Looking from the Past to the Future: Combined Heat and Power Performance Under California's Self-Generation Incentive Program

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Knowledge to Shape Your Future

CPUC Webinar

November 14, 2011

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Acknowledgements and Introductions

- Acknowledgements
  - California Public Utilities Commission (CPUC)
    - Overall direction on the SGIP
  - Program Administrators:
    - Day to day administration of the SGIP
    - PG&E, SCE, SCG, CCSE (on behalf of SDG&E)
  - Stakeholders
    - Provided essential performance data, access to operations information and review of evaluation studies
      - ✓ CHP industry
      - ✓ Utility customers acting as host sites
      - ✓ Academic community
- Introduction of team presenting today

Objectives of Today's Webinar

- Help inform the discussion on performance of combined heat and power (CHP) systems
- Provide CHP performance results based on ten years of operation of CHP systems under California's SGIP
  - Identify CHP performance in terms of efficiencies and availability of electricity generation and useful waste heat recovery
  - Place these results in a larger context of the energy landscape surrounding the deployment of CHP systems
  - Examine and discuss possible reasons for lower than expected performance
- Compare SGIP CHP performance to other CHP systems
  - Lessons learned along the way
  - New approaches being investigated
- Identify potential ways CHP performance can be improved in the future
  - CHP system performance
  - CHP can capture GHG benefits!
- Provide recommendations
- Answer questions

Agenda

- Background on the 2010 SGIP impact evaluation:
  - Objectives: what did we hope to learn
  - Scope: technologies evaluated and timeframe
  - Why a strong emphasis on CHP performance?
- The status of the SGIP and SGIP CHP systems at 2010
- Looking backwards: changes in the CHP SGIP fleet over time
- The SGIP 2010 impacts and CHP affects
- What to expect from CHP systems as the SGIP fleet moves forward
- Recommendations: improving CHP system performance and capturing GHG benefits
- Questions

Objectives of the 2010 SGIP Impact Evaluation

- Overall goal is to help policy makers and stakeholders make informed decisions regarding the SGIP design and implementation
  - Special interest in CHP performance and improving GHG emission reductions
- Specific objectives include program-wide and utility-specific impacts related to*:
  - Electrical energy production (monthly, annual)
  - Coincident peak demand (program as well as utility-specific)
  - Operating and reliability characteristics (e.g., capacity factor)
  - Compliance with thermal energy utilization and system efficiency requirements
  - Air pollution and greenhouse gas (GHG) emissions
- However, the 2010 impact evaluation also examines ten years performance of combined heat and power systems under the SGIP
  - Identify factors that possibly affected CHP performance
  - Pinpoint ways to help improve and sustain performance of CHP systems
  - Target specific ways that CHP design and operations can help the SGIP achieve significant reductions in GHG emissions

* Transmission and distribution system impacts were not examined under the 2010 SGIP impact evaluation as these were investigated in the report “Optimizing Dispatch and Location of Distributed Generation,” July 2010

Scope of the 2010 Impact Evaluation

- Technologies examined
  - CHP systems examined under the SGIP included all systems fueled by natural gas, propane or biogas
  - Investigated changes in the make up of the SGIP fleet as well as changes in the individual CHP technologies over time
  - Examined changes in performance of CHP technologies over time:
    - Efficiencies (thermal and electrical)
    - Utilization (e.g., capacity factor and availability)
  - Relationship between GHG emissions and performance
    - Electrical conversion efficiency and GHG emissions
    - Useful waste heat efficiency and GHG emissions
    - Impact of biogas (methane recovery) on GHG emissions
- However, the 2010 impact evaluation also examines ten years performance of combined heat and power systems under the SGIP
  - Identify factors that possibly affected CHP performance
  - Pinpoint ways to help improve and sustain performance of CHP systems
  - Target specific ways that CHP design and operations can help the SGIP achieve significant reductions in GHG emissions

Approach on Assessing CHP System Performance

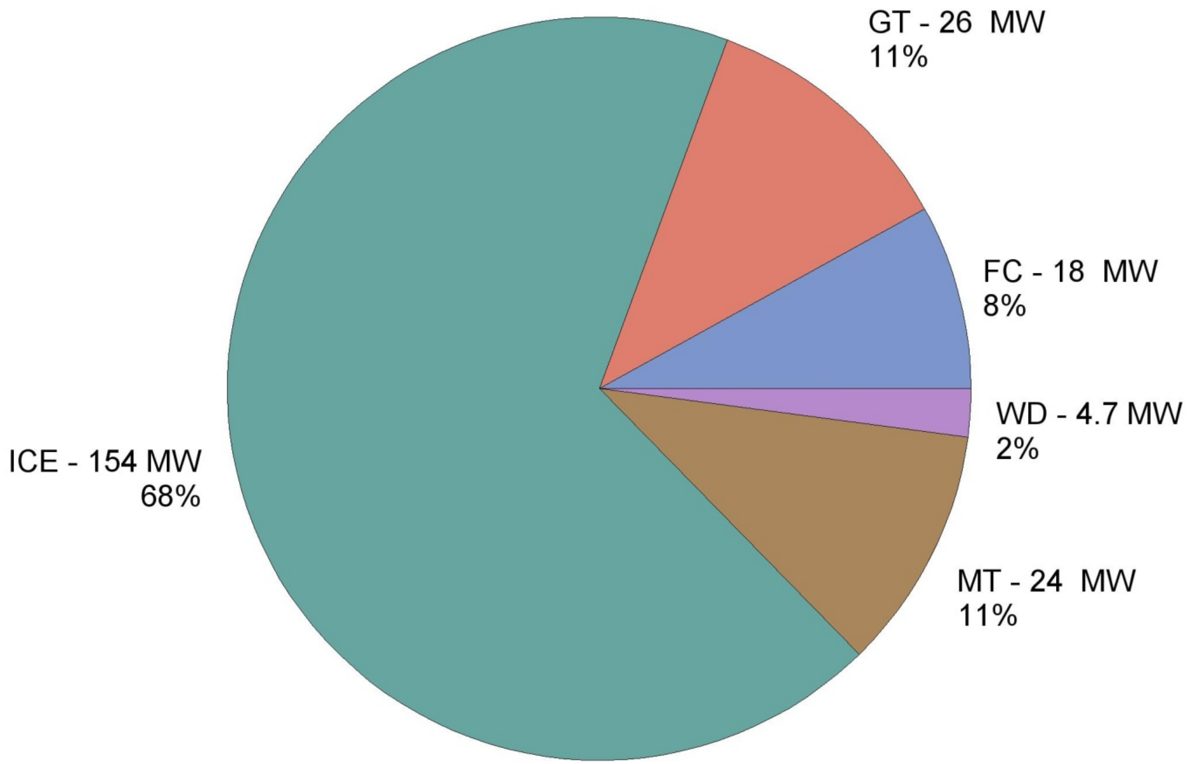
- Our assessment was broken into three parts that coincide with the operation of the SGIP from 2001-2010:
  - 2001-2006: the early SGIP fleet
    - Covers a broad range of technologies in their start up mode and with a high degree of growth
    - PV systems were initially eligible under the SGIP
      - ✓ Effective January 1, 2007, PV technologies were no longer eligible to receive SGIP incentives
  - 2007-2010: the mid-term SGIP fleet
    - The make-up of the SGIP fleet influenced by legislative changes, largely restricting the types of technologies eligible under the SGIP
      - ✓ Effective January 1, 2007, only fuel cells and wind turbines were eligible for the SGIP
      - ✓ In November of 2008, advanced energy storage was added to the eligibility list
      - ✓ In September of 2009, “directed” biogas technologies were made eligible
    - Increasing influence of GHG emission targets
  - Beyond 2010: the SGIP fleet moving forward

Breakdown of SGIP Projects by Technology and Fuel at the end of 2010

Technology & Fuel	Complete		Active (All)		Total		
	(n)	(MW)	(n)	(MW)	(n)	(MW)	Avg. Size (kW)
WD	8	4.7	18	22.8	26	27.5	1,059
FC–N	19	9.7	20	2.3	39	12.0	308
FC–R	8	5.5	8	15.0	16	20.5	1,278
FC-Directed	5	1.8	52	25.2	57	27.0	474
FC-Electric	4	1.3	-	-	4	1.3	325
ICE-N	229	140.4	4	1.7	233	142.0	610
ICE-R	21	13.7	2	0.8	23	14.4	626
GT-N	8	25.7	1	4.4	9	30.1	3,349
GT-R	-	-	1	0.8	1	0.8	750
MT-N	118	20.2	1	0.8	119	21.0	176
MT-R	21	3.8	1	0.2	22	4.0	181
AES	-	-	3	5.5	3	5.5	1,833
All	**441**	**226.8**	**111**	**79.3**	**552**	**306.1**	

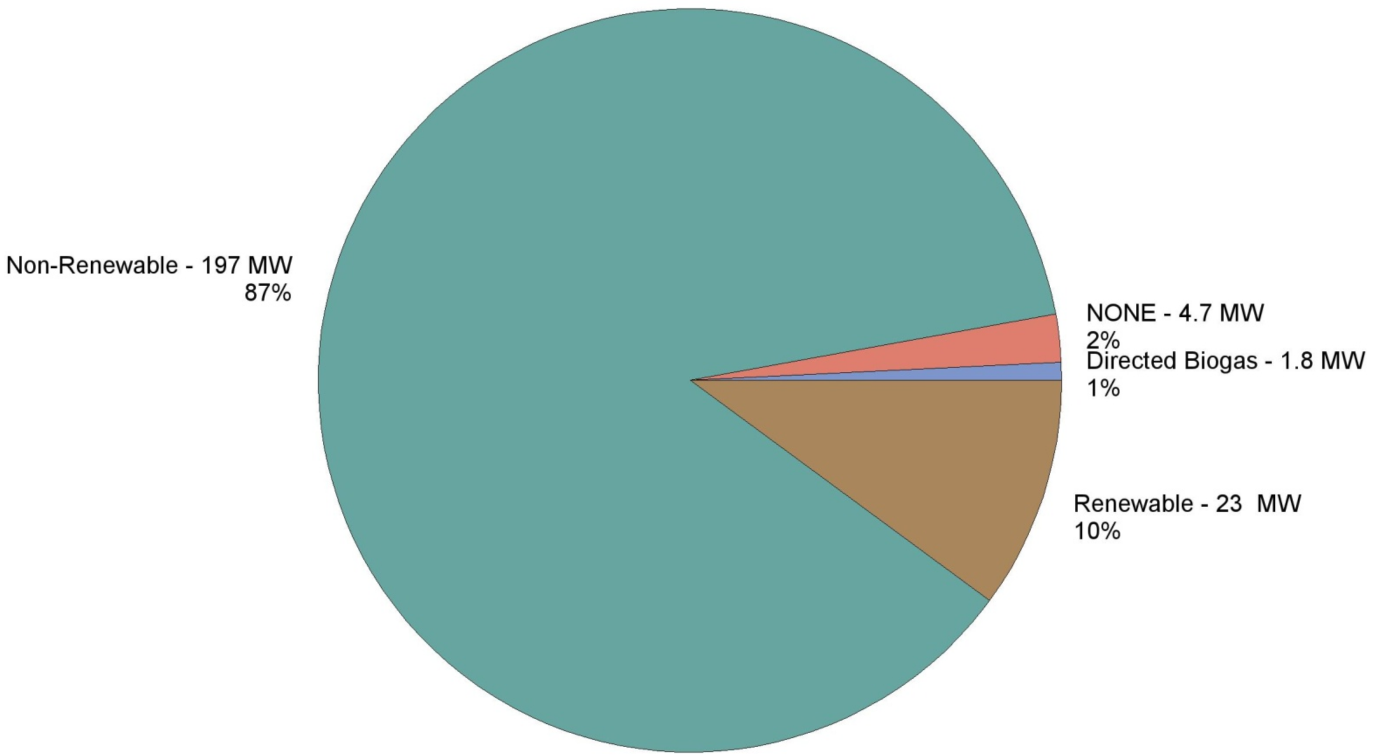
- By the end of 2010 most projects in the SGIP were non-renewable internal combustion engines and microturbines
- A large amount of non-renewable and directed biogas fuel cell projects were active and in the pipeline

