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Network Design Optimization of Combined Cooling Heating and Electric Power (CCHP) Fuel Cell Systems (FCS) and Distributed Energy Devices

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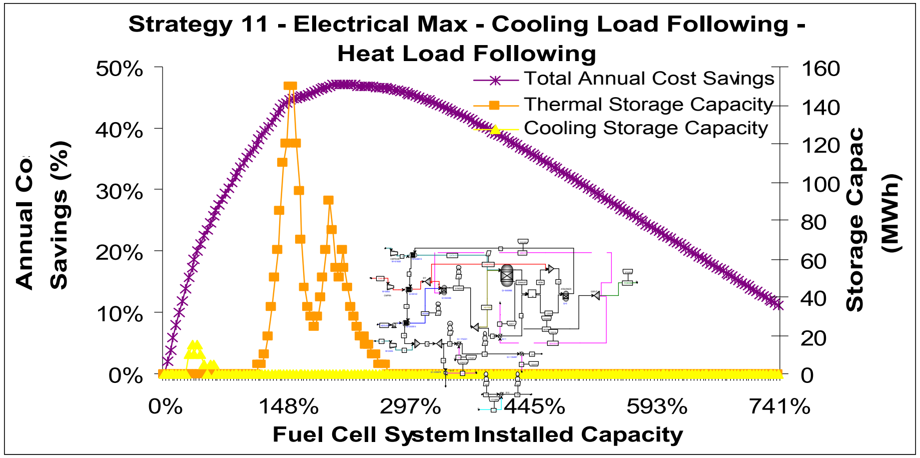
Problem

Project Purpose: Our research develops novel design and control strategies for combined cooling heating and electric power (CCHP) fuel cell systems (FCS).

Goal: Develop advanced, inter-disciplinary modeling capabilities to optimally design, install, and control integrated energy systems composed of CCHP FCS and energy storage for providing energy to buildings.

Approach: We develop models describing the thermodynamics, chemical engineering design, economics, and environmental impacts of integrated systems composed of CCHP FCS and energy storage in competition with other state-of-the-art generators.



Cost savings and optimal thermal and cooling storage capacity as a function of FCS installed capacity for one design strategy. Inset shows chemical engineering model of CCHP FCS.

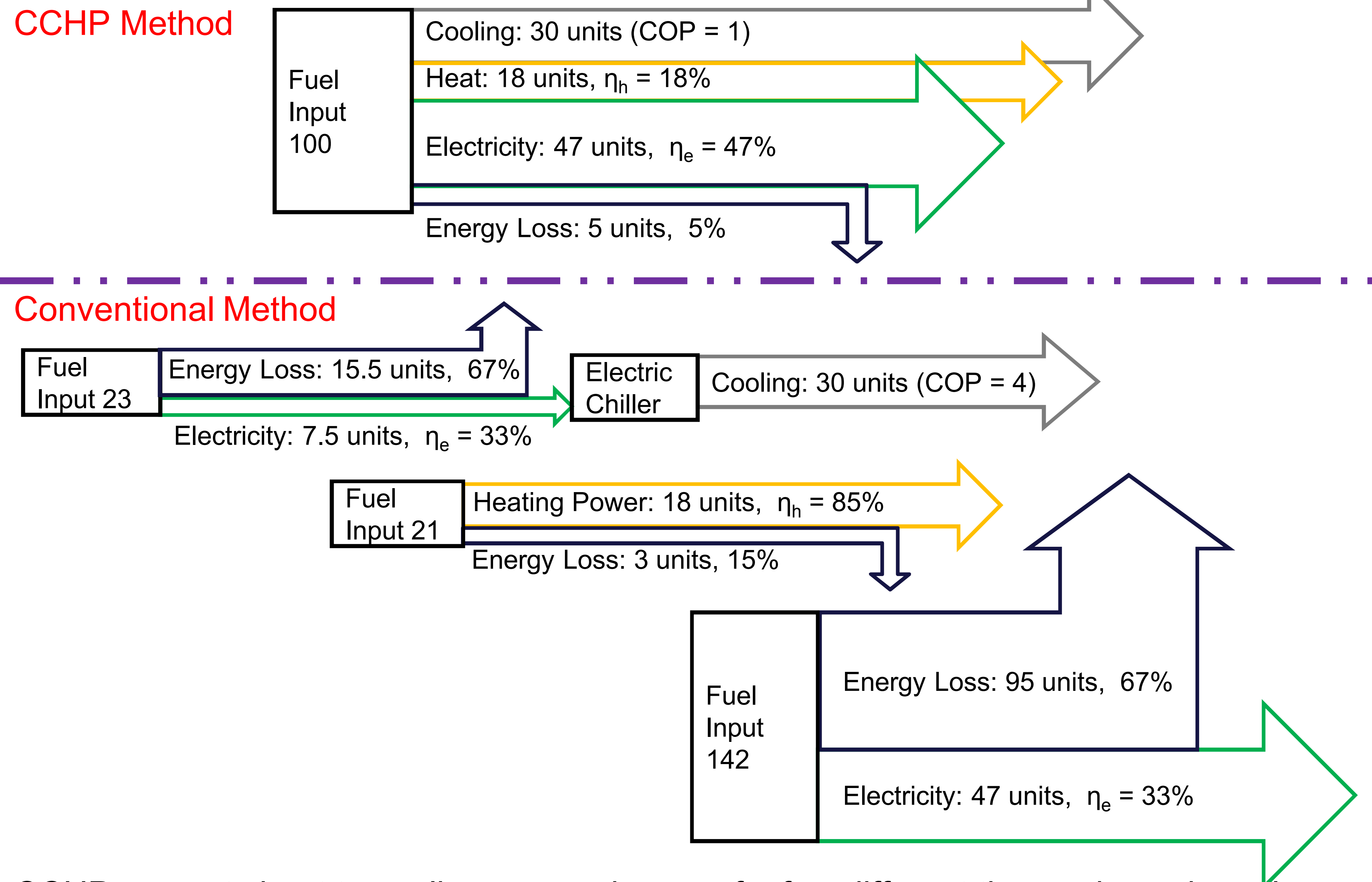
Key Accomplishments: Chemical engineering simulations indicate that CCHP FCS can achieve overall efficiencies of 80% or more. Thermodynamic models indicate that a double-effect absorption chiller will operate with a coefficient of performance (COP) of ~0.6 to 1.0 over FCS exhaust temperatures. Cost and CO_2 minimization strategies involve CCHP FCS with 1) electrical and thermal networking, 2) variable heat-to-power ratio, 3) tunable cooling-to-heat output, along with 4) maximum electrical output or electrical load following, 5) heat load following, and 6) cooling load following, in different orders, and 7) energy storage.

