Flexible Combined Heat and Power Valuation and Interconnection

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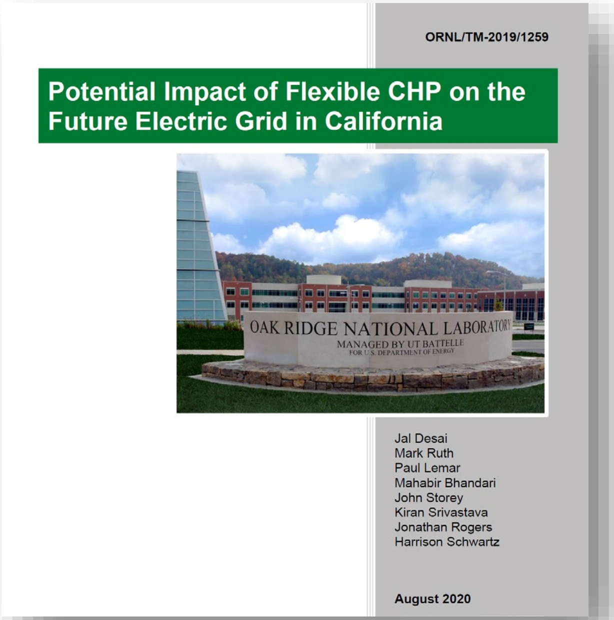
Flexible Combined Heat and Power Systems

- CHP systems can not only provide benefits to the onsite customer, but export surplus capacity to the grid
- Some studies have estimated flexible CHPs can have significant effect on the operating cost and also lower the number of grid stress hours in the California grid
- In a modernized grid that is rapidly evolving to include larger portfolio of intermittent renewable generation, firm resources like CHP may provide much needed stability for the future

Two units of Titan 130 CHP at Cornell University in New York



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

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Flexible CHP Systems

Benefits

- Provide capacity to the local utility
- Generate revenue from wholesale market participation
- Utilize asset that is already synchronized to provide capacity, operating reserves, or ancillary services
- Firm resource
- Resilience and backup power to site owner

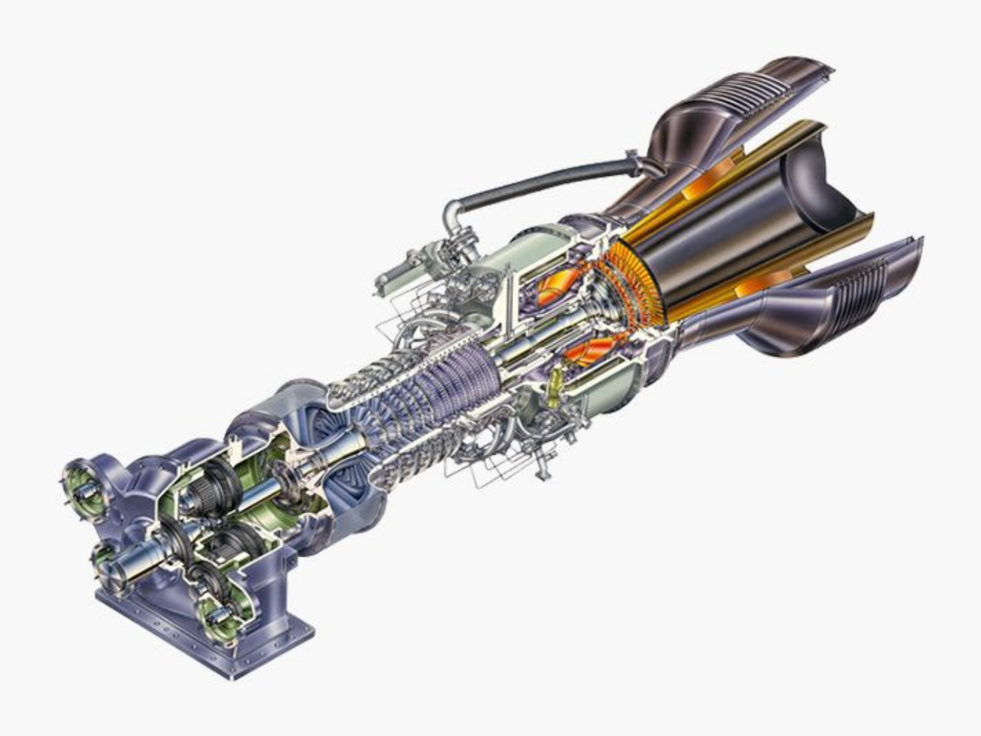
Challenges

- Added capital costs
- Added fixed O&M costs
- Fuel efficiency at part load
- Emissions at part load
- Interconnection requirements
- Wholesale participation rules for DERs developing

Project Objectives: Three Tasks to analyze CHP Modification

1. Grid Support Study and Validation
2. Grid Connectivity Requirements
3. Emissions Assessment

Expanding the operational window of a 16.5 MW gas turbine allow for greater turndown, and more flexibility in the power/heat ratios ---- how exactly does this modified CHP system enable grid support and add value?



Solar Turbine Titan 130 PG Generator Set
Courtesy of Solar Turbines

Project Key Summary

- Evaluated revenue streams and conducted benefit-cost analyses of traditional CHP system serving 100% base load with no grid export, and flexible CHP system, where a portion of the rated capacity is used for market services.
- “Flexible CHP” in this analysis refers to CHP sized above the baseload, e.g., “70% Flexible CHP” refers to oversizing and bidding 30% rated capacity for market services. This analysis did not consider peak firing.
- Market signals and benefits will have to be clear for site owners to consider exporting excess capacity to offset added capital and O&M costs, as CHPs have been installed primarily for customer bill management and resilience purposes.
- Provided a high-level overview of interconnection process and requirements, although actual requirements are specific to utility at the time of application. System Impact Studies or other technical studies may be needed to determine how the flexible CHP can export.
- Titan 130 may be subject to emission regulations of the California Air Resources Board (CARB). Emission limits may be anticipated to be 2 ppm NOx and 6 ppm CO, and additional emission controls are needed for the Titan 130 to meet CARB requirements.

Valuation of Flexible CHP to System Owners

DER and Energy Storage Analysis Framework

The analysis framework is a structured 4-step process

Scenario Development

- Identify the system or customer needs (thermal and electric)
- Identify associated conventional solutions
- Identify customer and market services, analysis parameters, constraints, data input required

Grid Service Analysis

- Identify, if any, transmission or distributions service requirements.
- Not applicable in this flexible CHP study

Market & Customer Service Analysis

- Assess the market & customer service value streams.
- Perform sensitivity analysis on the DER siting and sizing.

Cost-Benefit Analysis

- Evaluate the collective value streams
- Evaluate the changes in the costs of assets, O&M expenses overtime
- Specify results to a set of financial parameters.

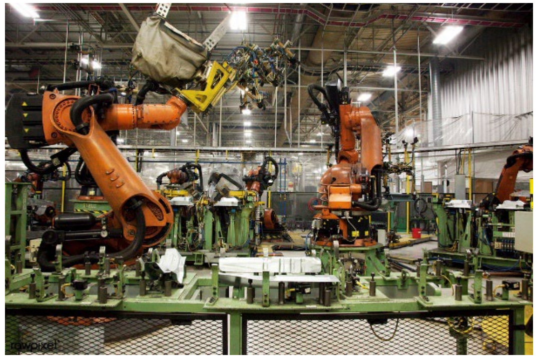
Hypothetical Site, Industrial CHP Customer in California

- Site selection: industrial / manufacturing load in California
- CHP systems are typically sized based on thermal loads
- Surveyed publicly available resources and assumed specific power-to-heat ratio
- Operation characteristics:
  - Steam requirements are fulfilled by modified Titan 130
  - Capacity factor = 96%, 2-week spring maintenance

Site / Industry	P/H Ratio	Location	Based on, Example from
Food & Beverage (Frozen Food)	2.79	Kern County, PG&E	Sunselect, Kern County, 2x 3.3 MW
Food & Beverage (Malt Beverages)	0.65, 0.85	Pasadena, SCE	Irwindale Miller – 12.5 MW NG CT
Petroleum Refining	0.26	LA County, SCE	Chevron, 40.7 MW
Manufacturing	1.00		
Analysis Assumption			
Food & Beverage at 96% / 8424 hrs	**H/P = 1.18** **P/H = 0.85**	**SCE, PG&E**	

Wastewater Treatment Plant

Food processing



Manufacturing

Flexible CHP in This Analysis

In this Analysis:

- **“Traditional CHP”** in this analysis refers to CHP sized based on the onsite thermal requirements, and site owner may purchase remaining electricity from the utility. This is traditional in the sense of how CHPs have been typically sized in the past decades. No grid export or no peak firing is considered.
- **“Flexible CHP”** in this analysis refers to CHP sized above the baseload. For instance, “70% Flexible CHP” refers to oversizing for the base load and bidding 30% rated capacity for market services.
- An OTSG is assumed to provide the thermal flexibility needed, as the load may vary between 70% to 100% of rated capacity of the system. The onsite thermal requirements are satisfied all the time.
- This analysis **did not consider peak firing**.

