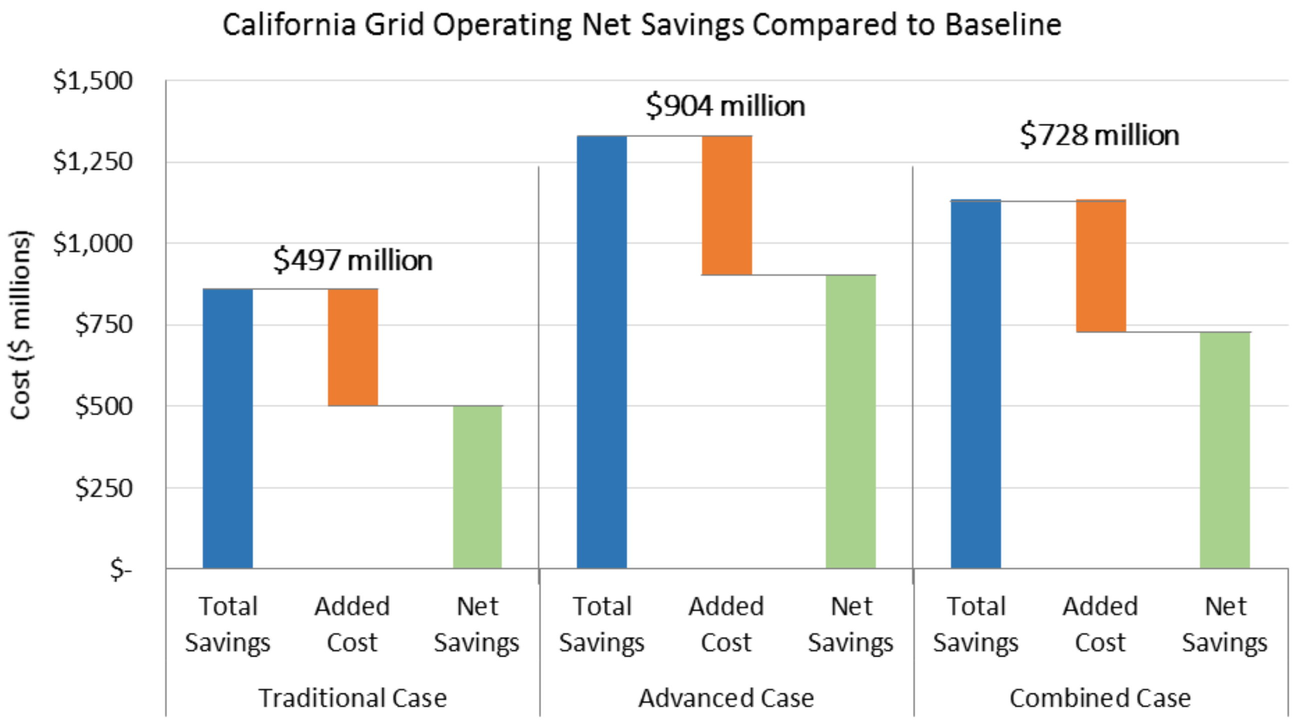
| Scenario | Capacity Payment ($20/kW-year) $ thousands | Capacity Payment ($100/kW-year) $ thousands |
| --- | --- | --- |
| **Traditional** | $149,320 | $746,600 |
| **Advanced** | $168,640 | $843,200 |
| **Combined** | $162,160 | $810,800 |

# Impact of Grid Revenue on CHP Owners




The ability to participate in grid services markets enables advanced technologies especially for larger systems

