# Predictive Cost Optimization Using Model Predictive Control at Stanford University

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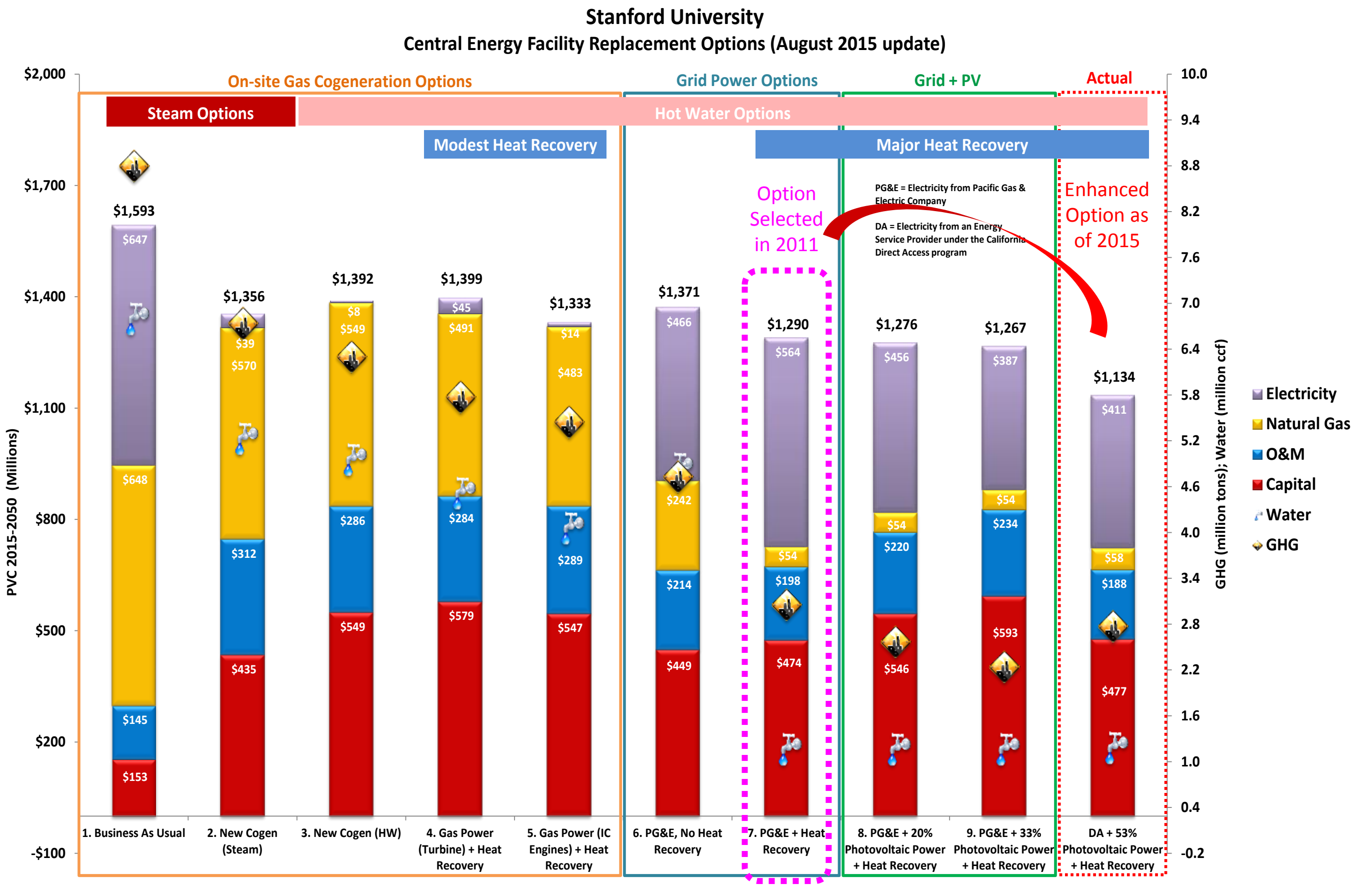
Stanford
ENERGY SYSTEM
INNOVATIONS

Stanford Energy System Innovations (SESI) is a sustainable energy program designed to meet the energy needs of the Stanford campus through at least 2050. After four years of planning and three years of construction, the SESI Central Energy Facility came online in March 2015.