Comparing with Other CHP Grid Support Configurations in Literature:

- There are other configurations analyzed in existing literature around the concept of Flexible CHP.
- The configurations analyzed in this study is most closely described by **“Advanced” configuration** in the paper referenced below, where a CHP is sized between baseload and peak load, or even above peak load

Configuration	Grid support	Other benefits
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 [14]	Limited, could support critical loads during grid outage
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 [15]	Could support all loads during grid outage
CHP sized above peak load	Provides up to 40% of the its capacity reserved for grid support, without constraints	Could support all loads during grid outage

“Potential Impact of Flexible CHP on the Future Electric Grid in California”, August 2020

Scenario Development: 3 Cases and 3 Sensitivities

- **Flexible CHP Cases**

CHP Cases	Flexible CHP Investment	Traditional CHP Investment	No CHP Investments
Traditional CHP	---	Titan 130 at 100%	No CHP
70% Flexible CHP	Titan 130 at 70%	Traditional CHP of a similar size (10.7 MW CHP)	No CHP
50% Flexible CHP	Titan 130 at 50%	Traditional CHP of a similar size (Taurus 70)	No CHP

- **Sensitivities**

Sensitivity	Comment
Utility Territory	Tariffs in SCE and PG&E
Natural Gas Price	Average prices from customers in CA are used in base case. This examines impact of natural gas at half the cost
Fuel Efficiency Improvements in CHP	Base case utilizes specifications from Titan 130. this sensitivity examines impact of improving part-load efficiency by 10% (i.e. 10% improvement in fuel flow and heat rate)

Value Streams and Value Stacking

- There are many values which DERs can provide throughout the grid domain, including generation, transmission, distribution and customer/end-user
  - T&D are not applicable for this case, as there are no specific T&D needs identified

Service	Grid domain	Market domain	Timing of Decision	Energy Duration Requirement
Resource Adequacy	Generation	Wholesale/ Resource Adequacy (RA)	3 years to 9 months ahead	Hours
Day-Ahead Energy Time Shift			Daily	Hours
Real-Time Energy Time Shift			System Operations	Minutes to Hours
Frequency Regulation				Minutes to Hour
Frequency Response				Minutes
Spinning Reserve				Minutes to Hour
Non-Spinning Reserve				Minutes to Hour
Flexible Ramping				Minutes
Black Start				Minutes
Demand Charge Reduction	Customer / End-user	Customer / End-user	Monthly	Hours
Retail Energy Time Shift			Real-time	Hours
Power Quality			Day-ahead to real-time	Seconds to Minutes
Backup Power			Day-ahead to real-time	Hours
Demand Response Program Participation			Day-ahead to real-time	Hours
Renewable Energy Net Energy Meter Program Participation			Real-time	Hours

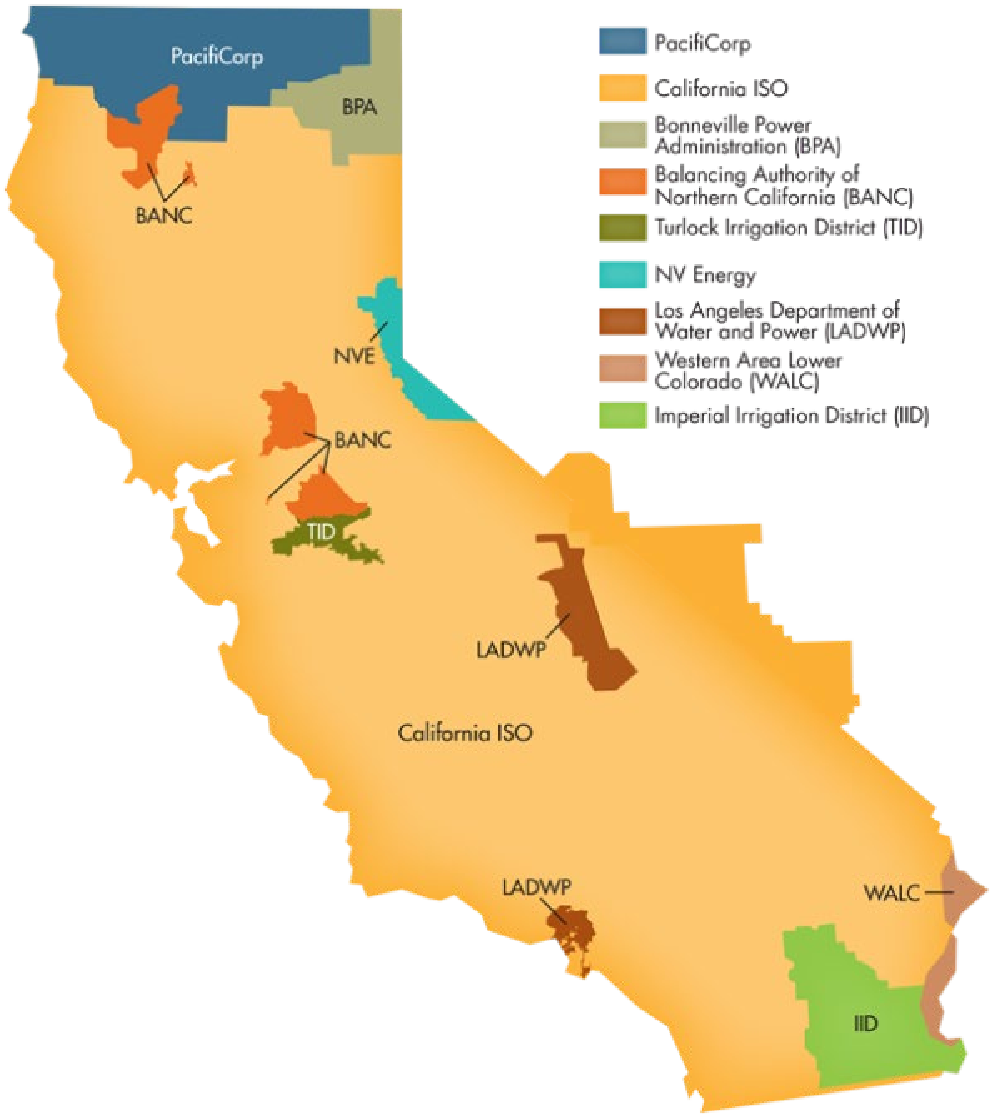
Investigated

Potential service

Source: EPRI

CAISO Overview

The California Independent System Operator is a non-profit Independent System Operator serving California. It oversees the operation of California's bulk electric power system, transmission lines, and electricity market generated and transmitted by its member utilities



Energy Time-Shift: The energy product is generally provided by DERs either by participating in the energy markets only, to provide energy time-shifting or generating bulk energy, or by jointly providing energy with other services

Frequency Regulation: The service provided by generating units equipped and operating with automatic generation controls that enables the units to respond to the ISO's direct digital control signals to match real-time demand and resources, consistent with established operating criteria

Spinning Reserves: Generation capacity that is already operating and synchronized to the system that can increase or decrease generation within 10 minutes. Spinning reserve is utilized primarily to protect against contingencies, notably unplanned outages of major facilities such as transmission lines or generators.