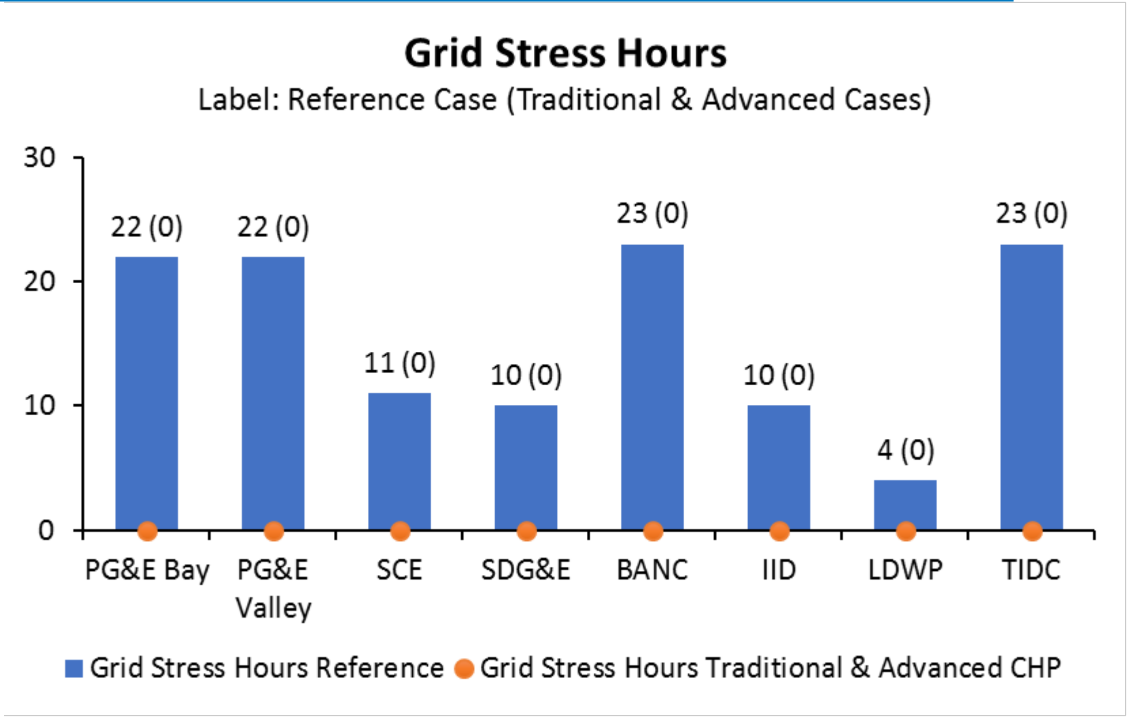
# Impacts on Cost to Operate the Grid




| CA Grid Costs | Ref. Case ($ million) |
|---|---|
| Emissions | $1,970 |
| Fuel | $8,174 |
| Start & Shutdown | $160 |
| VO&M | $342 |
| Reserve | $298 |
| Net Imports | $2,403 |
| **Total Cost** | **$13,347** |

Grid operating costs can be reduced by over $700 million (5% of total cost)

# Impacts on Grid Stress




Advanced CHP in California can eliminate hours with grid stress

# Conclusions

Advanced CHP can

- More than double capacity with a 6 year payback period
- Save site owners up to $760 million
- Reduce CA-ISOs operating cost by over $700 million
- Eliminate hours of grid stress in CA-ISO

# Thank you

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PR-6A20-XXXXX

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This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Advanced Manufacturing Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL Transforming ENERGY