R&D Goals and Milestones:

- Built detailed thermodynamic models of CCHP FCS validated by industrial data and literature.
- Developed advanced techno-economic optimization models of CCHP FCS and energy storage.
- Analyzed the impact of different engineering designs & market characteristics over 107,000 model runs.

Significance of Results: Results significantly reduce development time, costs, and environmental footprint for CCHP FCS; Sandia's modeling capabilities now exceed those of industry and other labs in this area; LDRD has resulted in DOE-funded spin-off projects of 225K in FY09 and 400K in FY10.

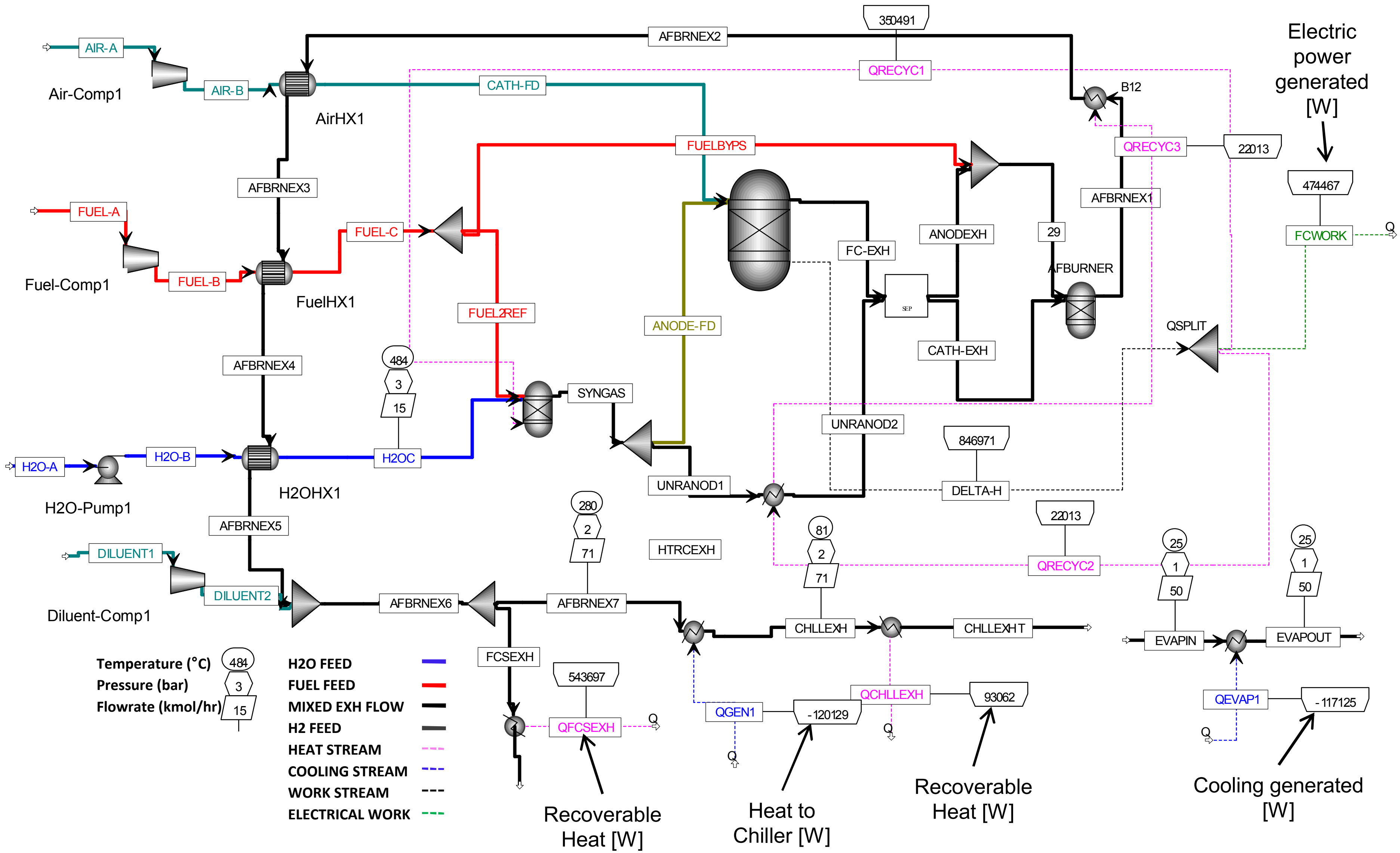
Power plants using combined cooling, heating, and electric power (CCHP) can reduce fuel consumption and CO_2 emissions by 46%.



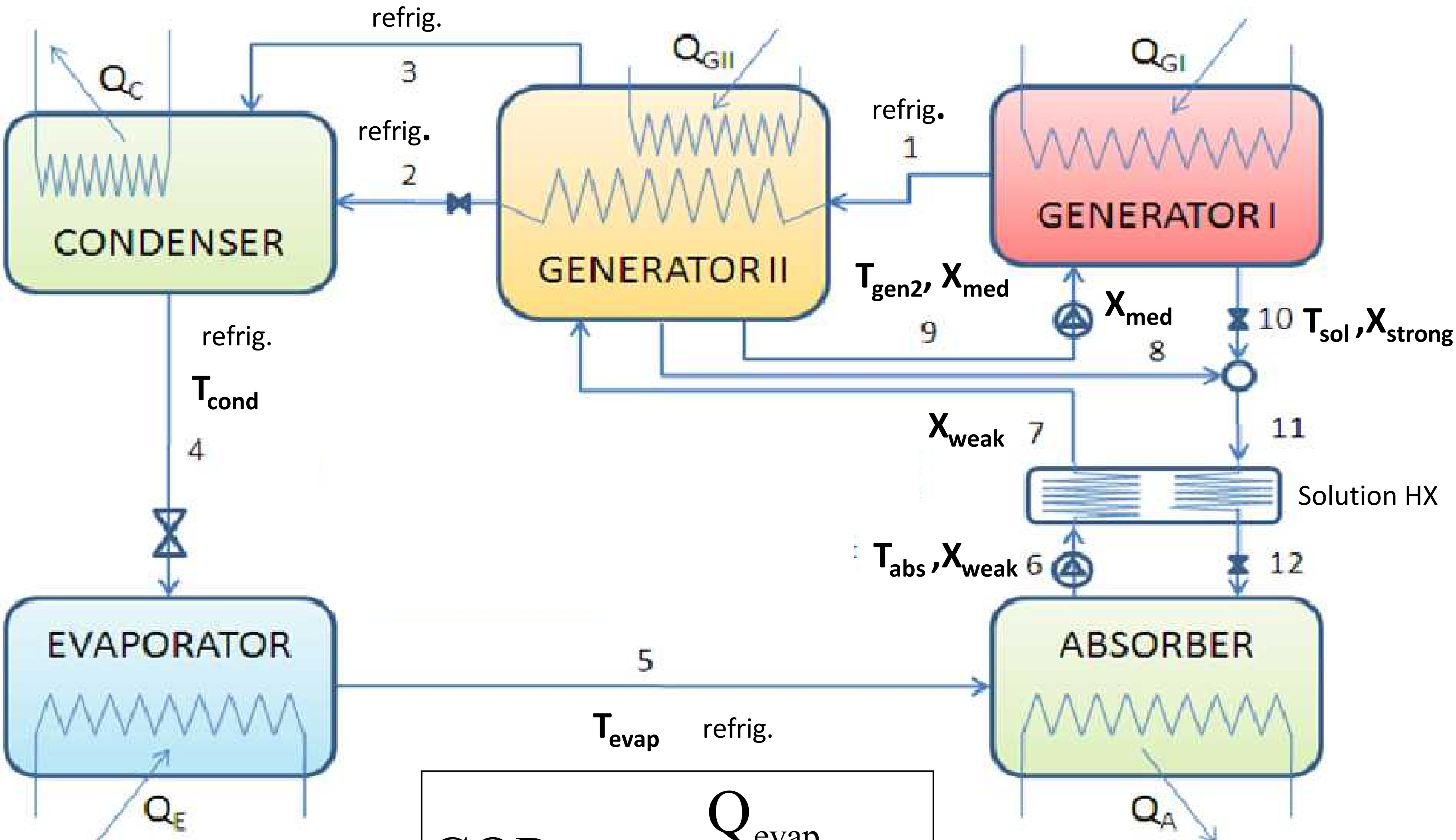
CCHP converts heat to cooling power via one of a few different thermodynamic cycles.