Installed Capacity by Technology Type in the SGIP at the end of 2010



- A total of 441 projects representing approximately 227 MW of rebated capacity were installed under the SGIP
- The vast majority of all systems installed were IC Engines

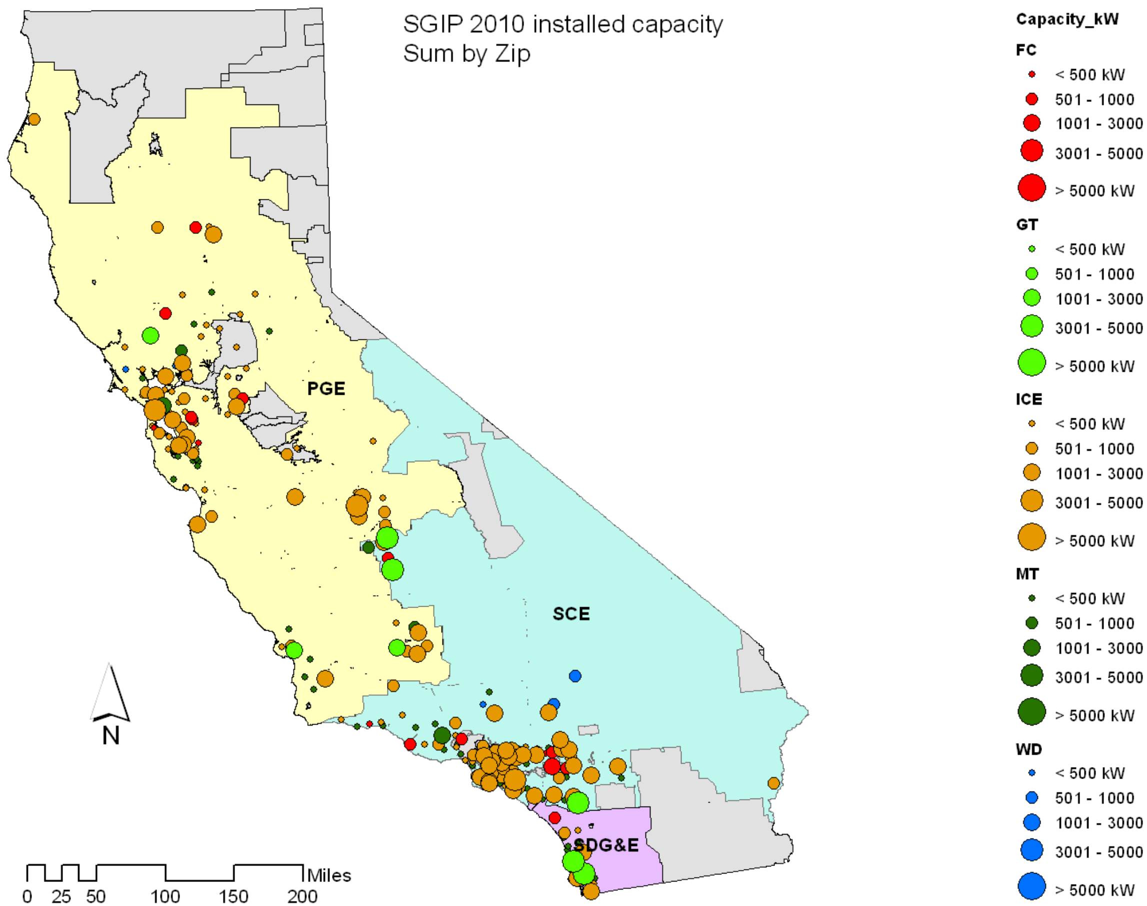
Installed Capacity by Fuel Type in the SGIP at the end of 2010



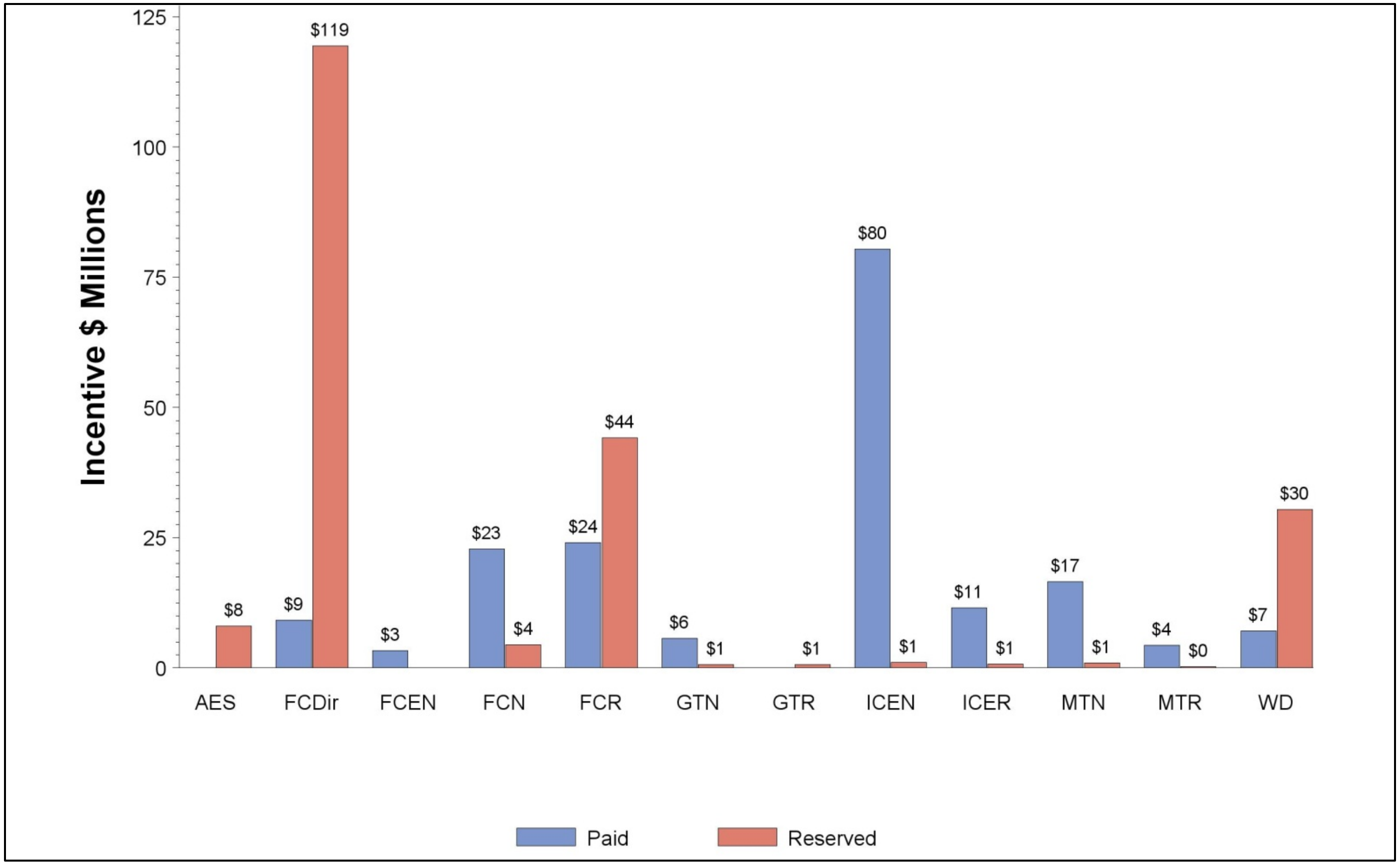
- Most systems in the SGIP were non-renewable fueled
- Approximately 10 percent used an on-site renewable fuel

Distribution of SGIP Projects by PA

PA	No. of Projects	Capacity (MW)
PG&E	193	87.1
SCE	93	40.1
SCG	111	75.1
CCSE	44	24.5
Totals	**441**	**226.8**

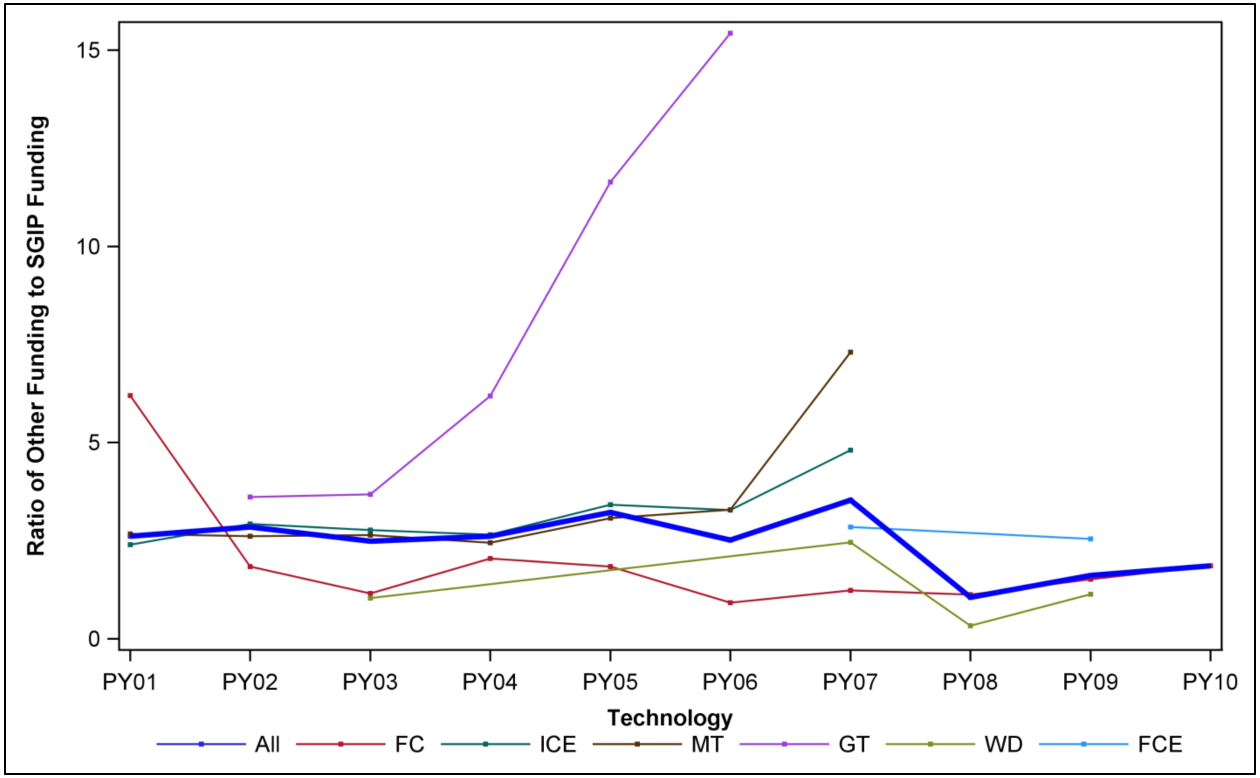


Incentives Paid and Reserved



- By the end of PY10, over $185M in incentive payments had been paid to Complete CHP projects. The reserved backlog totaled $210M
- Much of the reserved backlog by 2010 targeted fuel cells powered by directed biogas

Leveraging of SGIP Funding



- By the end of 2010, the SGIP represented a total investment of over $850 million in project costs making it the largest CHP program in the country
  - Nearly $180 million in funding had been provided under the SGIP for CHP systems; matched by over $470 million in other private and public funds
  - Leveraging of SGIP funding has remained between $2 – $4 of external funding for every SGIP dollar