Grid Service Analysis

- **Customer Load Managemen**t to reduce customer combined cost of electricity and natural gas, including energy and demand charges, by producing power and thermal energy locally
- **Energy Time Shift ("Energy Arbitrage")** which takes advantage of hourly price differentials, while meeting the primary objective constraints
- **Frequency Regulation or Frequency Response** to provide ancillary services to CAISO
- **Spinning Reserve** to provide the generation capacity of the system in case of contingencies

The following grid and customer services were not considered in this study but are services flexible CHP systems can provide:

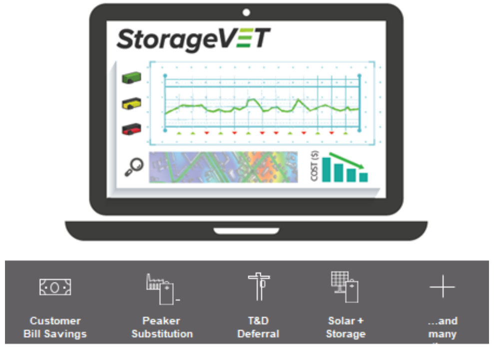
- **Backup Power** to increase reliability of customer load in case of a sustained grid outage
- **Local Utility Power Purchase Programs** to provide excess power generated from facilities to connected utility. For example, in California, the AB1613 programs provide utility customers with eligible CHP systems to execute a power purchase contract with local utility for selling energy to the utility.
- **Reactive support** such as VARS support
- **Resource Adequacy** to provide capacity to the wholesale market

DER-VET™ Distributed Energy Resource Value Estimation Tool

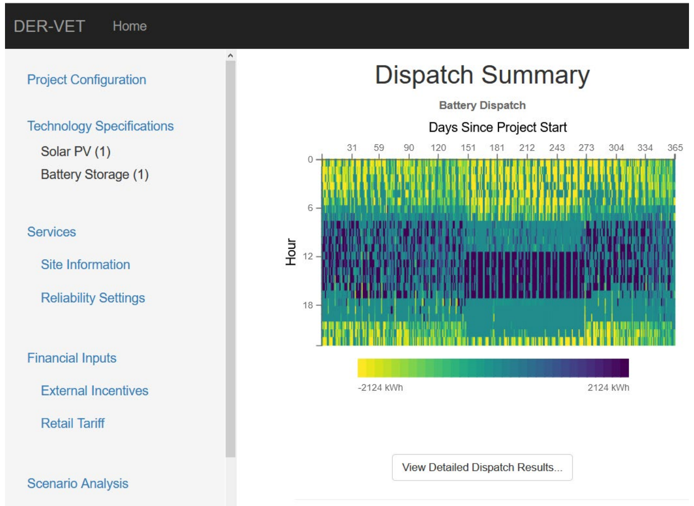
www.der-vet.com

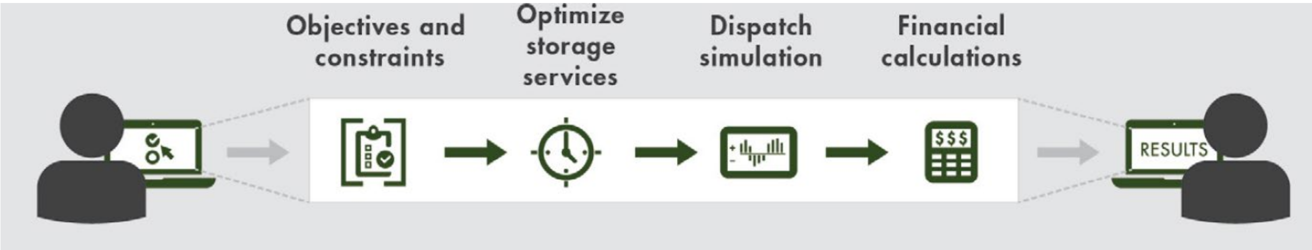
- *Overview*
  - Explores site-specific energy storage project value with stacked services
  - Customizable for location, storage technology, sizing, use cases
  - Time-series constraints, dispatch optimization simulation, project SOH, Pro forma cash flows, and CBA
  - Stand-alone and free access
- *Applications*
  - All grid services (wholesale, retail)
  - All storage technologies and sizes
  - Any grid location

StorageVET® 2.0 (Python)
Stand-alone
2018-2020+



DER-VET™ (Python)
Stand-alone & Web-hosted
2018-2022





CHP System Data Input and Assumptions

- A site owner would likely compare a traditional CHP system and flexible CHP system.
- CHP systems (flexible and traditional) can help meet thermal needs
  - Otherwise, an auxiliary boiler would be required

	Site Electric Load	Site Thermal Load
Traditional CHP	16.2 MW_e	19.12 MW_{th}
50% Flex. CHP	7.9 MW_e	9.32 MW_{th}
70% Flex. CHP	11.1 MW_e	13.08 MW_{th}

Titan 130 Estimated Part Load Performance Specification. Source: Solar Turbines

Specified Load	Full, 100%	70%	60%	50%
Turbine Net Output kW	15,878	11,082	9,499	7,939
Fuel Flow (LHV) MMBtu/hr	156.47	122.3	112.5	102.77
Heat Rate (LHV) Btu/kWh	9,854	11,035	11,839	12,945
Nominal Electrical Efficiency @ Terminals, %	34.626	30.9	28.8	26.359
Exhaust Heat Captured, MMBtu	69.7	58.4	55.7	52.9

Taurus 70 Performance Specifications. Source: Solar Turbines

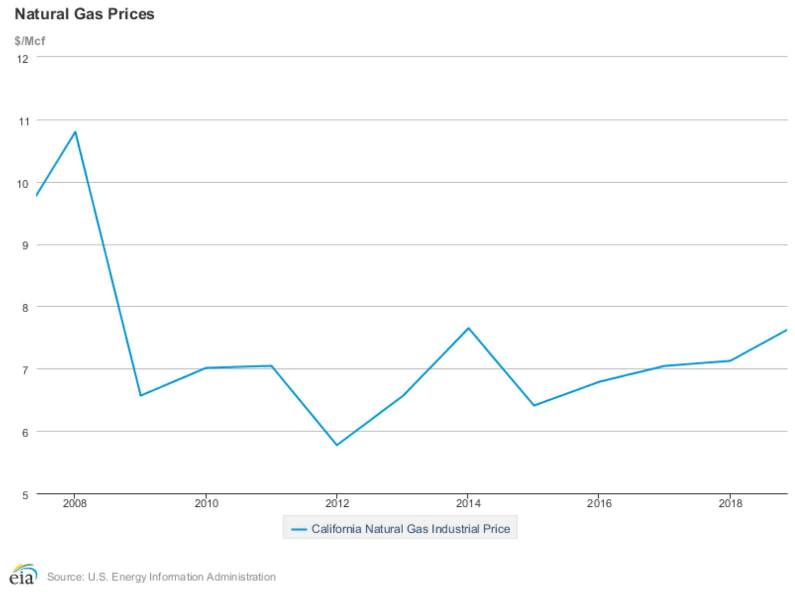
Specified Load	Full, 100%
Turbine Net Output kW	7,676
Fuel Flow (LHV) MMBtu/hr	78.5
Heat Rate (LHV) Btu/kWh	10,290
Overall Cycle Efficiency (LHV):	78.2%
Exhaust Heat Captured, MMBtu	32.98
Heat to Power Ratio	1.26