# Supporting Slides

# IGATE-E: National, Web-based CHP Potential Analysis

IGATE-E
IAC, ESA,and MNI Databases

↓

Database Schema**
45 tables-MySQL

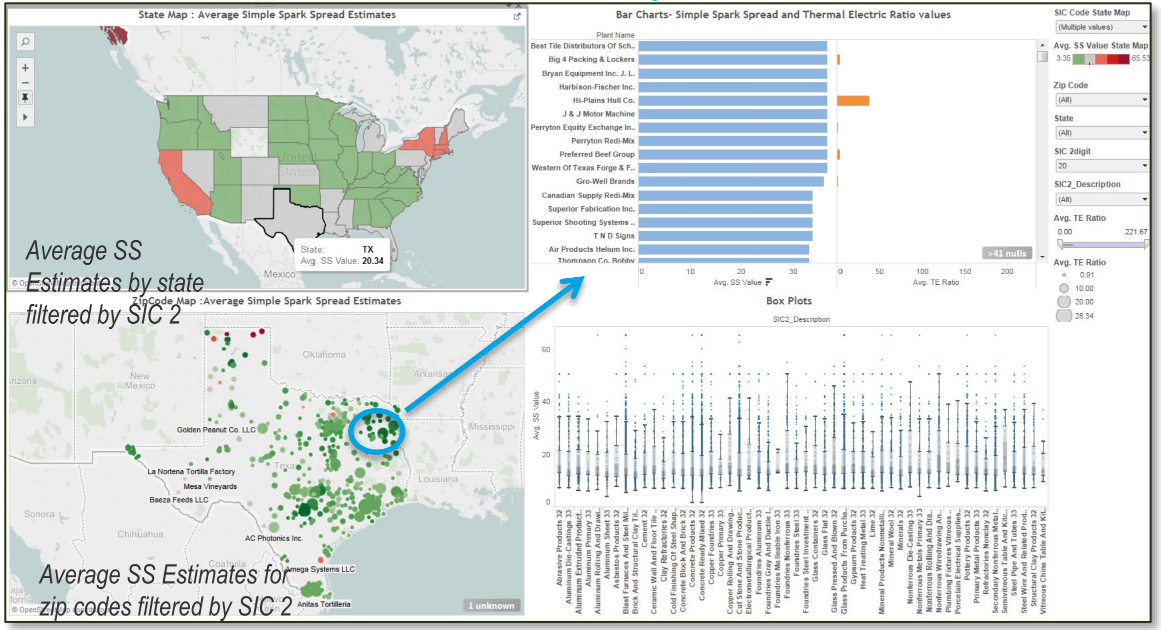
↓

Interactive Visual Analytic Dashboard

Manufacturing Plants and their Simple Spark Spread estimates, Thermal-Electric ratios
*at SIC, state, and zip code levels*

**State or Regional-level Overview**

**Plant Specific TE* ratios and SS* estimates**




**State, County, and Zip Code-level Filter/Zoom Capability**

**TE and SS Box Plots & Outliers by Industry Sub-sector**

**TE – Thermal to Electric ratio and SS – Simple spark spread, as defined in the CHP Resource Guide by Midwest CHP TAP.*
***A database schema of a database system is its structure described in a formal language supported by the database management system (DBMS) and refers to the organization of data as a blueprint of how a database is constructed (Source – Wiki).*

# Traditional CHP Cost and Performance Details

| Size Range | 0.1-0.8 MW | 0.8-2.0 MW | 2-5 MW | | | 5-10 MW | | 10-20 MW | | 20+ MW | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | Recip + Inverter | Recip + Inverter | Recip + Inverter | Recip | CT | Recip | CT | Recip | CT | Recip | CT |
| Operation of CHP Unit | | | | | | | | | | | |
| Installed Cost ($/kW) of CHP Unit | $3,075 | $2,566 | $2,274 | $1,949 | $3,051 | $1,548 | $2,184 | $1,436 | $1,597 | $1,324 | $1,382 |
| Nominal Electric Power (kW) | 633 | 1,141 | 3,325 | 3,325 | 4,600 | 9,341 | 7,965 | 18,682 | 21,745 | 28,023 | 43,069 |
| Net Electric Power (kW) | 633 | 1,141 | 3,325 | 3,325 | 4,324 | 9,341 | 7,487 | 18,682 | 20,440 | 28,023 | 40,485 |
| Thermal Output (MBTU/kWh) | 4.5 | 3.9 | 3.2 | 3.2 | 5.5 | 2.8 | 4.6 | 2.8 | 3.6 | 2.8 | 3.1 |
| Heat Rate (BTU/kWh HHV) | 9,890 | 9,074 | 8,342 | 8,342 | 13,648 | 8,342 | 11,685 | 8,207 | 10,308 | 8,207 | 9,611 |
| Net Heat Rate (BTU/kWh HHV) | 5,403 | 5,166 | 5,127 | 5,127 | 8,170 | 5,495 | 7,127 | 5,359 | 6,749 | 5,359 | 6,505 |
| Variable O&M (cents/kWh) | 2.5 | 2.3 | 1.9 | 1.9 | 1.4 | 1.6 | 1.3 | 1.0 | 1.0 | 1.0 | 1.0 |
| Variable O&M ($/MWh) | 25.0 | 22.6 | 19.1 | 19.1 | 14.1 | 16.0 | 13.0 | 9.7 | 9.7 | 9.7 | 9.7 |
| Incremental Installed Cost ($/kW) for Overload Capacity | $0 | $0 | NA | $0 | NA | $0 | NA | $0 | NA | $0 | NA |
| Total Capacity (kW) | 696 | 1,255 | NA | 3,658 | NA | 10,275 | NA | 20,550 | NA | 30,825 | NA |
| Overload Capacity (kW) | 63 | 114 | NA | 333 | NA | 934 | NA | 1,868 | NA | 2,802 | NA |
| Net Heat Rate (BTU/kWh HHV) of Overload Capacity | 6,815 | 6,087 | NA | 6,072 | NA | 6,039 | NA | 6,039 | NA | 6,039 | NA |
| Operating Limitation (Hrs/yr) | 500 | 500 | NA | 500 | NA | 500 | NA | 500 | NA | 500 | NA |