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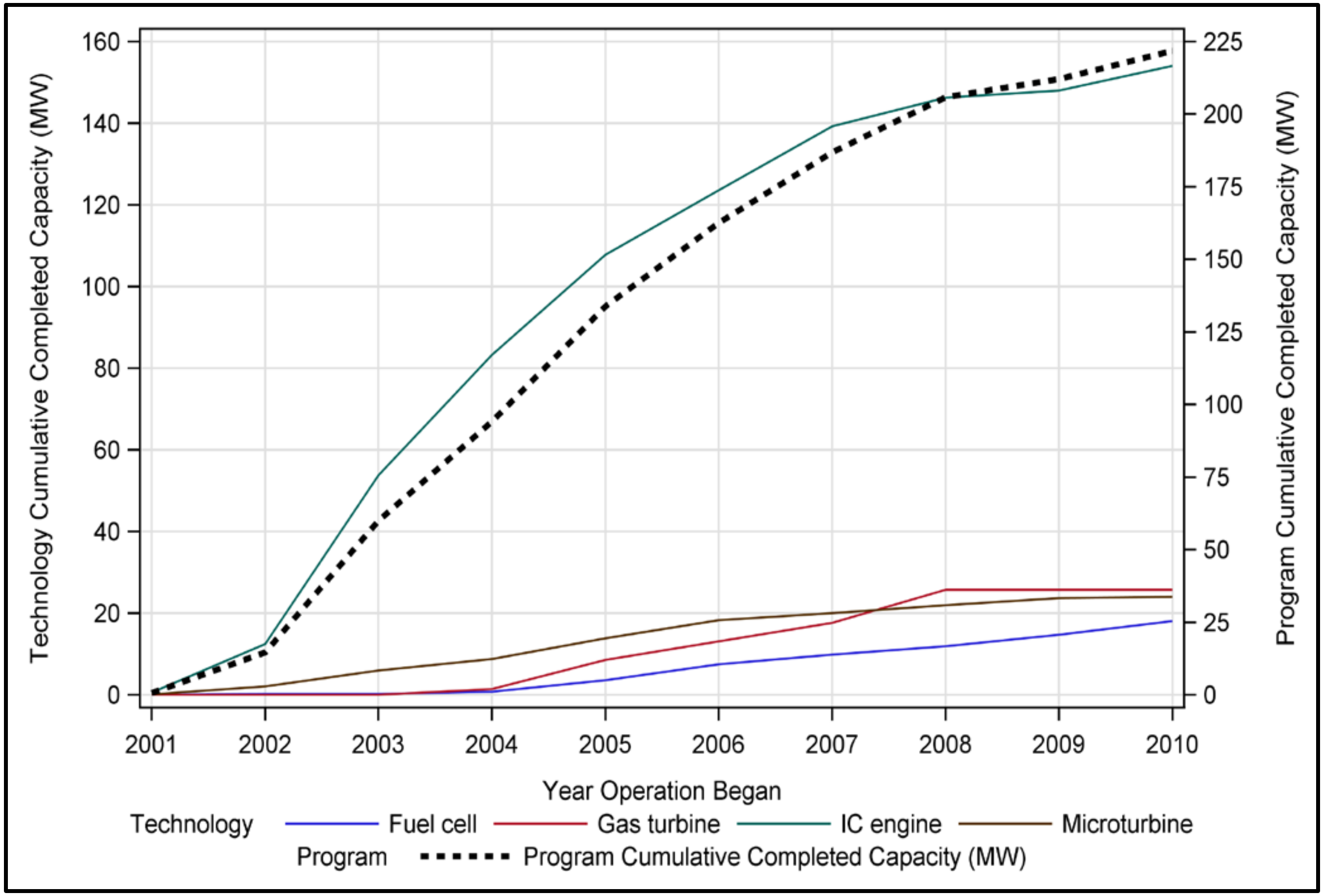
The SGIP Fleet Over Time: Growth in CHP Generating Capacity



- IC engines quickly dominate program capacity
- Capacities of newer technologies grow more gradually

Energy Landscape of the Early Fleet: Top 10 CHP Manufacturers

Manufacturer	System Type	No of projects	% of Total
Capstone	Microturbine	98	23%
Hess Microgen	IC Engine	45	10%
Dresser Waukesha	IC Engine	42	10%
Coast Intelligen	IC Engine	29	7%
Ingersoll Rand (Flex)	Microturbine	29	7%
Tecogen	IC Engine	27	6%
IPower Energy Systems	IC Engine	21	5%
Fuel Cell Energy	Fuel Cell	21	5%
Caterpillar	IC Engine	17	4%
Cummins	IC Engine	13	3%
Other		90	21%
Total		**432**	**100%**

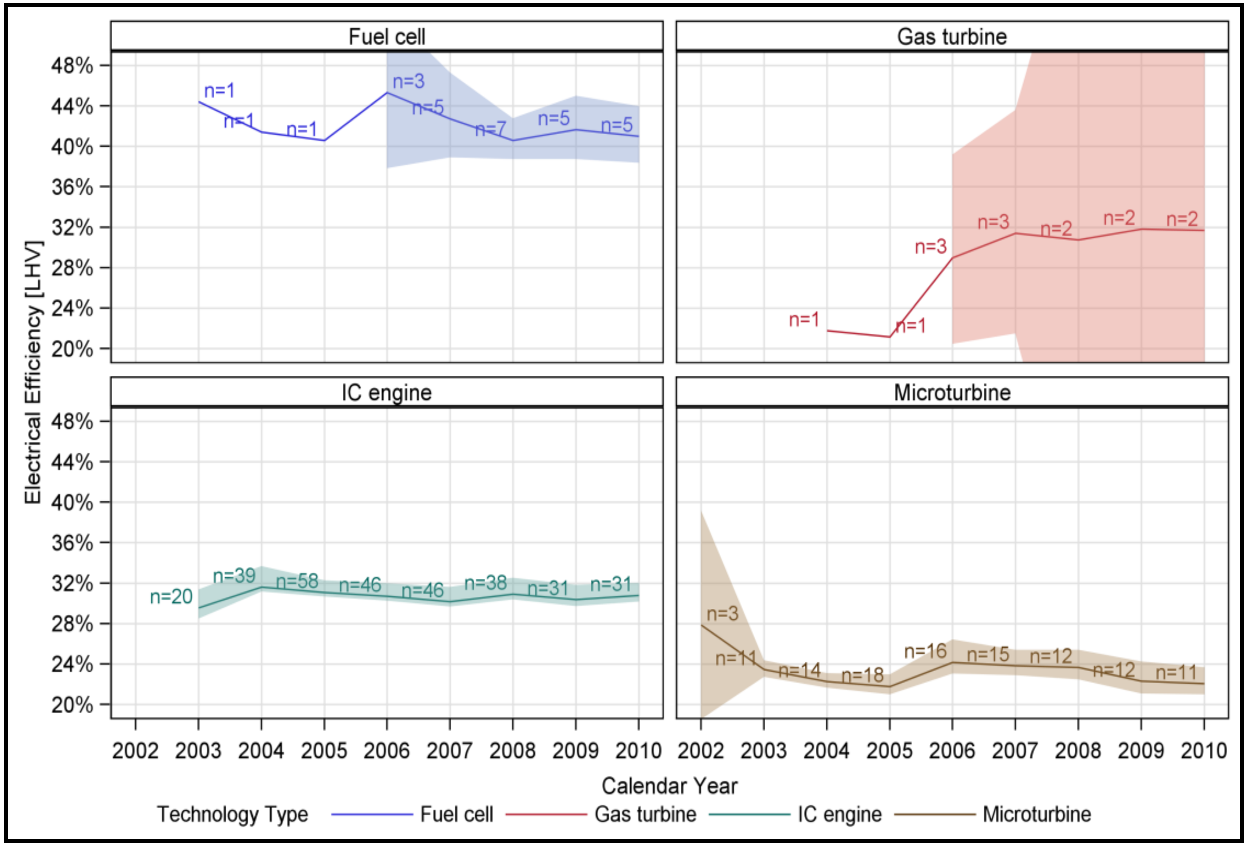
- Participation spread across numerous manufacturers
- More IC Engine manufacturers than microturbine or fuel cell manufacturers in Top 10 by # of projects

Energy Landscape of the Early Fleet: Top 10 Facility Types Using CHP Systems

Sector	No of projects	% of Total
Manufacturing	48	11%
Elementary/Secondary School	45	10%
Real Estate	36	8%
Public Administration	33	8%
Health Services	32	7%
Food Processing	30	7%
Digester WWTP	29	7%
Lodging Residential	29	7%
Misc Commercial	29	7%
College	28	6%
Other	93	22%
Total	**432**	**100%**

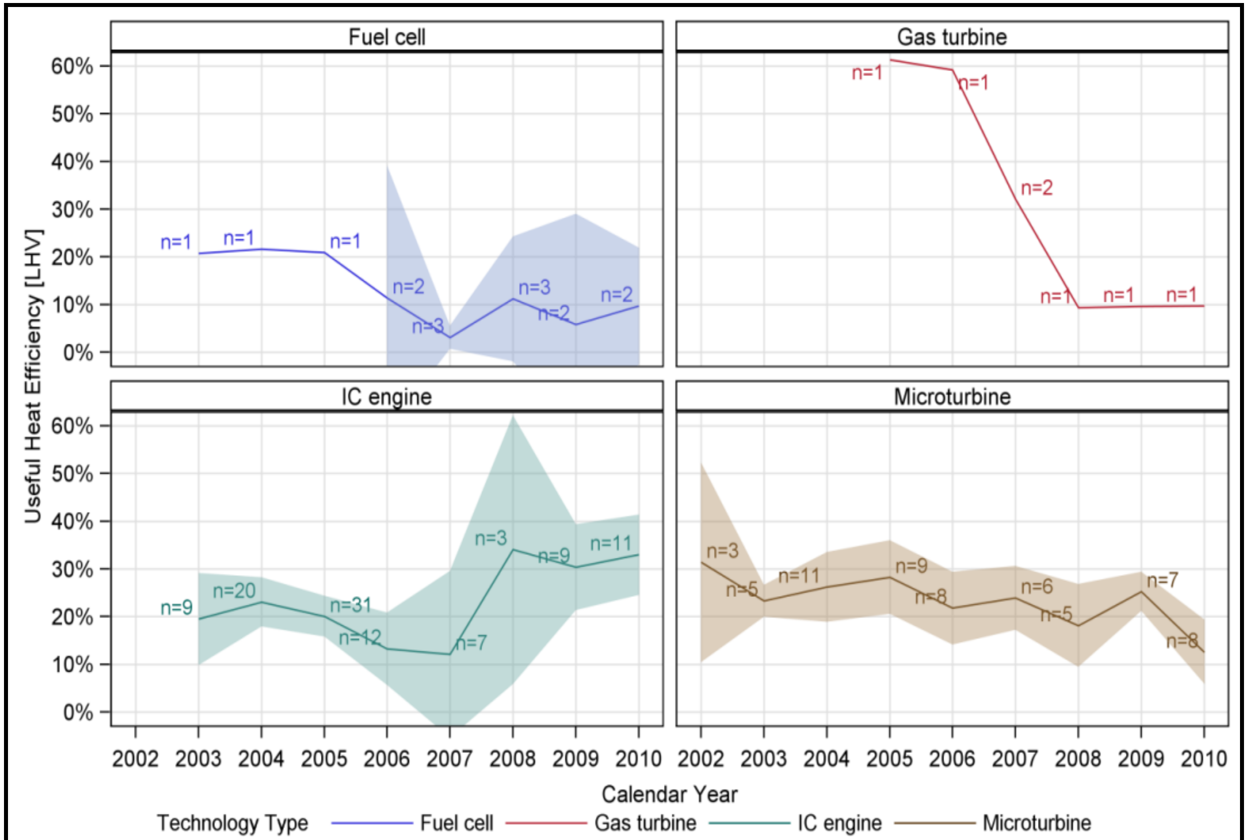
- Participation was spread across numerous facility types
- Participation was in facility types that historically have not utilized CHP to a great degree