Generic 10.67 MW Gas Turbine Performance Specification. Modified from DOE

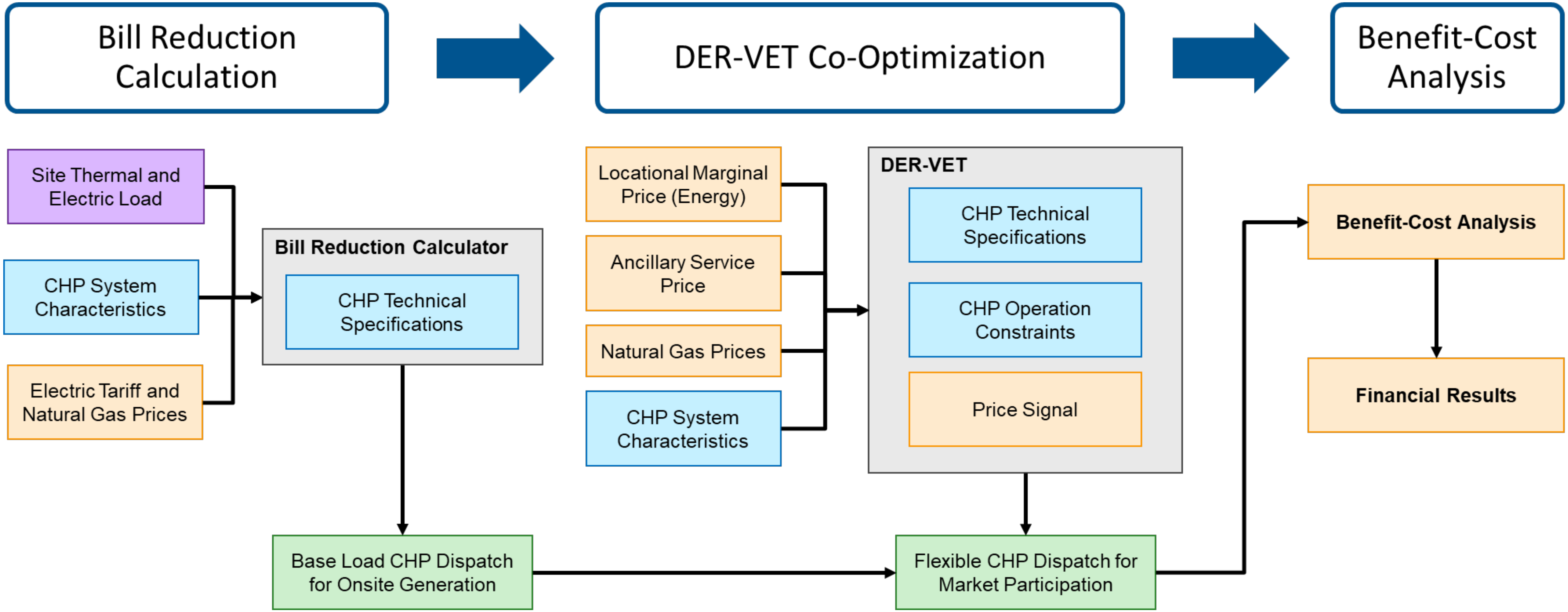
Specified Load	Full, 100%
Turbine Net Output kW	10,669
Fuel Flow (LHV) MMBtu/hr	117.12
Overall Cycle Efficiency (HHV)	68.2%
Exhaust Heat Captured, MMBtu	52.2
Heat to Power Ratio	1.43

Electric Utility Tariffs and Natural Gas Prices

- For electric utility, including standby rates, demand charges, energy charges
  - Time of use periods, including peak, part-peak, off-peak, super off-peak
  - Season: summer and winter
- **PG&E's Schedule B-20** and standby Schedule SB for (> 1MW customers)
- **SCE's Schedule TOU-8-S**, large general service, time-of-use rate with standby
- The natural gas price is assumed to be **$7/Mcf, or $6.75/MMBtu**
  - Averaged value for industrial customers in California
  - As provided by U.S. Energy Information Administration
  - California's natural gas prices are higher than rest of US
    - Sensitivity to see impact
- These components determine customer bill savings
  - Compare CHP investment versus no CHP investment



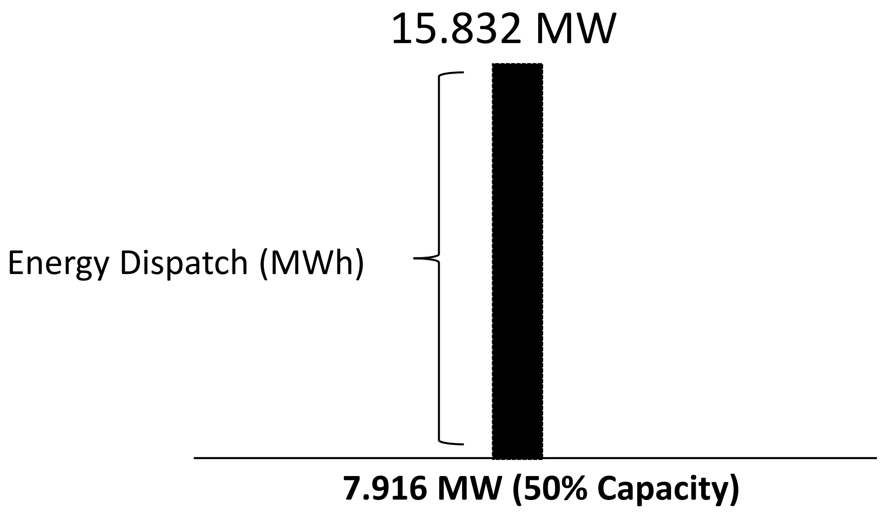
Analysis Framework



CAISO Wholesale Market Participation

- Assuming Gross Output @ specified site conditions: 15.832 MW
- There are 4 ways which flexible CHP system can participate in CAISO market for energy, spinning reserve, and frequency regulation services

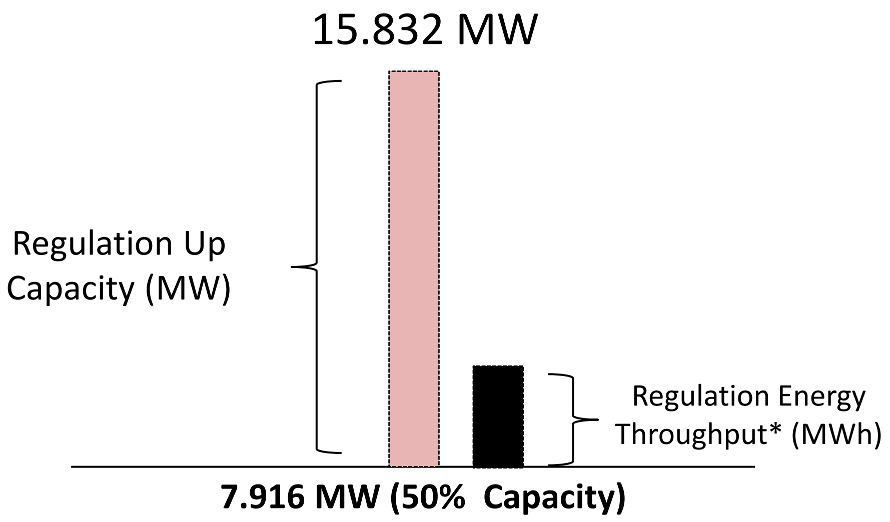
CASE 1: Turbine dispatches energy while operating at minimum capacity



❖ **When Grid Energy Price is significantly high as compared to Turbine Operational Cost**