Approach

We develop advanced chemical engineering and techno-economic-environmental models of CCHP FCS to optimally design and control these systems under different engineering performance and market characteristics.



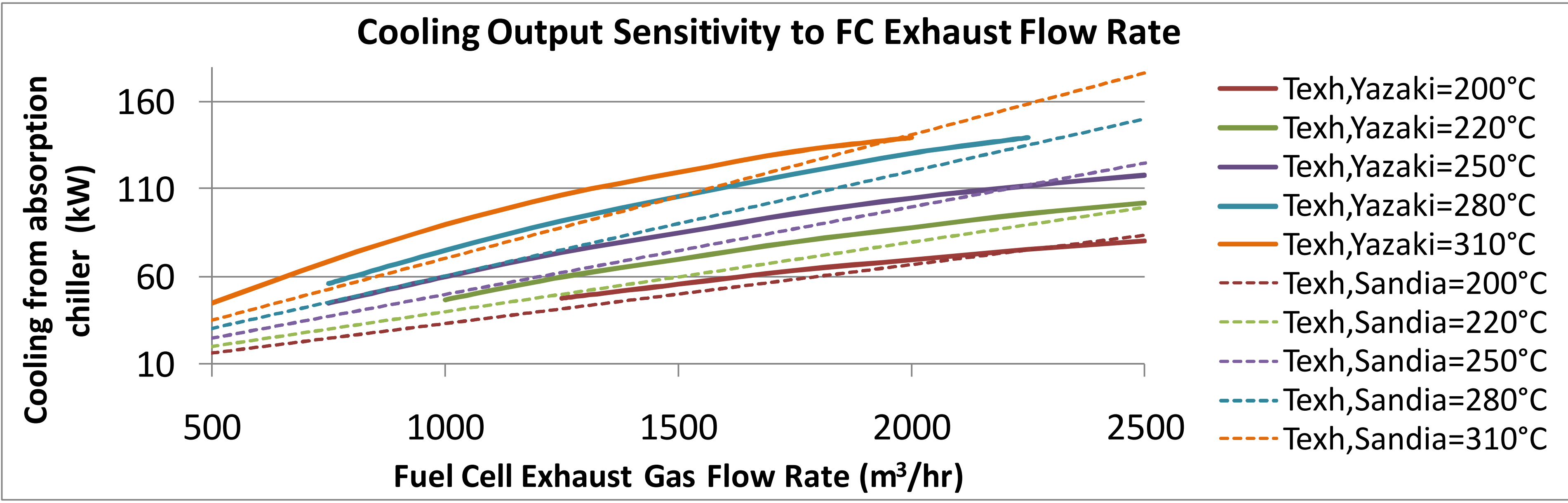
Chemical engineering CCHP FCS models include the physics of advanced double-effect lithium bromide absorption chillers.