Performance of CHP Fleet Over Time: Electrical Conversion Efficiency



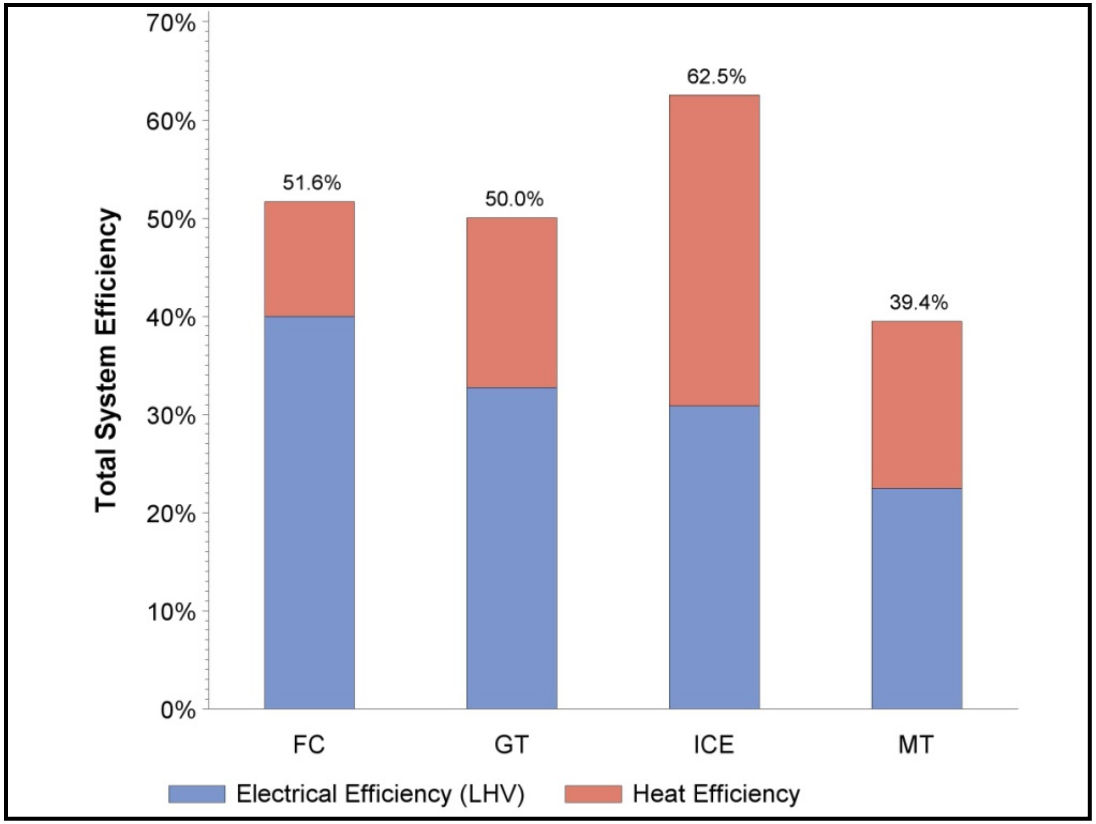
- Electrical conversion efficiency range from low 20% to mid 40%
- Electrical conversion efficiencies generally steady over time and fall into expected levels of performance

Performance of CHP Fleet Over Time: Useful Heat Recovery Efficiency



- Useful heat recovery efficiency ranged from 5% to 35%
- Useful heat recovery efficiency more erratic than electrical conversion efficiency and significantly lower than expected

Performance of CHP Fleet Over Time: Overall Efficiency at 2010



- Overall efficiency ranged from 39% to 62% in 2010
  - ✓ Generally lower than the expected 60% levels
- IC engine systems best overall efficiencies due to good heat recovery in 2010

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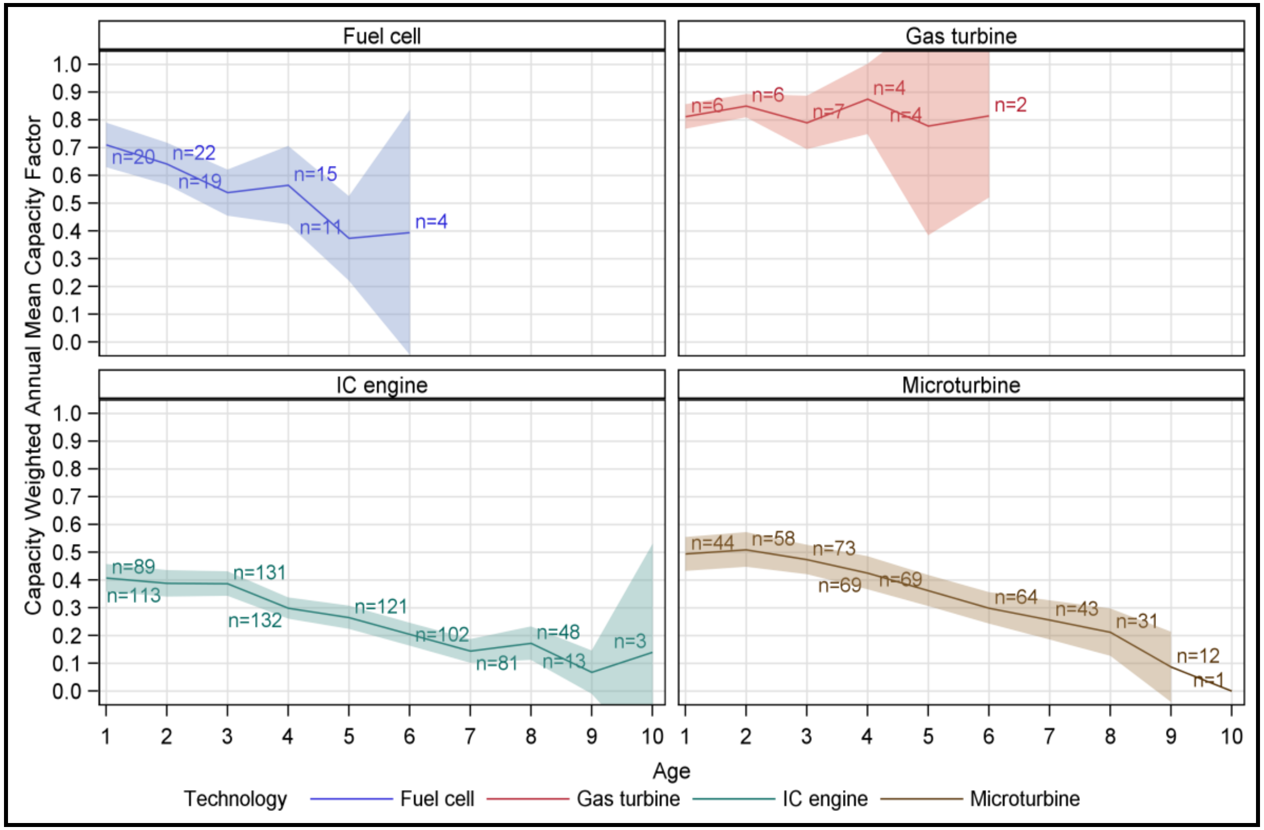
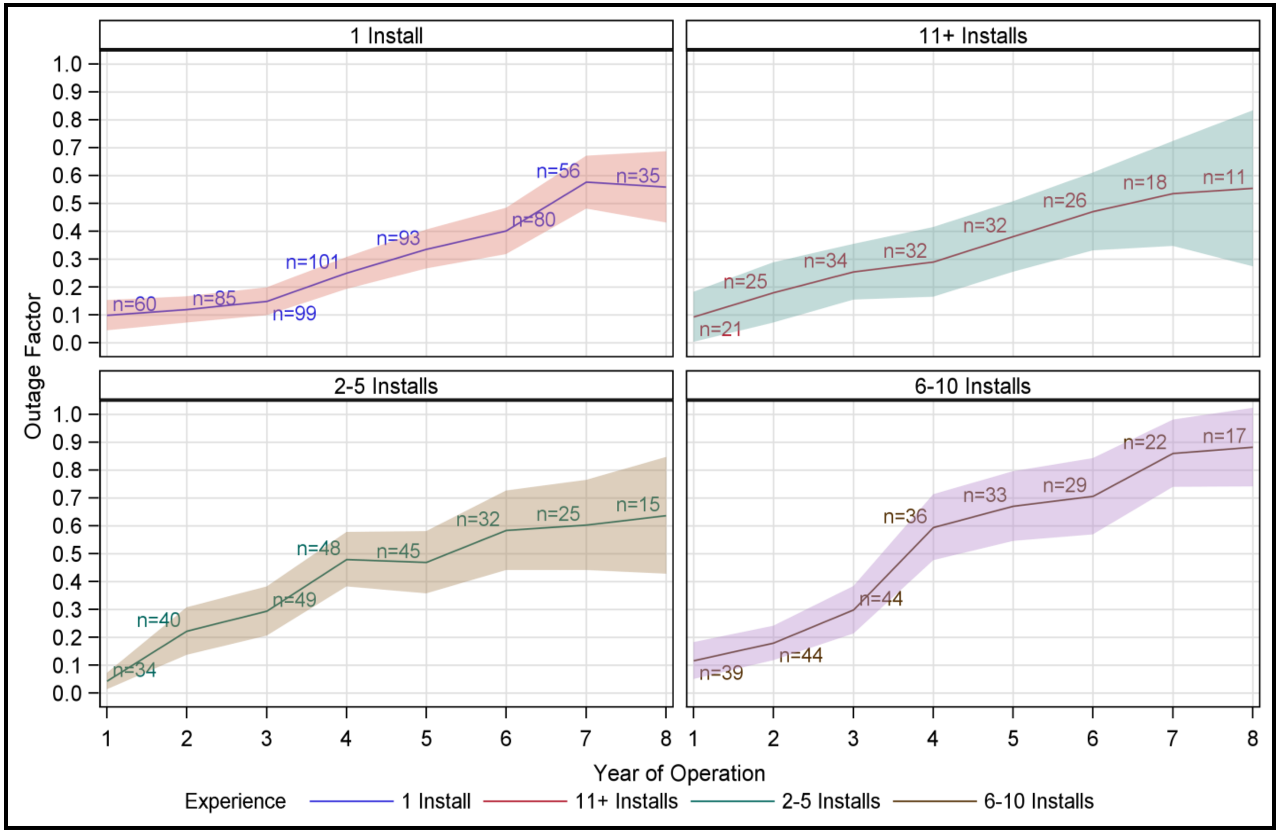
Examining Factors Affecting Performance: System Age and Utilization



- ❑ Annual capacity factor ranged from 0.05 to 0.88
  - ✓ Significantly lower than expected CF for IC engines and microturbines
- ❑ Rapid decline in utilization with age, except for gas turbine systems
- ❑ Program impacts dependent on capacity and utilization

Examining Factors Affecting Performance: System Age, Utilization, Developer Experience



- Annual outage factor indicative of serious utilization issues
- Annual outage factors increase with age, ranging from 0.05 to 0.9

Examining Factors Affecting Performance: System Age, Utilization, Developer Experience

Completion Year	Developer										Total
	RealEnergy Inc	California Power Partner	Chevron Energy Solutions	DG Cogen Partners LLC	Simmax Energy	Western Energy Marketers	PowerHouse Energy	Ciari Plumbing and Heating	OSEP LLC	Alliance Energy	
2001	1										1
2002	4	1	1	3	4	1					14
2003	2	3	8	3		3	3				22
2004		4	7	2	1		3	1	5		23
2005		5	7		2	1	3		3	3	24
2006		2	3					10	1	4	20
2007			1				2	2		1	6
2008			1				2			2	5
2009			1				1				2
2010		1									1
Total	**7**	**16**	**29**	**8**	**7**	**5**	**14**	**13**	**9**	**10**	**118**