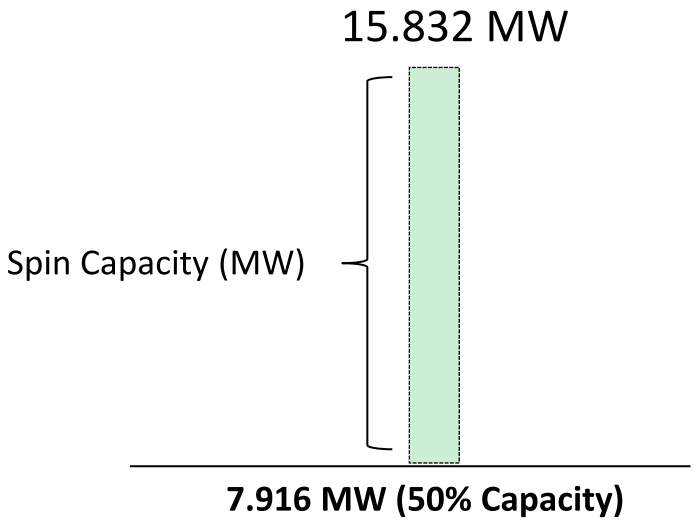
CAISO Wholesale Market Participation

CASE 2: Turbine offers Regulation Up while operating at minimum capacity



- **When Regulation Up price is high**
- **When Grid Energy Price is high**

CASE 3: Turbine offers Spin while operating at minimum capacity

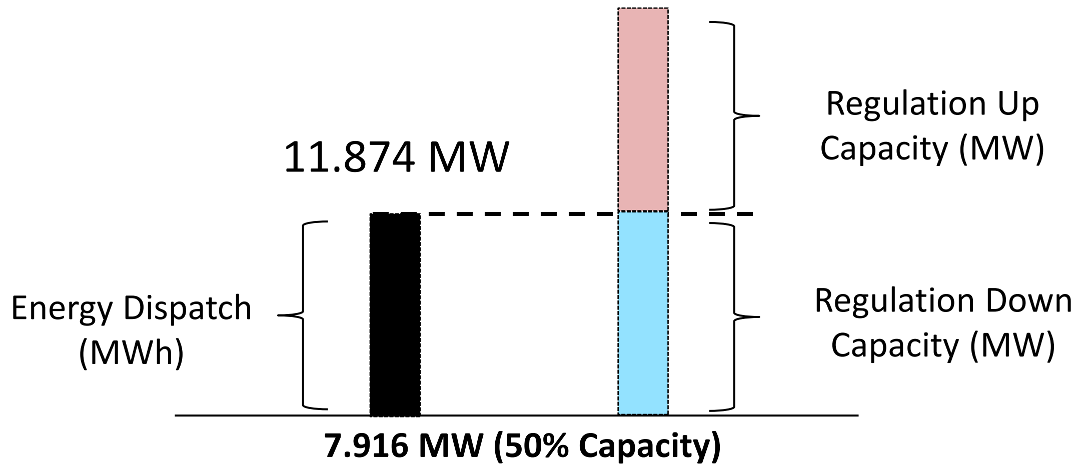


- **When Spin price is high**
- **When Grid Energy Price is low**

***Regulation Energy Throughput =** k-value X Reg Up/Reg Down Capacity*
(k-value is calculated based on AGC signal)

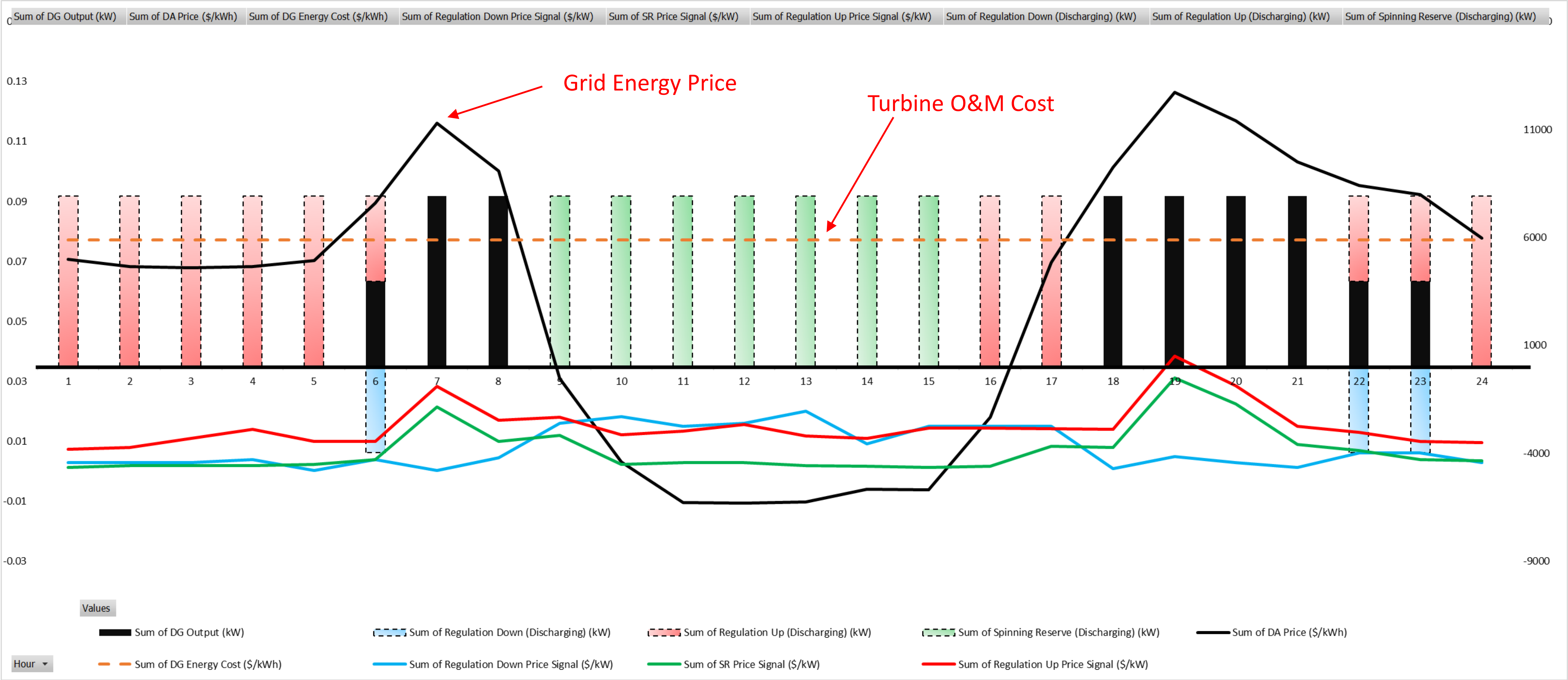
CAISO Wholesale Market Participation

CASE 4: Turbine offers symmetric capacity of Reg Up & Reg Down while operating at 75% rated capacity



- ❖ **When both Reg Up & Reg Down prices are high**
- ❖ **When grid energy price is significantly high**

Turbine Operation (February 6th)

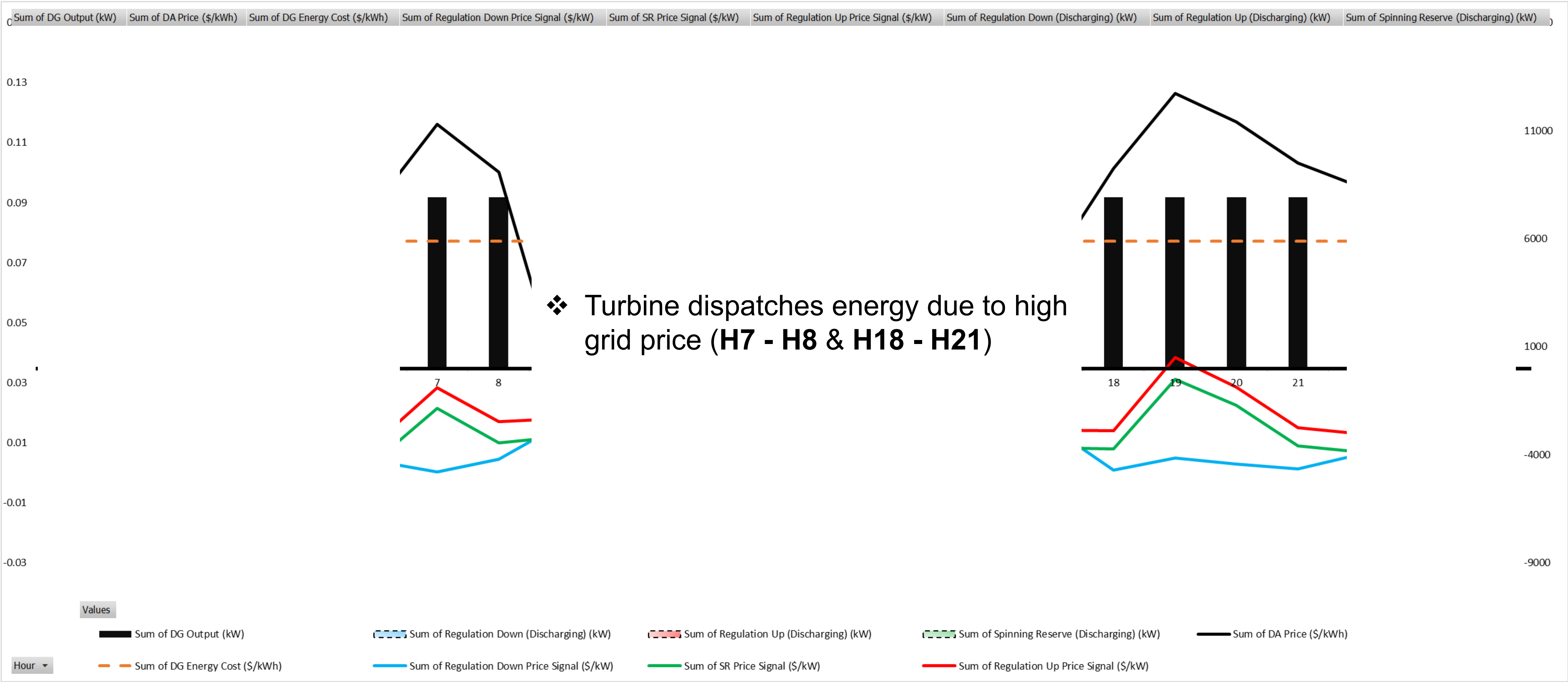


Note: Energy dispatch due to Regulation Energy Throughput is not included in the graph. (Included in financial results)