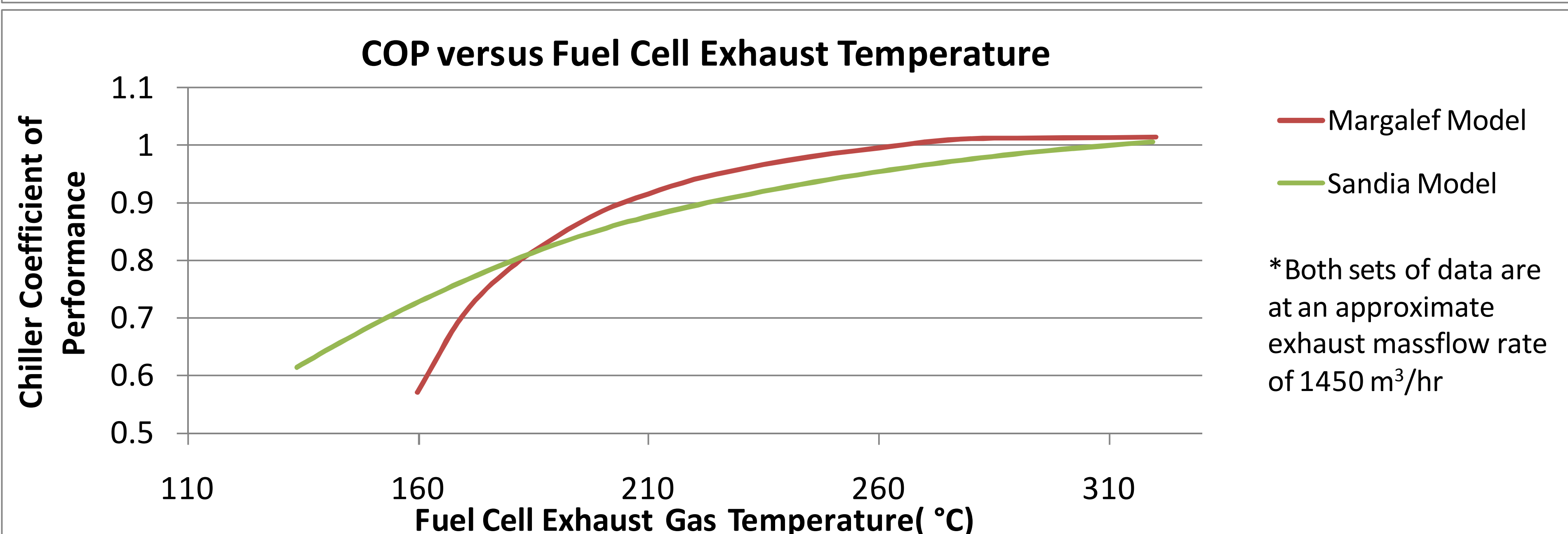


$$\mathrm{COP} = \frac{Q_{evap}}{Q_{gen1} + Q_{gen2}}$$

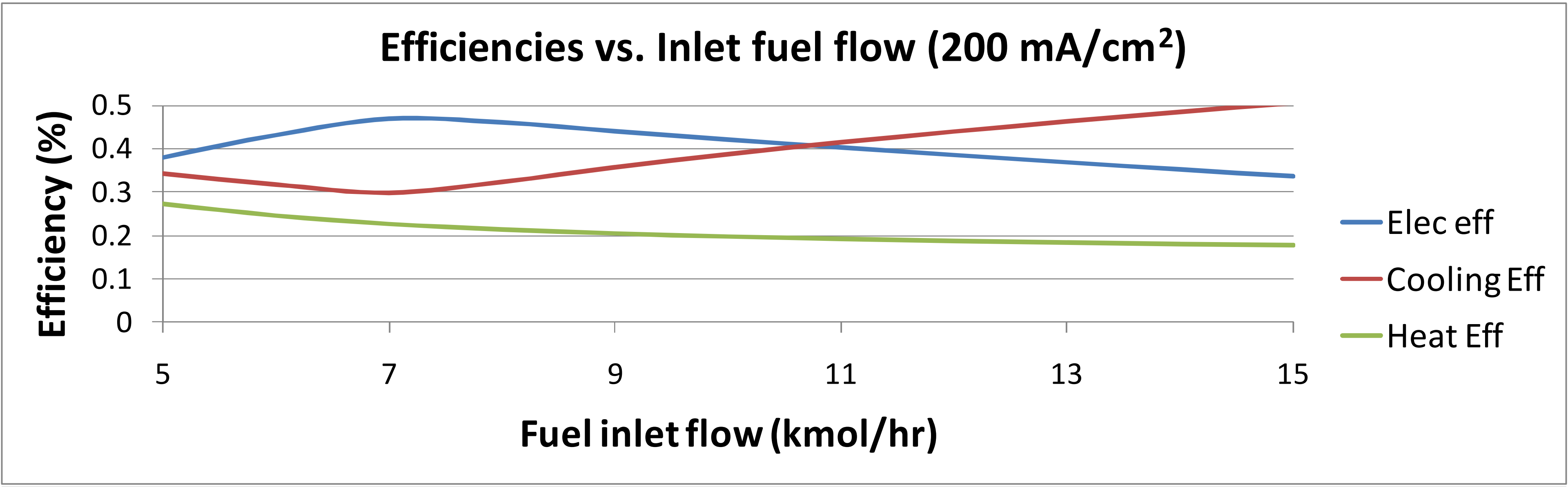