- Top 10 counts of completed systems among developers ranges from 5 to 29

The Early Fleet: 2001-2006
Key Takeaways

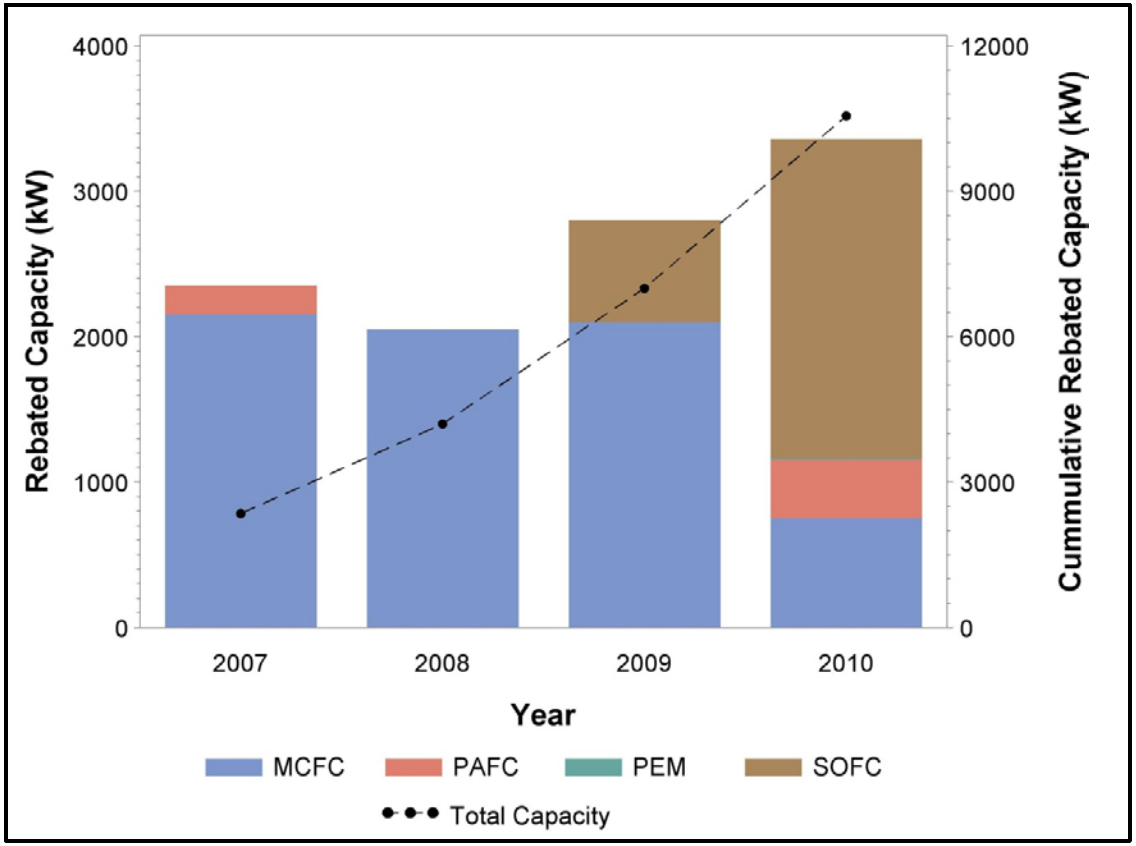
- Participation
  - IC Engines and microturbines dominated the CHP makeup
  - Facility types represented newer applications of CHP
- Performance
  - Annual utilization
    - Diminution rate generally higher than expected (w/exception of GT)
    - Relatively low average values raise concerns for financial performance
  - Efficiency
    - Electrical
      - In general agreement with expectations
    - Heat recovery
      - Generally lower than expected
        - Suggests electrical load following (as compared to heal load following)
        - Financial implications
        - GHG emissions impacts implications

The Mid-Term Fleet: 2007-2010

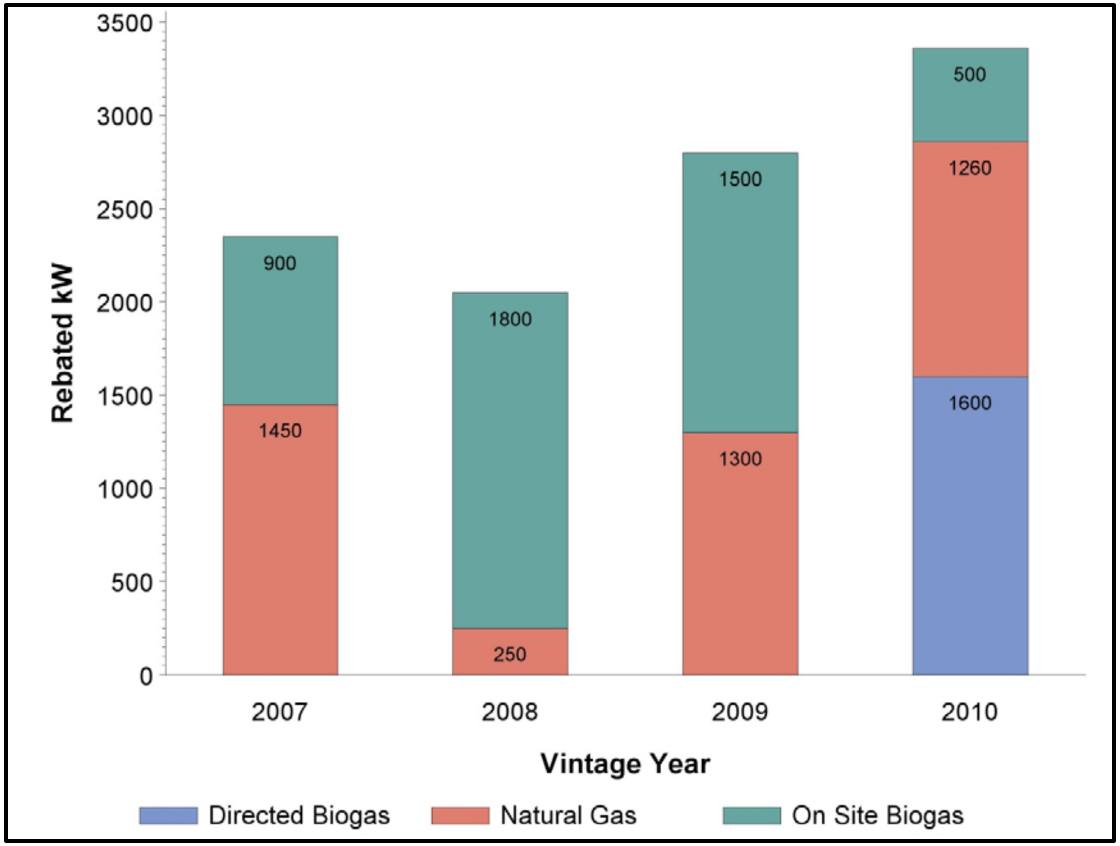
Growing Roles for Fuel Cells & Directed Biogas

- Effective PY 2007 eligible technologies list shortened
  - New projects limited to fuel cells and wind only
  - Existing projects remained in program
- Fuel cell technology overview
  - Fuel cell types: PAFC, MCFC, SOFC, PEMFC
  - Electrical efficiency: 40-50%
  - Fuel cells certified by CARB exempt from AQMD air emissions permitting
- Directed biogas
  - Biogas produced off-site is nominated for an SGIP project
    - ✓ Contractual (as opposed to physical) arrangement
  - September 2009 CPUC Decision 09-09-048
    - Directed biogas eligible for renewable fuel incentive levels

The Mid-Term Fleet:
Completed Fuel Cell Capacity by Fuel Cell Type



The Mid-Term Fleet: Completed Fuel Cell Capacity by Fuel Type



The Mid-Term Fleet: Key Takeaways

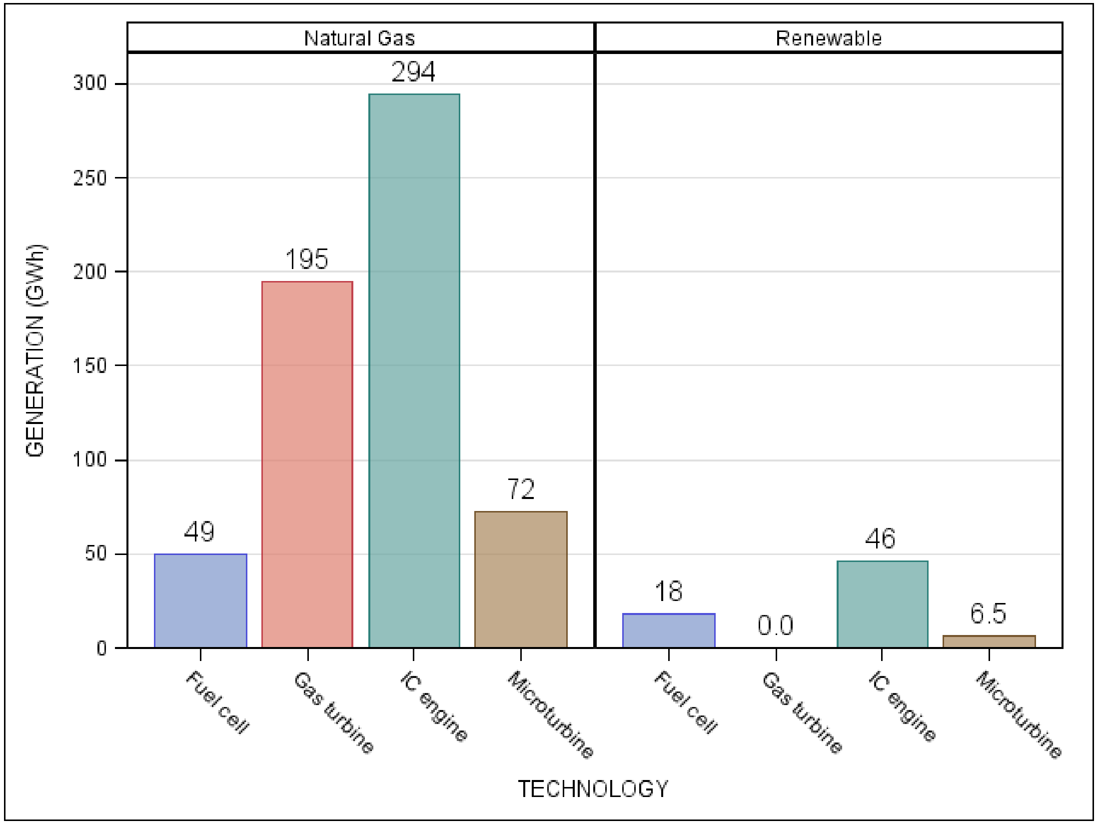
- The mid-term SGIP fleet saw another major shift in the make up of the projects
  - New projects restricted to fuel cells, wind and advanced energy storage
- First PEM and SO fuel cell completions achieved
- Directed biogas began to assume prominent role

Electricity Generation from SGIP by Technology and Fuel at 2010

Technology	Natural Gas (MWh)	Renewable (MWh)	Total (MWh)	Percent
FC	49,426	18,121	67,546	**9.9**
GT	194,789	0	194,789	**28.6**
ICE	294,281	46,099	340,380	**49.9**
MT	72,289	6,496	78,785	**11.6**
Total	610,784	70,716	681,500	**100**
Percent	**90%**	**10%**	**100%**	

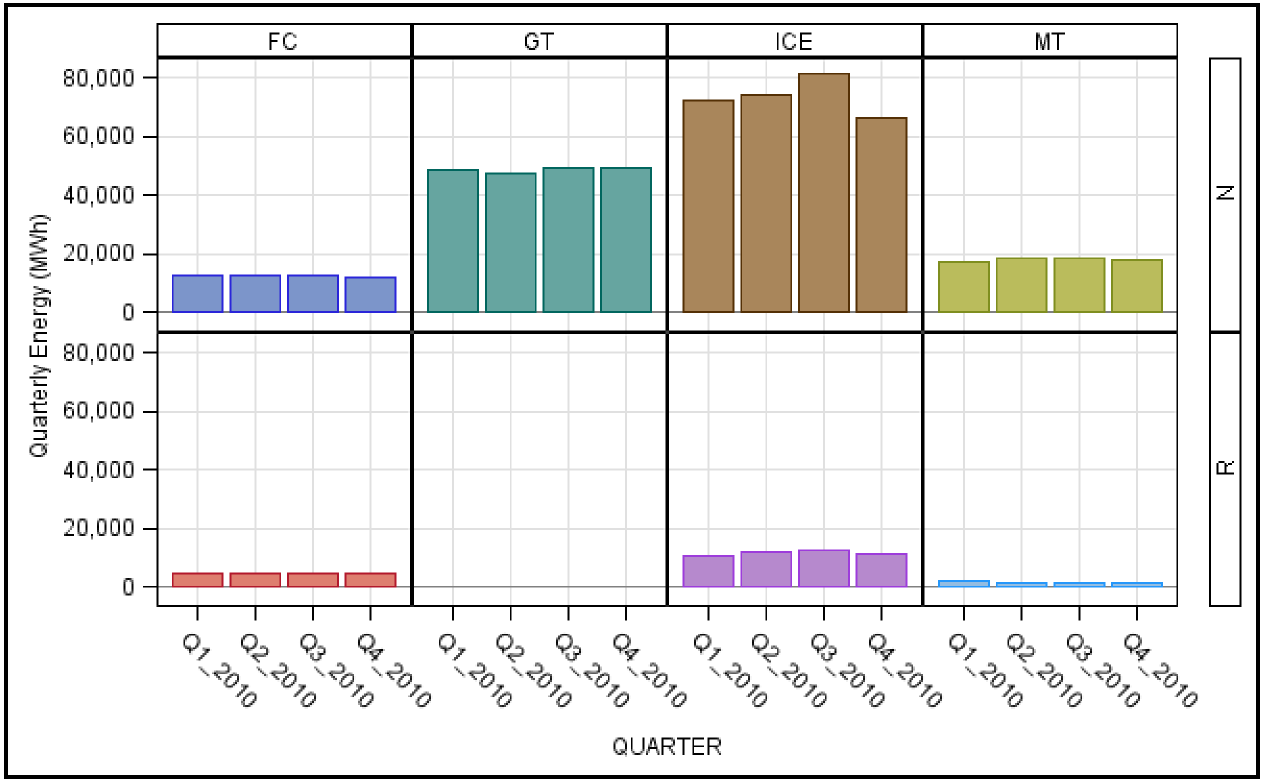
- SGIP provided over 680,000 MWh of electricity to CA during 2010
  - ✓ Enough electricity to meet the needs of over 100,000 homes
- Natural gas fueled systems generated 90% and renewable fueled systems generated 10% of electricity
- 49% of electricity was generated by IC engines