Notes: Based on DOE Tech Characterizations, costs escalated to 2024. Some improvements to part load efficiency of advanced recip units assumed.
Variable cost based on $8.1/MMBTU forecasted natural gas price to industrial users
Steam generation for STIGCHP at $45/kW (Jacobs Consultancy, Control Technologies Review, Cogeneration Units, Prepared For Clean Air Strategic Alliance, February 2010)

# Advanced CHP Cost and Performance Details

| Size Range | 0.1-0.8 MW | 0.8-2.0 MW | 2-5 MW | | | 5-10 MW | | | | 10-20 MW | | | | 20+ MW | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Technology** | Recip + Inverter | Recip + Inverter | Recip + Inverter | Recip @ 60% | CT with STIG | Recip @ 60% | Recip | CT with STIG | CT with STIG CHP | Recip @ 75% | Recip | CT with STIGCHP | CT with STIG | Recip @ 75% | Recip | CT with STIGCHP | CT with STIG |
| **Operation of CHP Unit** | | | | | | | | | | | | | | | | | |
| Installed Cost ($/kW) without Surplus Capability | $3,075 | $2,566 | $1,949 | $2,566 | $3,051 | $1,548 | $1,548 | $2,184 | $2,229 | $1,453 | $1,548 | $1,642 | $1,597 | $1,358 | $1,548 | $1,427 | $1,382 |
| Installed Cost ($/kW) of CHP Unit with Surplus Capability | $3,400 | $2,891 | $2,274 | $3,304 | $3,288 | $2,625 | NA | $2,421 | $2,466 | $1,938 | NA | $1,879 | $1,834 | $1,811 | NA | $1,663 | $1,618 |
| Nominal Electric Power (kW) | 633 | 1,141 | 3,325 | 1,611 | 4,600 | 5,511 | 9,341 | 7,965 | 7,965 | 14,012 | 18,682 | 21,745 | 21,745 | 21,017 | 28,023 | 43,069 | 43,069 |
| Net Electric Power (kW) | 633 | 1,141 | 3,325 | 1,611 | 4,324 | 5,511 | 9,341 | 7,487 | 7,487 | 14,012 | 18,682 | 20,440 | 20,440 | 21,017 | 28,023 | 40,485 | 40,485 |
| Thermal Output (MBTU/kWh) | 4.5 | 3.9 | 3.2 | 3.9 | 5.5 | 3.3 | 2.8 | 4.6 | 4.6 | 3.1 | 2.8 | 3.6 | 3.6 | 3.1 | 2.8 | 3.1 | 3.1 |
| Heat Rate (BTU/kWh HHV) | 9,890 | 9,074 | 8,342 | 9,712 | 13,648 | 8,861 | 8,143 | 11,685 | 11,685 | 8,617 | 8,143 | 10,308 | 10,308 | 8,617 | 8,143 | 9,611 | 9,611 |
| Net Heat Rate (BTU/kWh HHV) | 5,403 | 5,166 | 5,127 | 5,778 | 8,170 | 5,592 | 5,296 | 7,127 | 7,127 | 5,494 | 5,296 | 6,749 | 6,749 | 5,494 | 5,296 | 6,505 | 6,505 |
| Variable O&M (cents/kWh) | 2.5 | 2.3 | 1.9 | 1.7 | 1.4 | 1.0 | 1.0 | 1.3 | 1.3 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| **Operation at Surplus Capacity** | | | | | | | | | | | | | | | | | |
| Incremental Installed Cost ($/kW) for Surplus Capacity | $1,200 | $1,200 | $1,200 | $1,061 | $390 | $1,453 | NA | $390 | $435 | $1,168 | NA | $618 | $573 | $1,073 | NA | $618 | $573 |
| Total Capacity (kW) | 791 | 1,426 | 4,156 | 2,731 | 7,117 | 9,341 | NA | 12,323 | 12,323 | 18,682 | NA | 29,429 | 29,429 | 28,023 | NA | 58,290 | 58,290 |
| Surplus Capacity (kW) | 158 | 285 | 831 | 1,120 | 2,793 | 3,830 | NA | 4,358 | 4,836 | 4,671 | NA | 8,989 | 7,684 | 7,006 | NA | 15,221 | 15,221 |
| Net Heat Rate (BTU/kWh HHV) | 6,661 | 6,897 | 6,540 | 4,986 | 4,045 | 4,800 | NA | 3,463 | 7,383 | 4,820 | NA | 7,921 | 3,138 | 4,820 | NA | 7,874 | 3,699 |
| Operating Limitation (Hrs/yr) | 500 | 500 | 500 | 6,000 | 500 | 6,000 | NA | 500 | 500 | 6,000 | NA | 500 | 500 | 6,000 | NA | 500 | 500 |