Turbine Operation (February 6th)

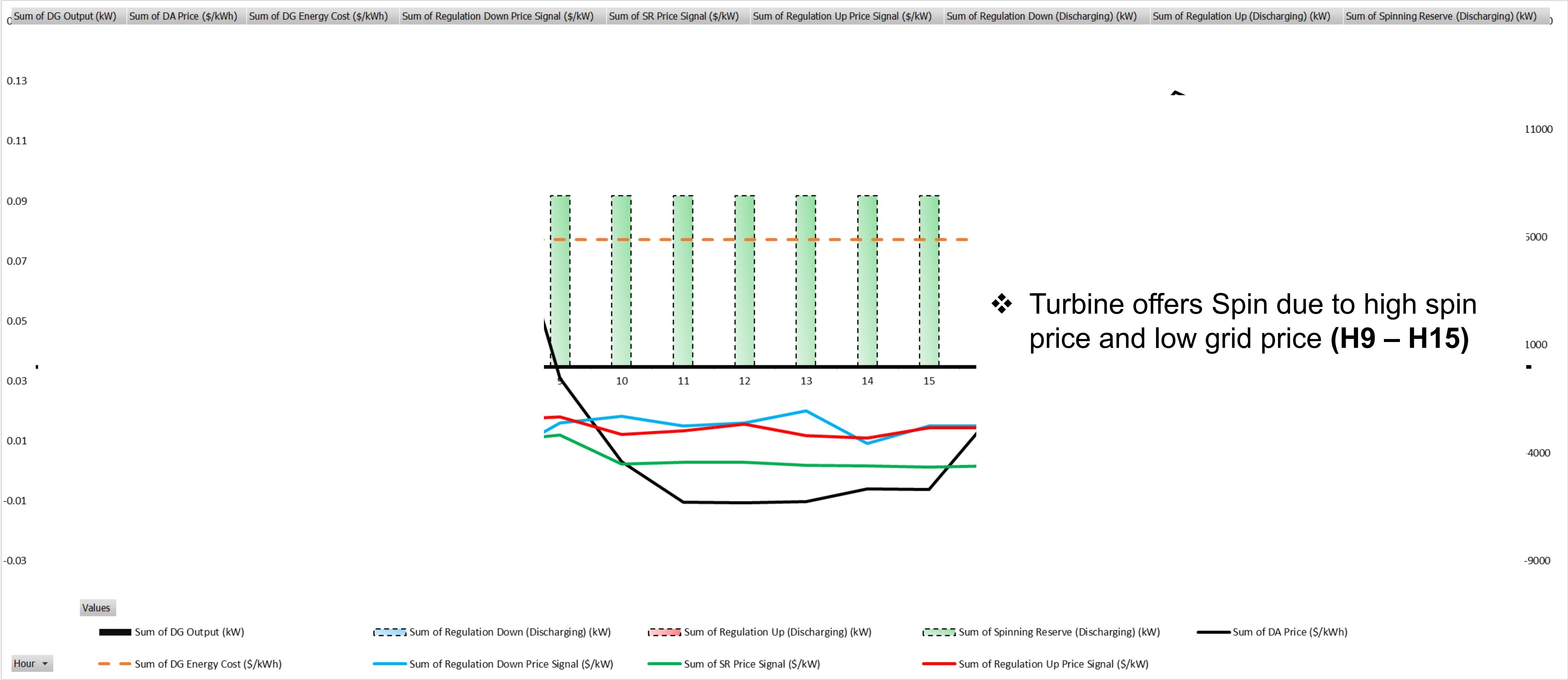
- Turbine offers Regulation Up due to high Reg Up price **(H1 – H5)**

Turbine Operation (February 6th)



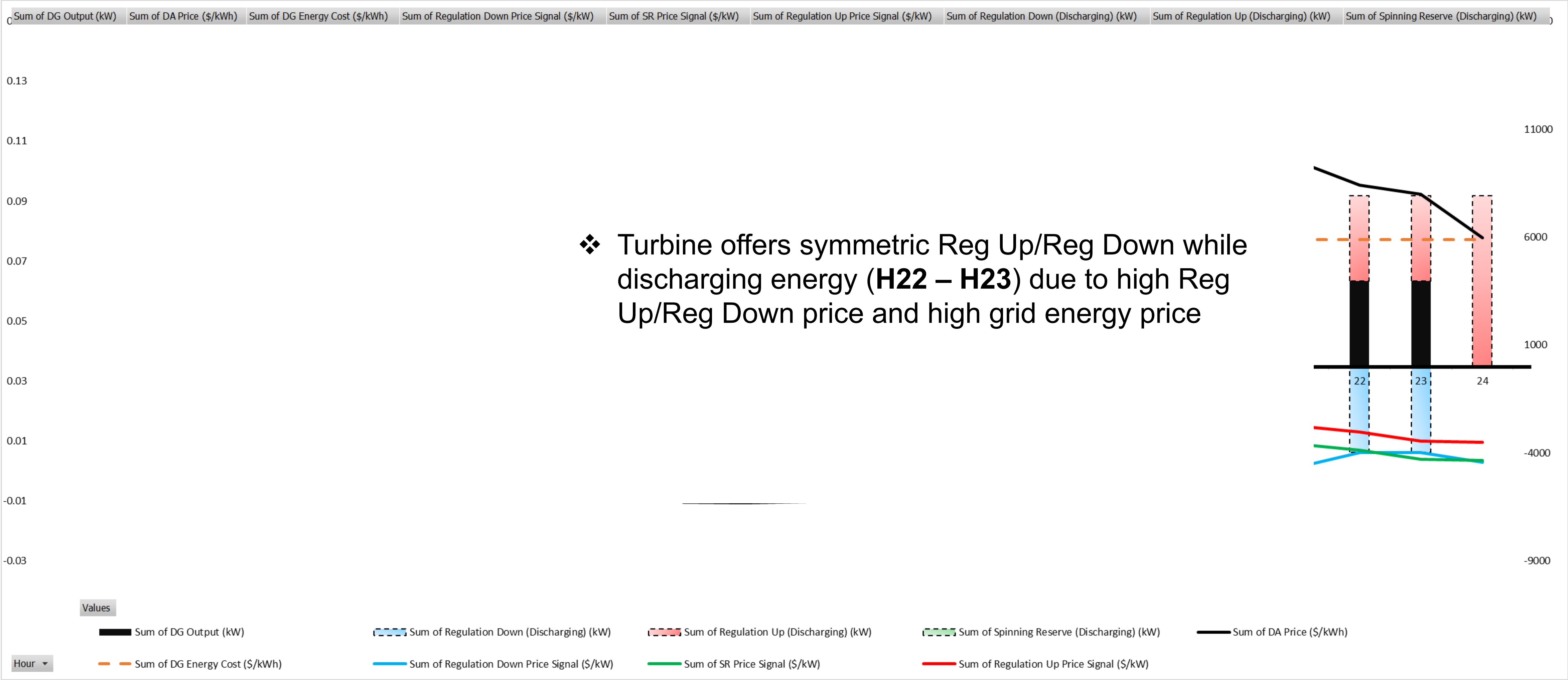
- Turbine dispatches energy due to high grid price (**H7 - H8 & H18 - H21**)

Turbine Operation (February 6th)



- Turbine offers Spin due to high spin price and low grid price **(H9 – H15)**

Turbine Operation (February 6th)



- Turbine offers symmetric Reg Up/Reg Down while discharging energy (**H22 – H23**) due to high Reg Up/Reg Down price and high grid energy price