Further Breakout of Electricity Delivery: Technology and Fuel Type



- IC engines and gas turbines fueled by natural gas provided the greatest amount of generation during 2010
- IC engines and fuel cells showed some powering by biogas fuels

Breakout of Electricity Generation by Quarters During 2010



- Not surprisingly, electricity generation was steady throughout the year with little seasonal variability regardless of prime mover technology

Heat and Fuel Impacts from SGIP Systems During 2010

	Estimated Boiler Gas Displaced	Estimated Fuel Consumed
Technology	**Billion Btu**	**Billion Btu**
FC	44	459
GT	351	2,030
ICE	1,094	3,314
MT	189	1,107
Total:	**1,678**	**6,911**

- CHP systems consume fuel to generate electricity and displace fuel that would have otherwise been used to meet on-site heat demand
  - ✓ Waste heat recovery systems captured nearly 25 percent of the energy content of fuel consumed by the CHP systems

End-Uses Served by Recovered Useful Thermal Energy

End Use Application	Completed Systems (n)	Completed Capacity (kW)
Heating Only	252	100,784
Heating & Cooling	80	61,257
Cooling Only	39	33,811
Undetermined	7	1,768
Total:	**378**	**197,620**

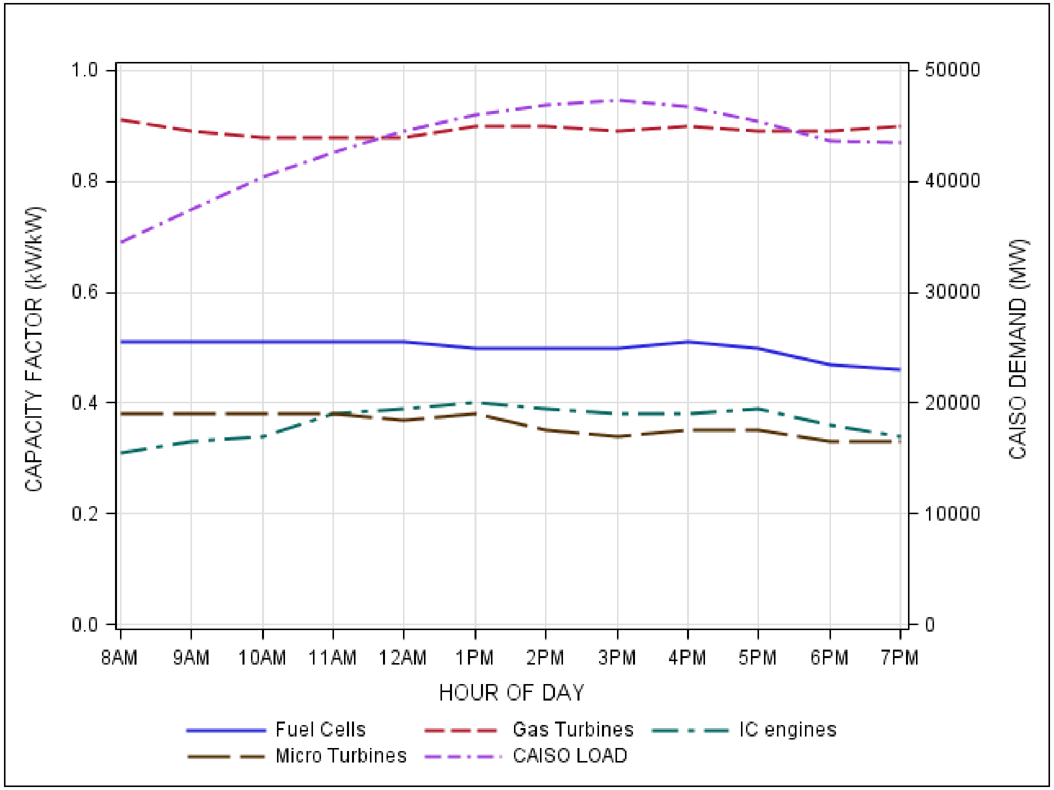
- Most SGIP systems use the waste heat for heating only
  - ✓ However, note that on an installed capacity basis, CHP systems almost equally use recovered heat for heating and cooling
- About 30% use the heat recovered for cooling by means of absorption chillers

CHP System Efficiency Relative to PUC 216.6 Requirements

Technology	Number of projects (n)	216.6 (a) Efficiency (%)	216.6 (b) Efficiency (%, LHV)	CHP System Efficiency (%, LHV)
FC	19	23%	46%	52%
GT	8	35%	41%	50%
ICE	230	51%	47%	63%
MT	121	43%	31%	40%

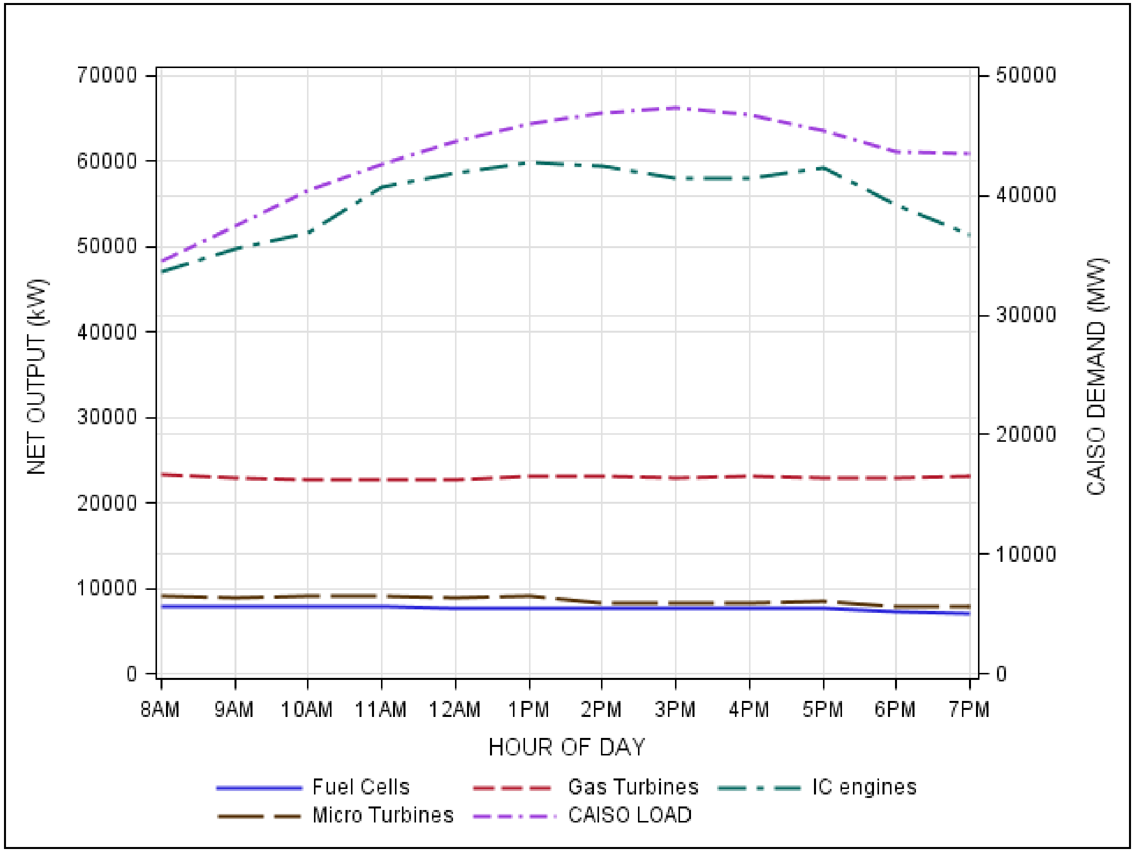
- PUC 216.6(b) requires CHP systems achieve at least 42.5% efficiency
  - ✓ Efficiency based on electrical plus ½ of thermal useful
  - ✓ Fuel cells and IC engines passed
  - ✓ Gas turbines fell a little short, but microturbines fell significantly lower than required
- However, only IC engines would exceed the 62% system efficiency threshold expected by the CPUC

CAISO Peak Day Capacity Factor by Technology



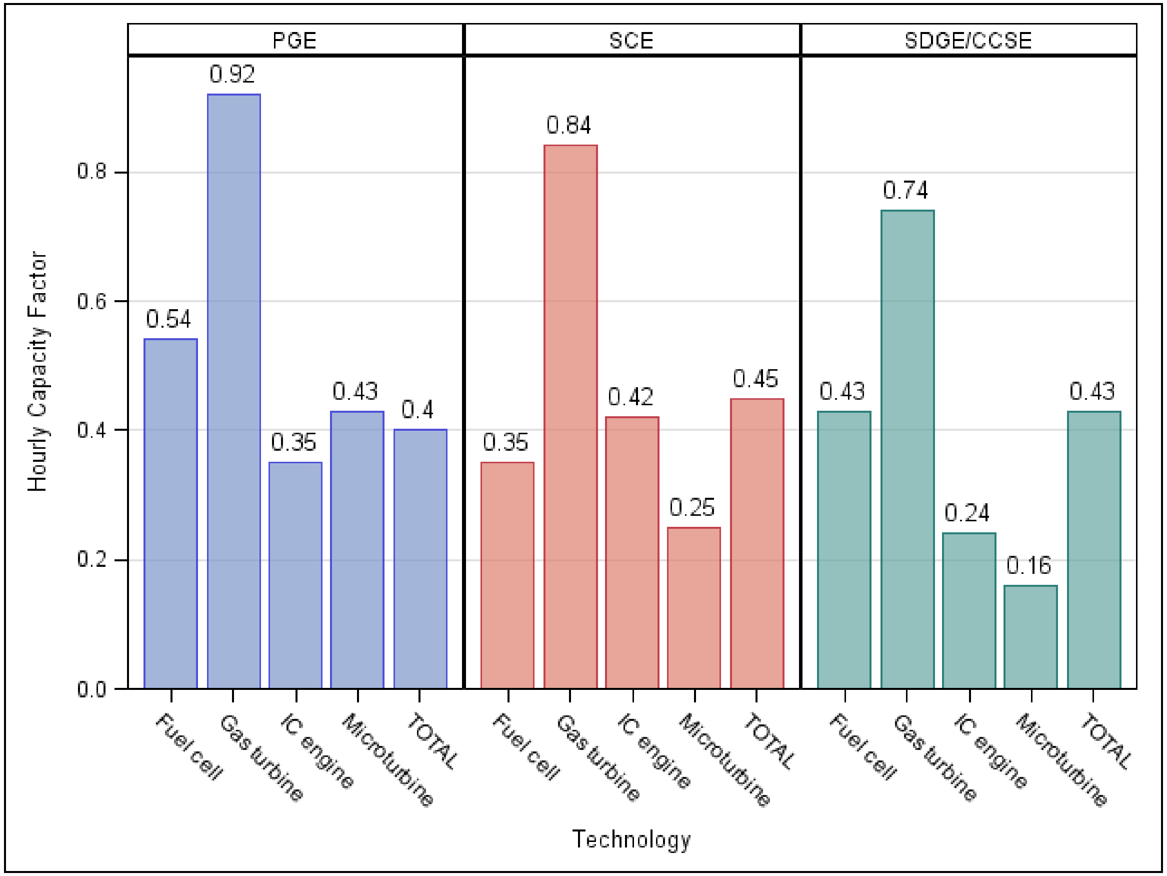
- Total rebated capacity of on-line projects was nearly 216 MW
- Total impact coincident with the CAISO peak load was estimated to be about 97 MW
- Collective peak hour capacity factor on the CAISO 2010 peak was approximately 0.46 kW per kW of rebated electricity generating capacity