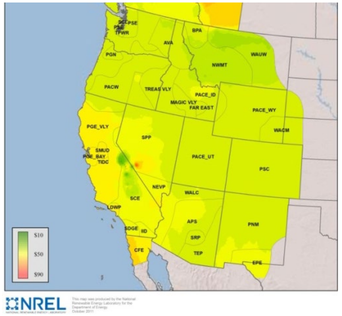
Notes: Based on DOE Tech Characterizations, costs escalated to 2024. Some improvements to part load efficiency of advanced recip units assumed.
Variable cost based on $8.1/MMBTU forecasted natural gas price to industrial users
Steam generation for STIGCHP at $45/kW (Jacobs Consultancy, Control Technologies Review, Cogeneration Units, Prepared For Clean Air Strategic Alliance, February 2010)

# Ways Flexible CHP can Support the Grid

| Goal | How Flexible CHP Supports the Goal |
|---|---|
| **Grid Reliability** | Installations can improve power quality, provide ancillary services, and relieve grid congestion |
| **Customer Resilience** | Systems can allow critical loads to continue operation during grid outages and provide dispatchable power for microgrids |
| **Energy Efficiency** | Uses less fuel and is more efficient, which saves energy compared to conventional, separate electricity generation and heat production |
| **DER Integration** | Can help utilities integrate new renewable distributed energy resource (DER) deployments and balance variable loads |
| **Locational Value** | Can be deployed at strategic locations on the system where it is needed most thus relieving grid congestion |
| **Affordability** | Can often meet system needs more cost effectively than investments in traditional assets, thus lowering costs for ratepayers across the utility system |
| **Emissions Reductions** | Efficient CHP systems have lower emissions than conventional grid resources, and can be used to meet emissions reduction targets (ex: states w/ GHG goals) |