Annual Revenue

Scenario	% onsite gen vs. market	Improved Fuel Efficiency	Fuel Price ($/MMBTU)	SCE Node			PG&E Node		
				Total Revenue			Total Revenue	Variable O&M	
1	50/50	No	6.75	$784,922	$12,412	$772,510	$1,095,533	$15,357	$1,080,176
2	50/50	No	3.375	$1,206,774	$74,885	$1,131,889	$1,479,555	$82,643	$1,396,912
3	50/50	Yes, 10%	6.75	$862,250	$14,997	$847,253	$1,150,662	$18,365	$1,132,297
4	70/30	No	6.75	$470,893	$7,446	$463,447	$657,236	$9,213	$648,023
5	70/30	Yes, 10%	6.75	$517,272	$8,985	$508,287	$690,310	$11,017	$679,293

- For a given turbine and fuel price, there is more value in operating the turbine in the PG&E node than the SCE node
- Lower fuel price and turbine heat rate increases the net revenue significantly
- Larger turbine capacity increases net revenue appreciably

Results – Base Case

- B/C ratio for flexible CHP is not as competitive as traditional CHP for the same load
- 50% Flexible CHP less cost effective than 70% Flexible CHP
- There is no consistency of savings between utilities, indicating site specific analysis for cost-benefit
  - PG&E tariffs are more expensive for constant load
- Even with added CAISO market services, 50% Flexible CHP case is not as cost effective as traditional CHP
  - Bill savings dominates revenue, so 70% Flexible CHP more cost competitive

		% for Onsite Gen	Utility	Natural Gas Price	Improved Fueled Efficiency	Bill Savings Electric + Gas for Year 1	Net Present Value over 20 years	B/C Ratio
Traditional CHP	Trad. CHP Case #1	100% 15.8 MW (Titan 130)	SCE	Base Case	----	$8,694,384	$53,506,248	2.50
50% Flexible CHP	Trad. CHP Case #2	100% 7.6 MW (Taurus 70)	SCE	Base Case	No Flex CHP	$4,092,360	$23,146,941	2.23
	50% Flex. CHP Case #1	50% 15.8 MW (Titan 130)	SCE	Base Case	No	$2,898,707	$7,069,442	1.23
	50% Flex. CHP Case #2	50% 15.8 MW (Titan 130)	SCE	50%	No	$5,258,320	$29,064,715	1.92
	50% Flex. CHP Case #3	50% 15.8 MW (Titan 130)	SCE	Base Case	Yes	$3,482,079	$13,607,038	1.44
70% Flexible CHP	Trad. CHP Case #3	100% 10.7 MW	SCE	Base Case	No Flex CHP	$5,685,900	$28,342,319	2.33
	70% Flex. CHP Case #1	70% 15.8 MW (Titan 130)	SCE	Base Case	No	$5,735,389	$30,513,202	1.93
	70% Flex. CHP Case #2	70% 15.8 MW (Titan 130)	SCE	Base Case	Yes	$6,429,565	$37,547,063	2.14

Results – Sensitivity Case

- B/C ratio for flexible CHP still is not as competitive as traditional CHP for the same load
- For 50% Flexible CHP, if NG price is half the cost, B/C ratio comes closer, indicating that cost of NG can significantly impact revenue
- For 70% Flexible CHP, 10% improved fuel efficiency at part load improves B/C ratio
- 70% Flexible CHP cases are stronger, indicating bill savings is important

		% for Onsite Gen	Utility	Natural Gas Price	Improved Fueled Efficiency	Bill Savings Electric + Gas for Year 1	Net Present Value over 20 years	B/C Ratio
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	70% Flex. CHP Case #2	70% 15.8 MW (Titan 130)	SCE	Base Case	Yes	$6,429,565	$37,547,063	2.14

Key Points of Flexible versus Traditional CHP

- Different in cost of electricity and gas, which is sum of:
  - Natural gas used for CHP
    - Major difference – higher fuel efficiency at full load (Traditional CHP T70 or Traditional 10.7 MW CHP), compared to running at part load (Flexible CHP T130)
    - ***Higher NG cost for flexible case***
  - Purchase of remaining electricity needs, due to different H/P ratios for systems
  - Standby rates
- Added costs that scale with $/kW:
  - Capital cost for T130 versus T70, (or T130 versus Generic 10.7 MW)
  - Additional FOM because FOM is based on $/kW-yr
- **Market revenue from CAISO (PG&E node)**
  - **$648,023 per year** for 70/30 case and $1,080,176 **per year** for 50/50 flexible case
  - Added O&M costs (FOM almost doubled and VOM slightly for operating in the market)
- Same revenue for avoided boiler O&M and capital costs
- Total Revenue (market participation, bill reduction, avoided boiler O&M):
  - Tradition CHP remains most competitive, but 70% Flexible or a higher portion may be close to traditional CHP

Flexible CHP Interconnection

Select Interconnection Queue

Rule 21 Export

Wholesale Distribution Tariff

FERC vs CPUC Jurisdiction?

CAISO Participation?

>60kV is Transmission

Select Applicable Cue for Minimized Cost

Summary

Interconnection requirements are site- and utility-specific

Deliverability status may significantly impact project economics

Current rules for grid-exporting revenue projects are still challenging

Advance planning and understanding of timelines are key to successful interconnection

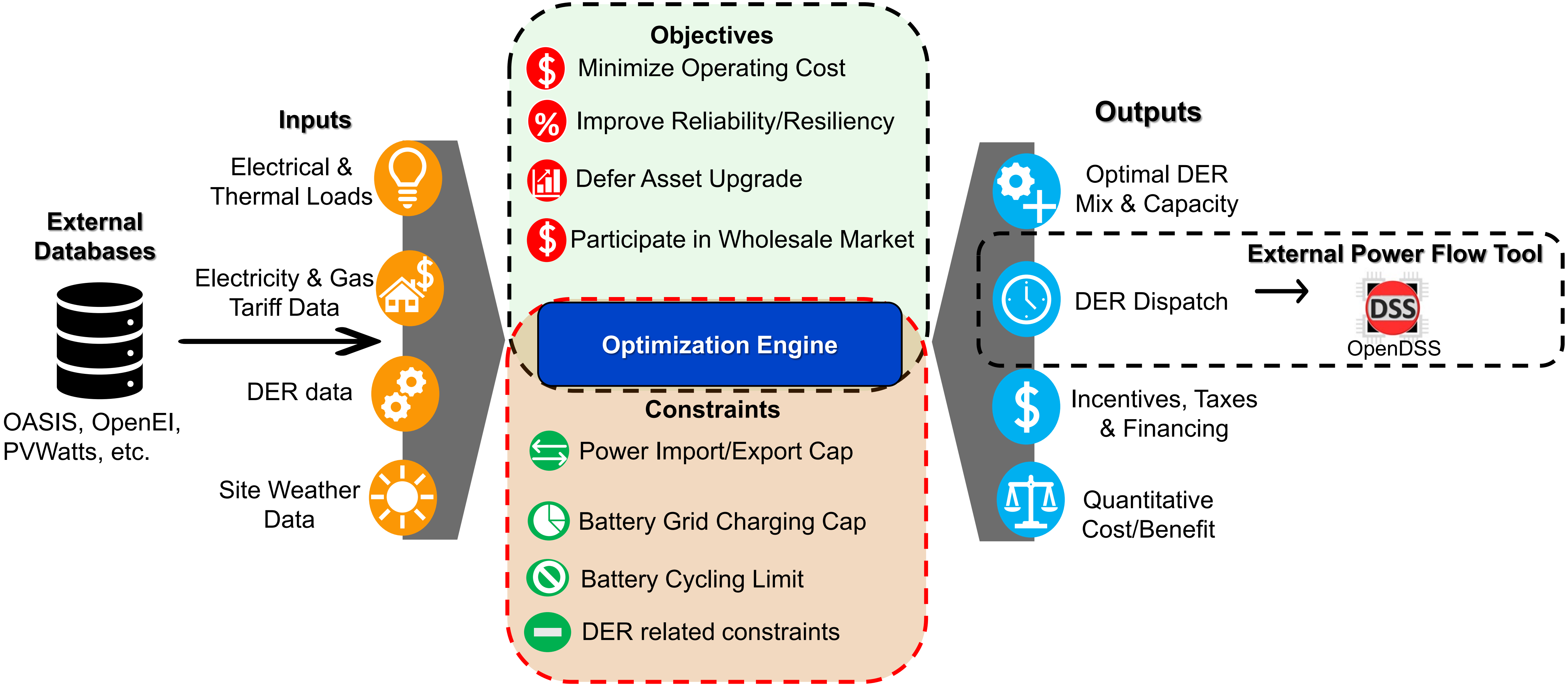
Key Takeaways

Conclusion and Research needs

- **Potential firming resources** for electric grid of the future
- **Market signals and grid services** will need to be transparent for site owners to consider flexible CHP
  - Open-source tools for site-specific analysis
- **Interconnection requirements may pose challenges**, but standards and rules are evolving
- Post-combustion emission controls may be needed in some sites with specific emissions requirements
- Need: More granular publicly available industrial load data
  - Thermal and electric hourly profile, much like the different commercial types

Thank you!