CAISO Peak Day Net Production by Technology



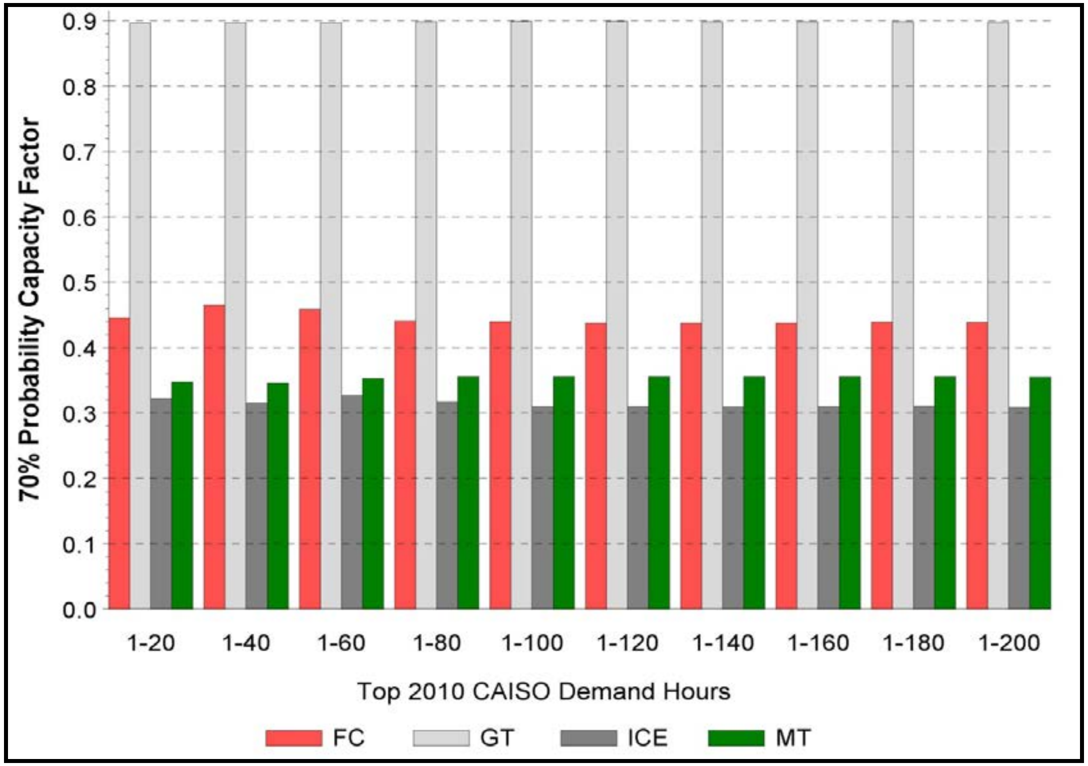
- ❑ Fuel cells, gas turbines, and microturbines showed flat generation profiles over the course of the CAISO peak day
- ❑ Only IC engines showed changes in hourly generation

2010 Peak Hour Capacity Factor at Utility Level by Technology



- Although IOUs have different peak demand at different times, the responsiveness of CHP systems to peak is fairly similar within the technology type

CHP Addressing CAISO Peak Demand Over Top 200 Hours of Demand



- Unlike intermittent resources (e.g., wind or solar), CHP systems show steady ability to meet electricity demands over the top demand hours
  - ✓ Suggests that CHP could be used by utilities to provide firming to intermittent renewables

Impacts of CHP Systems on GHG emissions

- GHG emissions impacts reported starting in 2005
  - Increasing interest in the ability of SGIP systems to capture GHG emission reductions
  - Basis is the "net" GHG emissions relative to energy or fuel supplied by external sources (e.g., the grid)
- For on-site electricity, GHG emissions from SGIP systems are compared only to GHG emissions from utility power generation
  - If the SGIP system is not in operation, displacement of CO_2 emissions from central station power plants is equal to zero
- For on-site heating, GHG emissions from SGIP systems are compared to GHG emissions associated with existing on-site boilers

GHG Emission Estimate Methodology Overview

- SGIP System CO_2 Emissions : Emissions of CO_2 from SGIP DG systems are estimated based on the hour-by-hour electricity generated from SGIP facilities throughout the 2010 year
- Electric Power Plant CO_2 Emissions : CO_2 emissions from conventional power plants are estimated on an hour-by-hour basis over all 8,760 hours of 2010
  - The estimates of utility-generated CO_2 are based on a methodology developed by Energy and Environmental Economics, Inc. (E3) and made publicly available on its website as part of its avoided cost calculator

GHG impact of Heating and Cooling Services

- CO_2 Emissions Associated with Cooling Services:
  - Estimates of avoided CO_2 emissions are based on the hour-by-hour electricity savings from electric chillers
- CO_2 Emissions Associated with Heating Services:
  - Waste heat is recovered from the operation of CHP systems
  - Estimates of avoided CO_2 emissions are based on displacement of on-site boiler fuel by recovered waste heat

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GHG Emissions Calculations

$$DeltaGHG_{ih} = SGIPGHG_{ih} - \left(BasePpEngo_{ih} + BasePpChiller_{ih} + BaseBlr_{ih}\right)$$

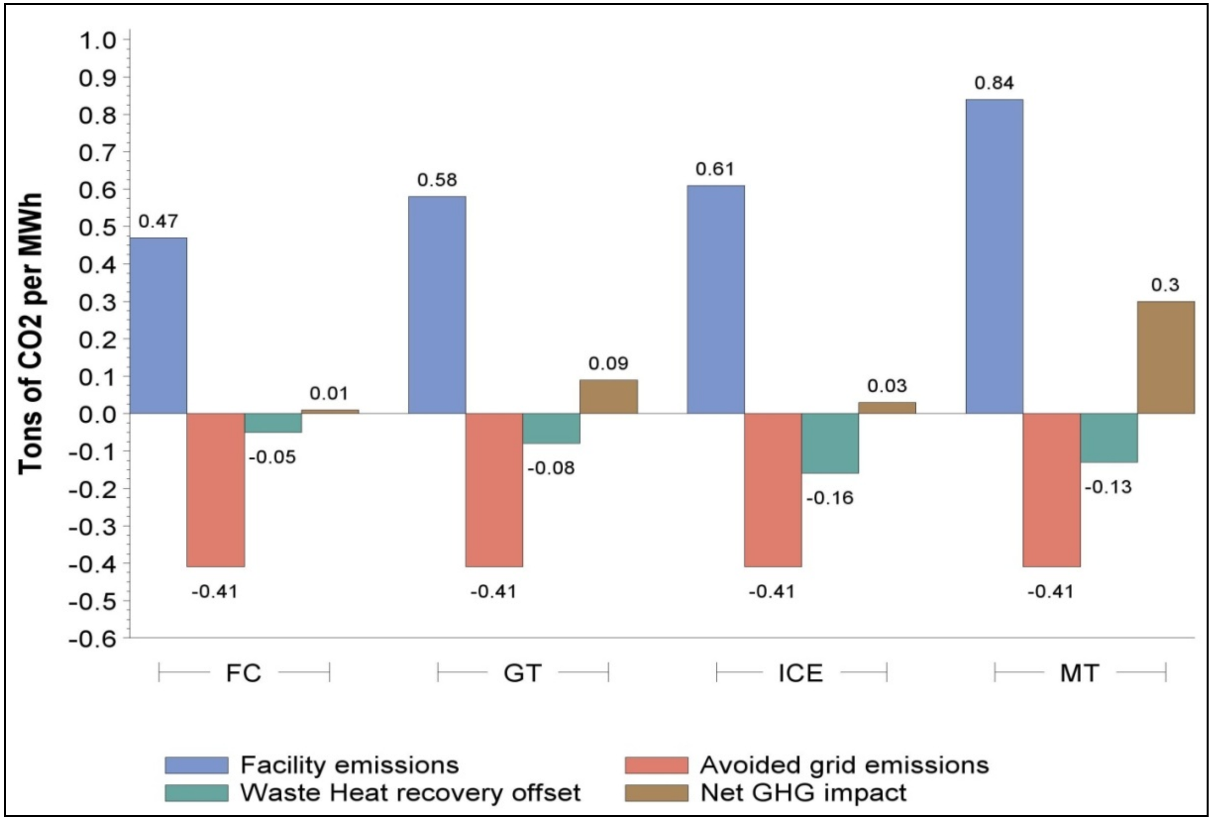
SGIP facility emissions

Baseline emissions

where:

$DeltaGHG_{ih}$ is the net change in GHG emissions attributable to the SGIP for participant *i* for hour *h* due to displacement of on-site electricity and on-site fuel

Summary of Net GHG Emissions in 2010



- Positive GHG emission impacts represent an increase in CO_2
- Net GHG emission impacts are shown in brown
- CO_2 impact factors range from 0.30 tons per MWh for microturbines to 0.01 tons per MWh for fuel cells

2010 GHG impacts: Key Findings

- CO_2 emissions from non-renewable-fueled SGIP systems exceed CO_2 emissions from the displaced grid-based electricity
- Useful waste heat recovery operations act to reduce CO_2 emissions that would have resulted from use of on-site boilers
- The magnitude of the reduced boiler CO_2 emissions is insufficient to enable non-renewable CHP systems to have net negative GHG emission values

Looking Forward:
The SGIP Fleet after 2010

- Final decision modifying the SGIP was issued by the CPUC in September 2011
  - Expands the portfolio of technologies, changes incentives approach and operational requirements
- IC Engines and microturbines are eligible once again
  - Last eligible in 2007
  - Must meet NOx limits
    - 0.07 lbs/MWh
    - Credit given for heat recovery
- Incentives approach:
  - 50% of incentive provided upfront as capacity
  - Remaining incentives provided as performance-based incentives
    - Incentives paid out as PBI in 5 annual payments
- CHP system performance requirements
  - Efficiency: Tied to GHG emission reductions but based on expectation of 62% overall efficiency
  - Utilization: Must achieve annual capacity factor of 80%
  - GHG emissions: Targets zero net GHG emissions reductions