Results

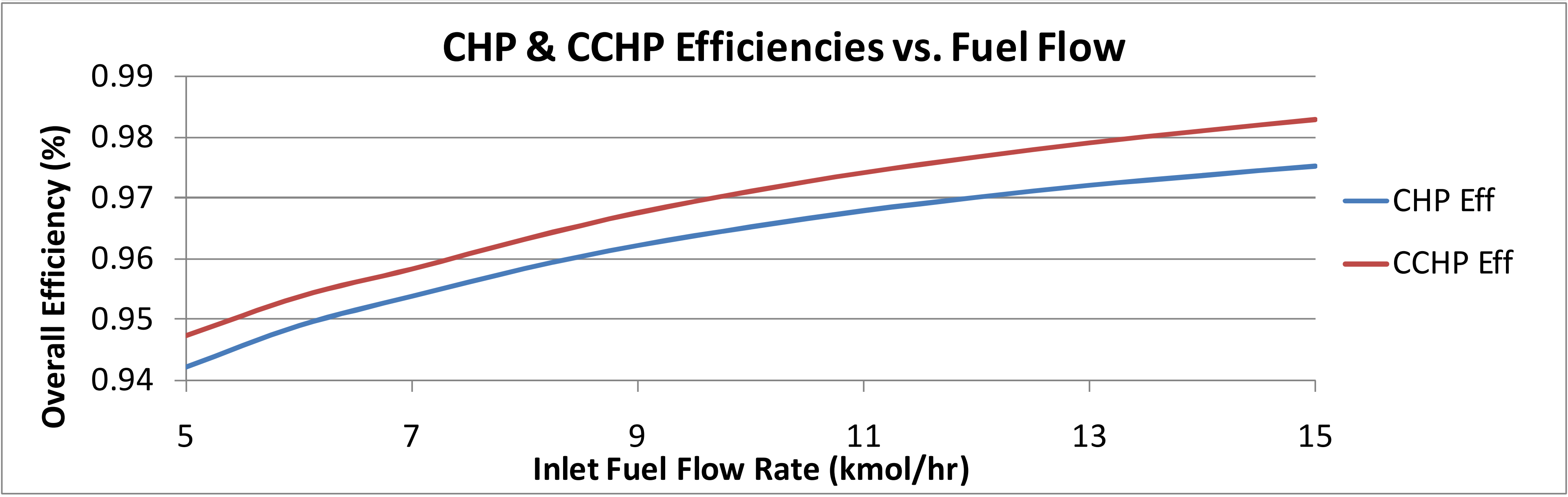
Our models are independently verified with data from manufacturers and the literature.