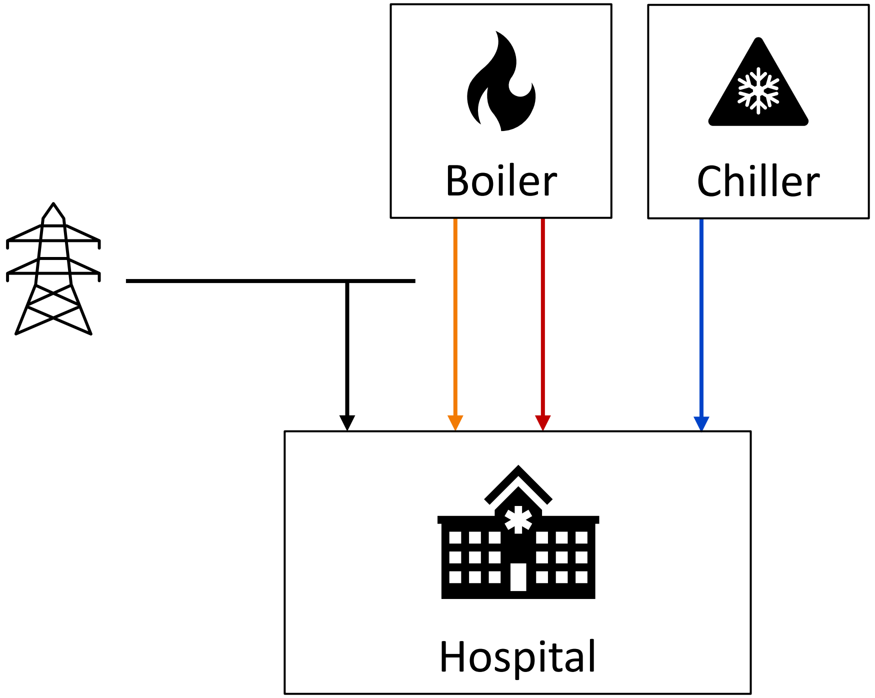
DER-VET Optimization Framework

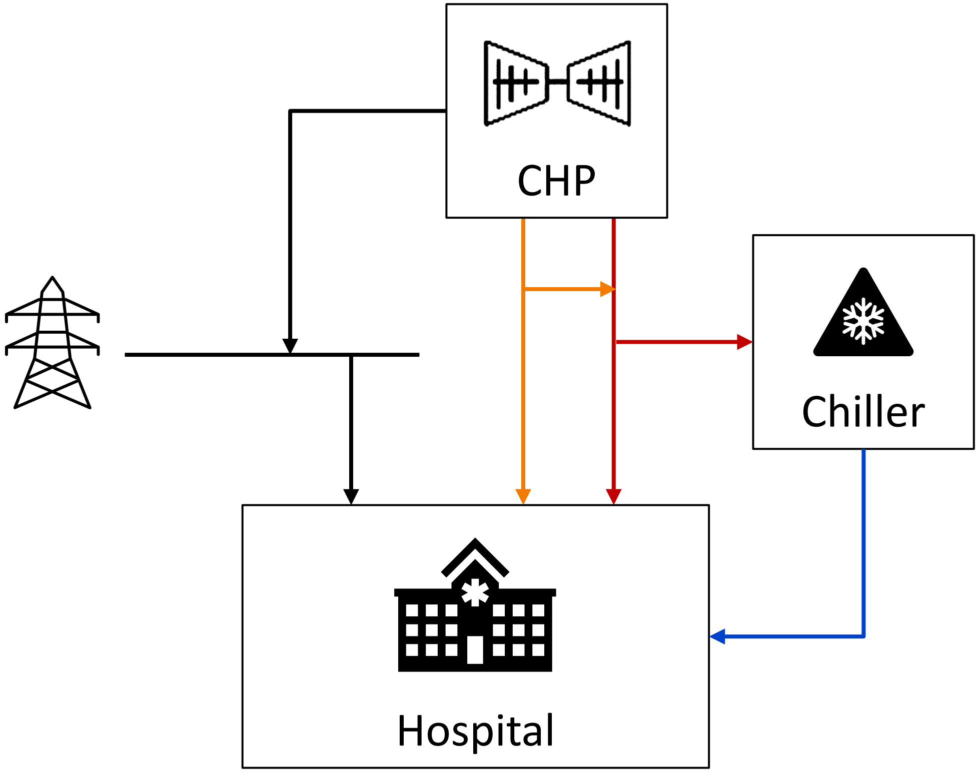


*DER-VET is CEC funded open-sources software tool. https://www.der-vet.com/

CHP Use Cases in DER-VET: Scenarios

- Hospital: hot water, steam and cooling load
- Wastewater Treatment Plan: hot water and steam thermal loads, no cooling load
- Industrial: no hot water load, steam and cooling load





https://www.epri.com/research/products/000000003002021882

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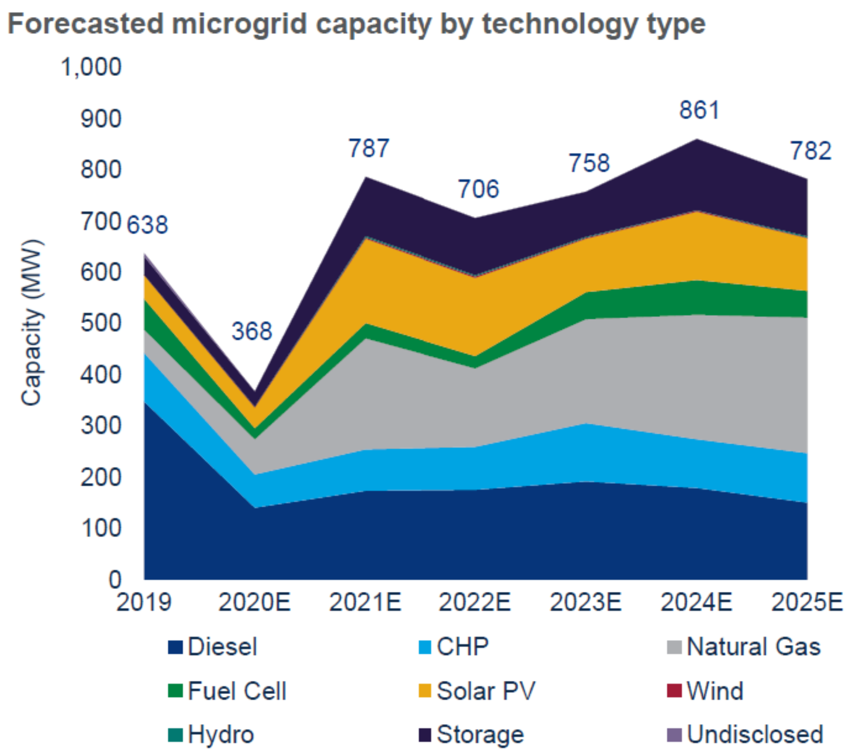
- Alternative energy carriers
- Blending hydrogen
- Uses of CHP to reduce emissions
  - Across smaller and medium scales
  - Commercializing prime movers
  - Alternative fuels
  - Resilience



Source: Wood Mackenzie Grid Edge Service, Microgrid Forecast

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