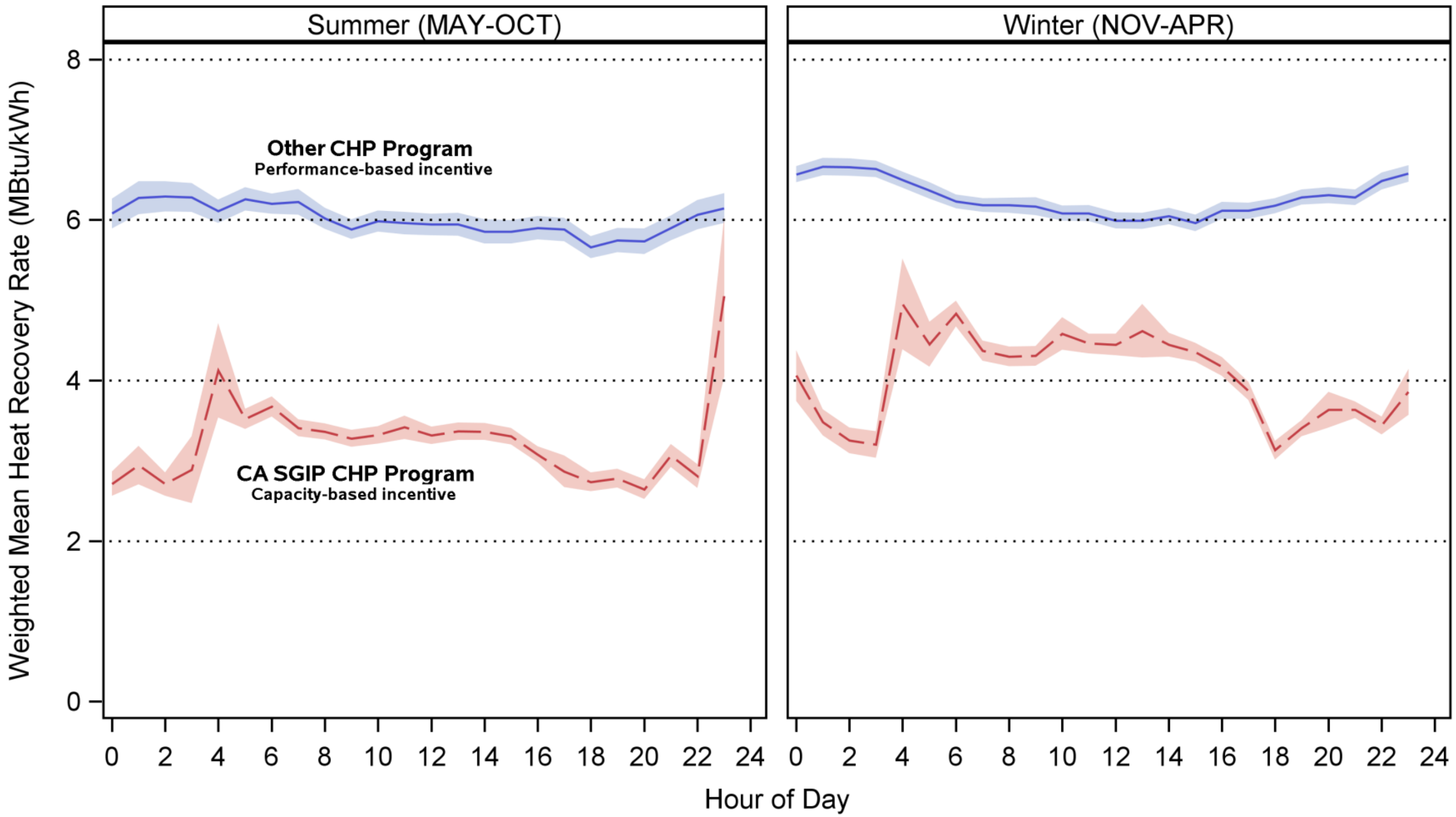
Lessons Learned from 10 Years of SGIP CHP Operation

- Electrical conversion efficiencies have remained fairly stable over time and have matched expected values
- Useful waste heat recovery efficiencies have been significantly less than expected
  - Manufacturer specifications indicate thermal energy that could be available to meet on-site needs
  - However, there isn't always good correlation between thermal energy supplied and on-site thermal demand
    - May be due to lack of coincidence between electrical demand and thermal demand
    - May be due to over sizing of generator to meet electrical demands versus thermal energy demands
- Overall system efficiencies have tended to be lower than expected 60% levels
- Annual capacity factors for CHP systems (with the exception of gas turbines) have been lower than expected and decreased significantly over time
- CHP systems are showing net positive GHG emissions
  - Largely due to lower than expected useful waste heat recovery

Moving Forward: Critical Factors

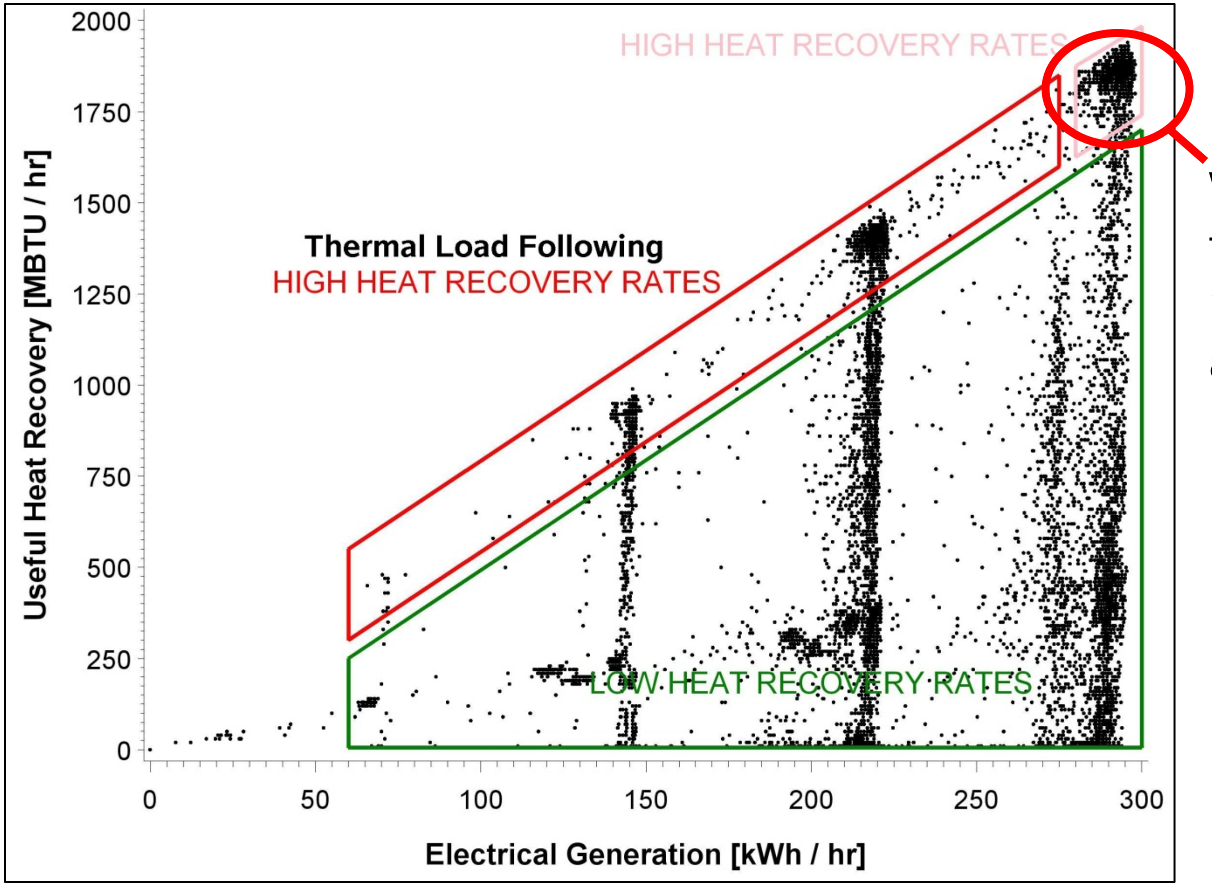
- Achieving and sustaining needed performance
  - High useful waste heat recovery is essential to meeting the efficiency and GHG targets
  - Requires careful coordination between program design and program implementation
  - Follow through is necessary to ensure performance does not deteriorate over time
- Are these goals achievable?
  - Examples among SGIP participants
  - Comparisons to other efforts

PBI will tend to encourage high heat recovery rates



- Other CHP program requires designing to thermal load
  - Heat recovery rates have been higher than those observed for SGIP

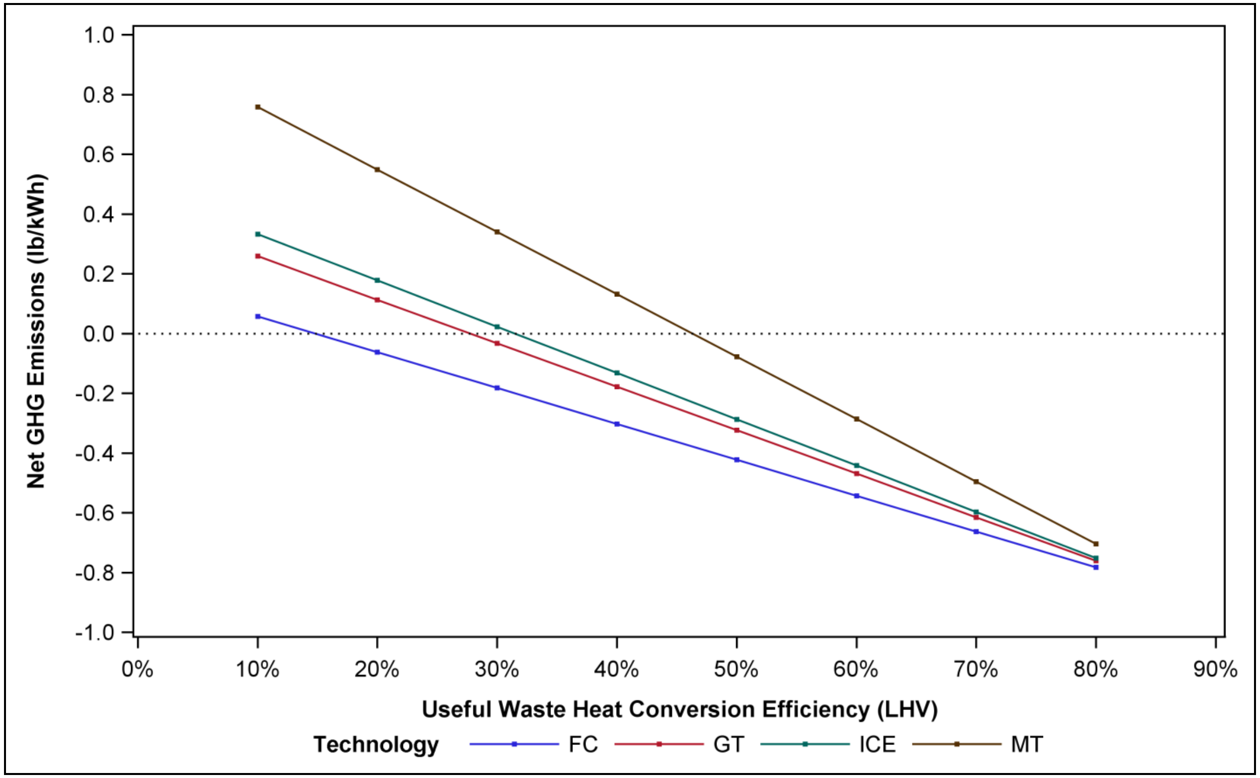
Host facility selection will be critical in the future



Will need CHP system to be operating here most of the time to satisfy all PBI requirements

- Thermal load following involves tradeoffs
  - Increase CHP system efficiency
  - Decrease utilization (Electric Capacity Factor)

Relationship Between GHG and Useful Thermal Energy



- Net GHG emissions are linked quantitatively to electrical and useful thermal energy efficiencies
- Our analysis shows that for CHP technologies deployed in California, achieving zero or better net GHG emissions requires most CHP systems to obtain useful waste heat conversion efficiencies of greater than 30%

Recommendations: Program Design

- Deliberate program design is critical to ensuring CHP systems perform as expected
  - Program designs should set clear and explicit targets for CHP performance:
    - Capacity additions expected over time for the program
    - Electricity to be delivered annually and electricity savings
      - ✓ Take into account if cooling load will be served
      - ✓ Specify if export is allowed and under what conditions
    - Amount of peak generation to be achieved at the program level
    - Thermal energy to be supplied and associated fuel savings
      - ✓ Set thermal load following as a necessary condition
        - Subject to annual CF requirements
    - System life (years)

Recommendations: Program Design

- For California, capturing GHG emission reductions was critical
  - GHG emission reductions for CHP systems are driven by achieving high and sustained levels of useful waste heat recovery
    - Essential that thermal output of CHP system is sized to meet thermal demand at the site
    - Where electrical demand is also driving the system economics, ensure you know coincidence of thermal and electrical demands and balance them accordingly

Recommendations:
Implementation – Role of Performance Information

- CHP system performance modeling
  - Program participants
    - Project eligibility screening
  - Program implementers
    - Program performance sensitivity analysis
- Development of accurate models is challenging
  - CHP system performance is complex and multi-dimensional
    - Magnitude *and* timing of electrical and thermal loads
    - Retail electric and natural gas rates may change
    - Behavioral factors involved with operating CHP DG
  - Tradeoff between cost and accuracy of model inputs
- Require applicants/project developers to use similar or same modeling assessment tools and document key assumptions

Questions and Contact Information

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