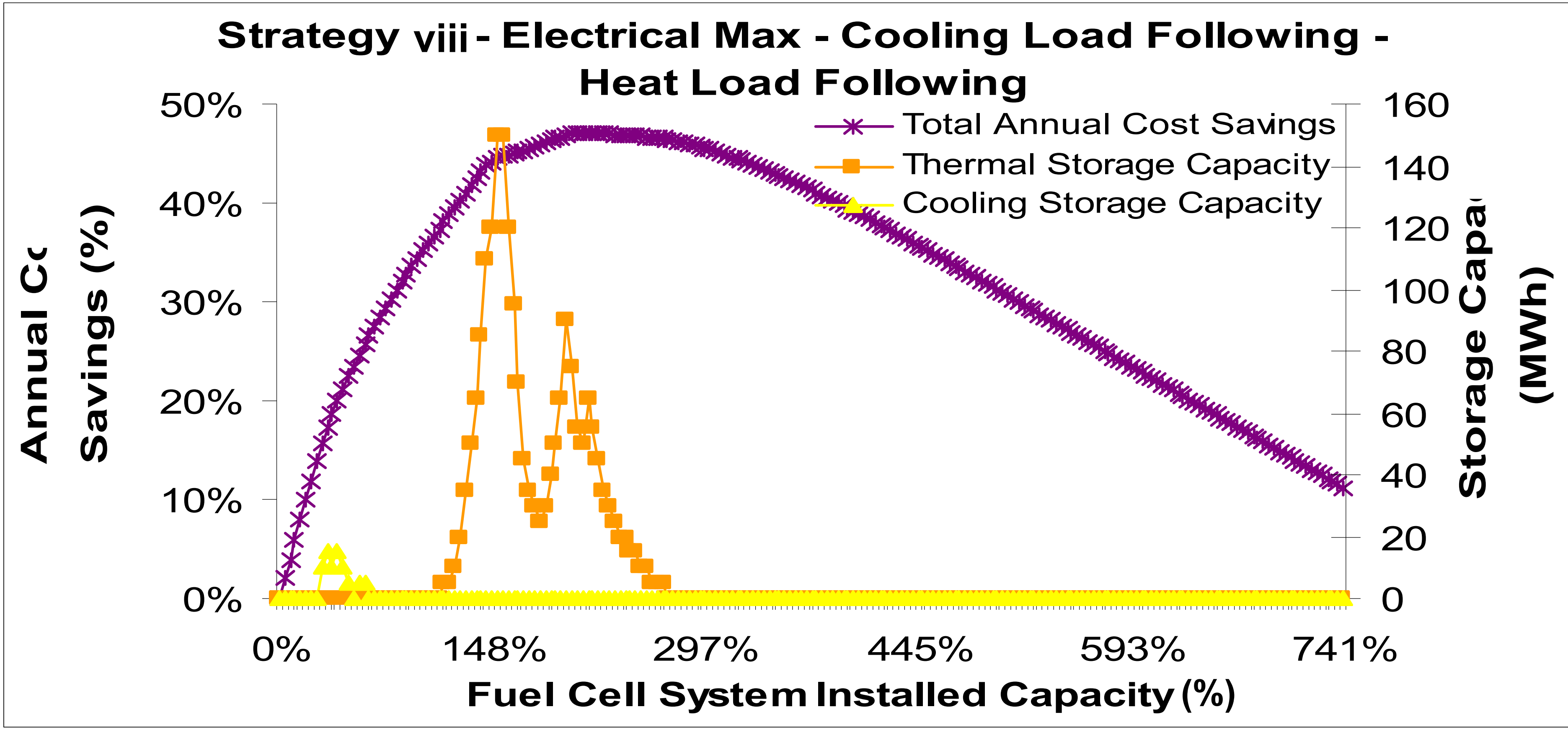
Our models successfully reproduce measured performance of both CHP and CCHP FCS over a wide operating range.