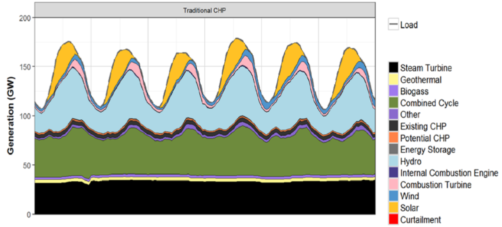
# PLEXOS production cost model

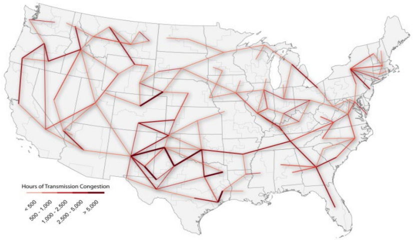
- Simulate operation of electric power system
- Hourly or sub-hourly chronological
- Commits and dispatches generating units based on:
  - Electricity demand
  - Operating parameters of generators
  - Transmission grid parameters
- Used for system generation and transmission planning
  - Increasingly used for real-time operation



Locational prices, production cost

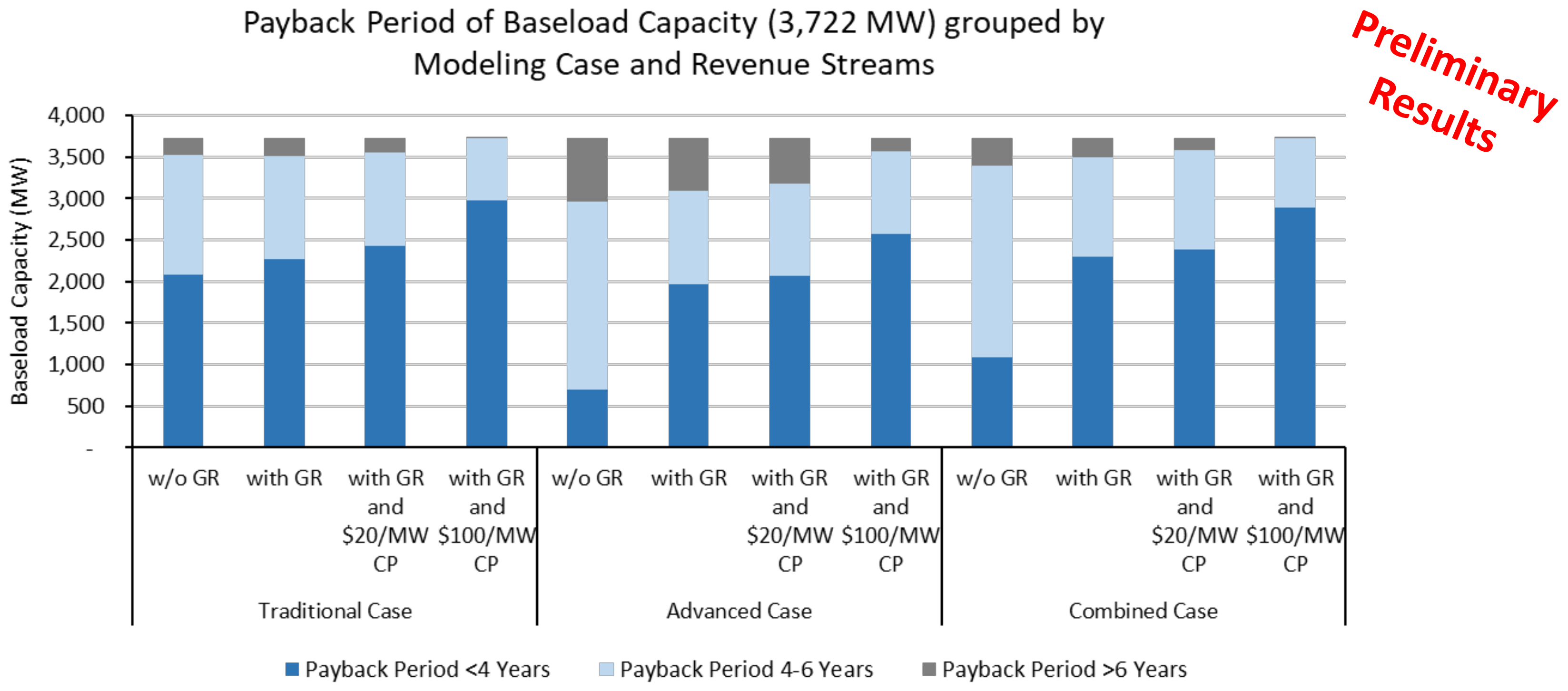
Dispatch information, fuel usage



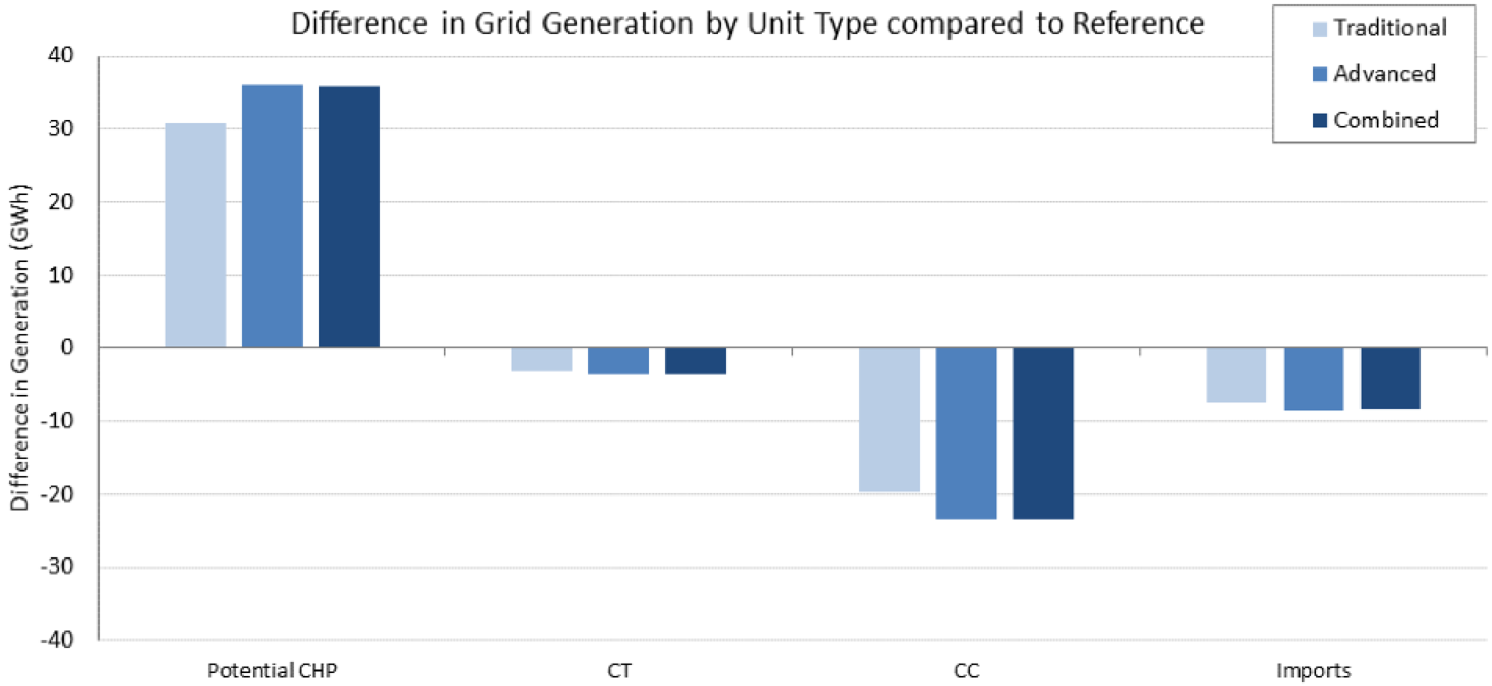

Transmission congestion

# Impact of Grid Revenue on Population of CHP Owners




If both grid services and capacity payments are available, payback periods are <6 years at almost all primary sites

# Impacts on Grid Operation Profiles




Advanced CHP in California offsets combined cycle units, combustion turbines, and imports