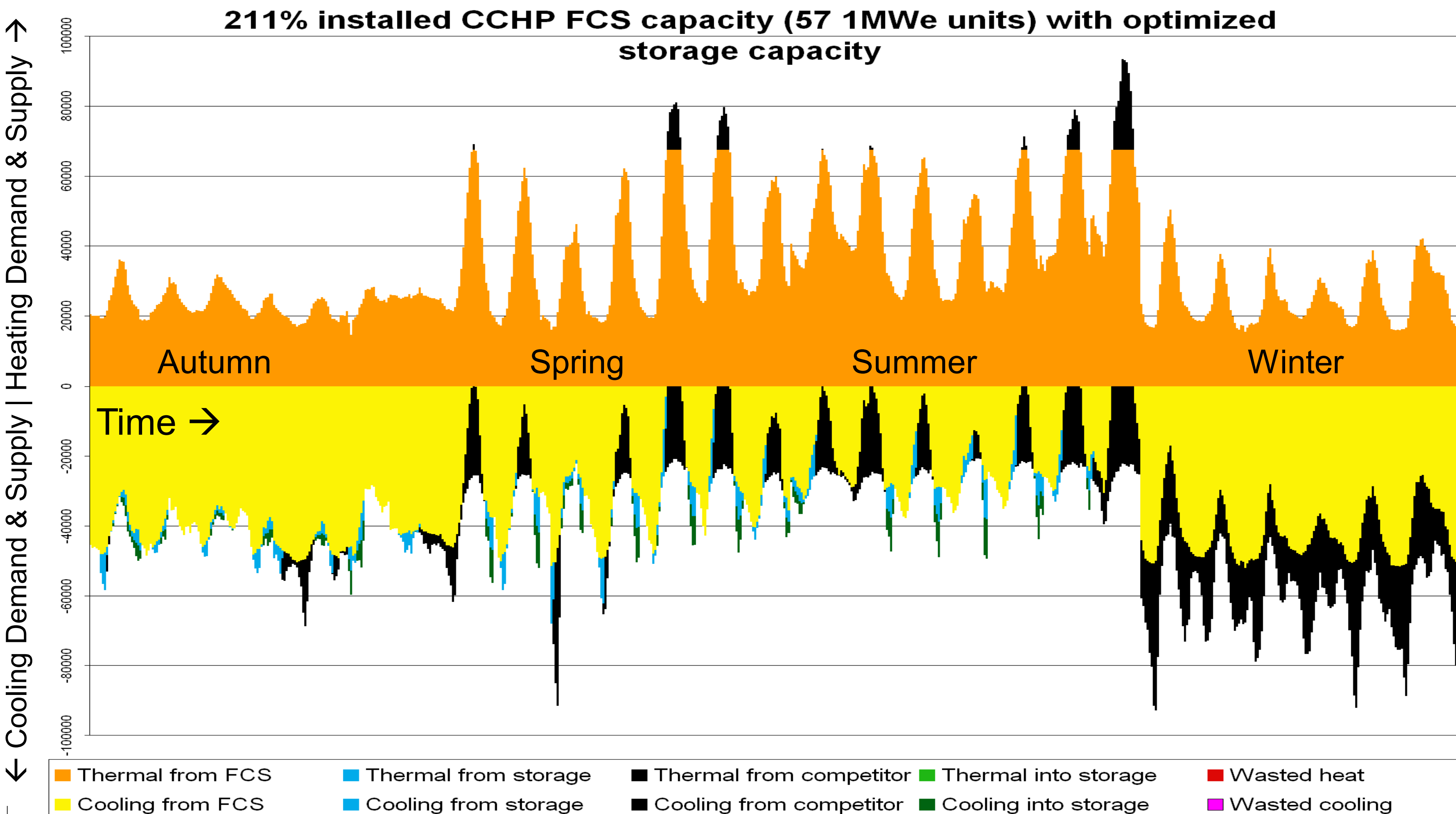
Fuel Utilization = 85%; Oxygen Utilization = 28%; Current Density = 200 mA/cm^2

Depending on market conditions and engineering performance, costs are often lowest with our strategy vii -- networking; variable heat-to-power; tunable cooling-to-heat; maximum electrical as the primary control; and load following heat & then cooling demands.



Strategy viii shows bimodal optimal heating storage capacity and multi-modal optimal cooling storage capacity, caused by the seasonal shape of the demand curves.

Our models identify the optimal dispatch of CCHP FCS and energy storage over time.



This control strategy has CCHP FCS energy systems that directly satisfy heating needs (orange), feed all excess heat to cooling (yellow), fill storage (green) after meeting instantaneous cooling demand, and finally discharge cooling storage (blue) during supply lags. In this example, heating and cooling demand curves are reversed.

Significance

- Our chemical engineering models of FCS coupled with absorption chillers describe the fundamental physics of components and reproduce measured system-wide performance data.
- Models indicate that CCHP FCS can achieve efficiencies above 80% with careful thermal integration.
- Double-effect lithium bromide (LiBr) chillers will operate with a coefficient of performance (COP) of between 0.6 and 1.0 over FCS exhaust temperatures.
- For most of the market and design permutations investigated, strategy vii [electricity maximizing (EX), heat load following (H), cooling load following (C)] is the most economical. However, for some permutations either strategy v [electricity load following (E), H, C] or viii [EX, C, H] is best, particularly with no grid connection.
- Thermal storage is occasionally economical; cooling storage is rarely economical; electrical storage is not economical.
- Strategies v [E, H, C] and vii [EX, H, C] have the lowest CO_2 emissions.
- Our optimized CCHP FCS designs have the lowest costs and CO_2 emissions of any fossil-fuel-capable distributed generator. Our modeling capability reduces the development time, costs, and environmental footprint for implementing CCHP FCS and greatly exceeds modeling capabilities of industry and other labs in this area.
- This LDRD project has resulted in DOE-funded spin-off projects of $225K in FY09 and over $400K in FY10.