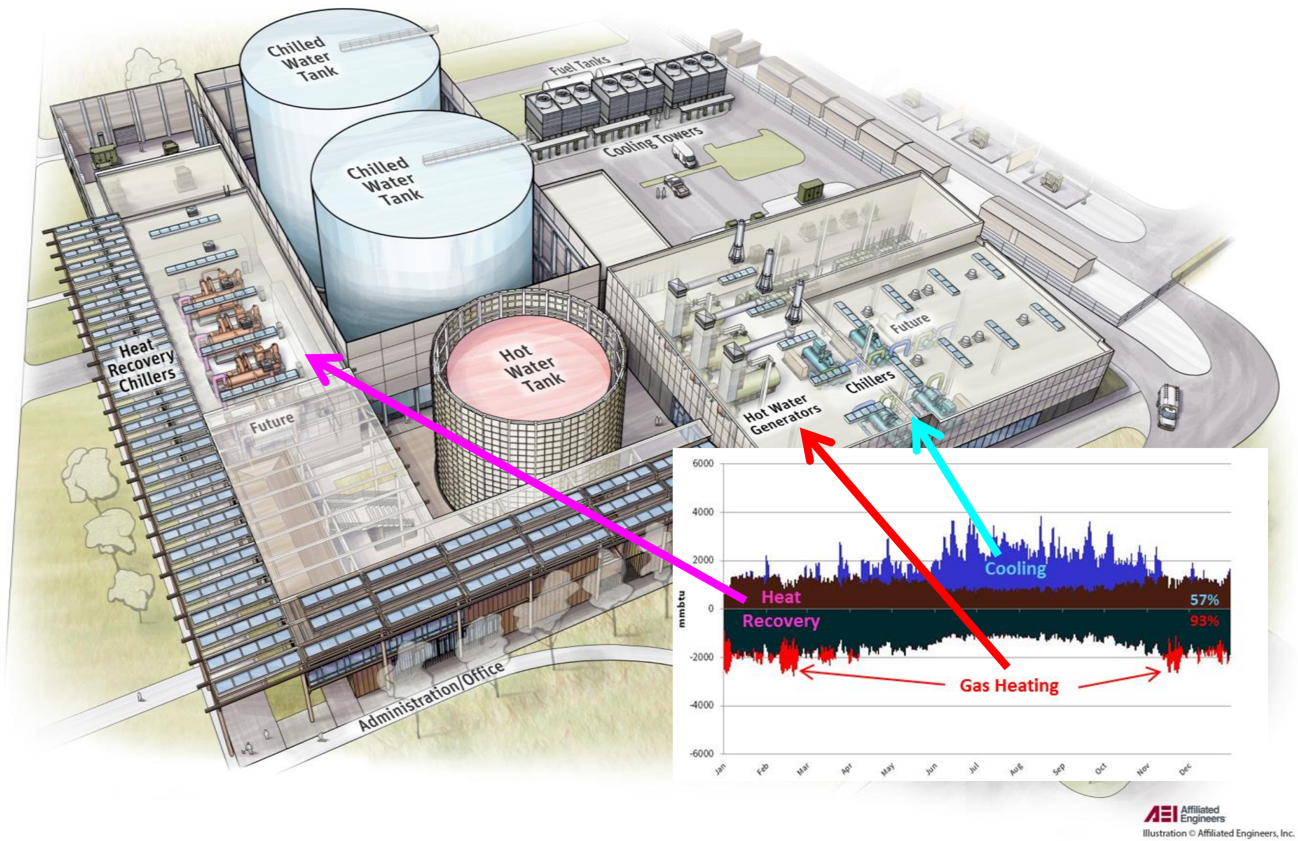
## Benefits

- Reduce campus greenhouse gas emissions by **68%** (and growing)
- Reduce campus drinking water use by an additional **15%**
- Save **$459** million over Business As Usual case over next 35 years

# Energy Options Considered in 2011



# SESI's Central Energy Facility



# Key SESI Program Elements

**Heat Recovery**
(District level application)

**New thermal distribution**
(Steam to hot water)

**Thermal Energy Storage**
(Hot and cold water)

**High-voltage substation**
(60kv/12kv)

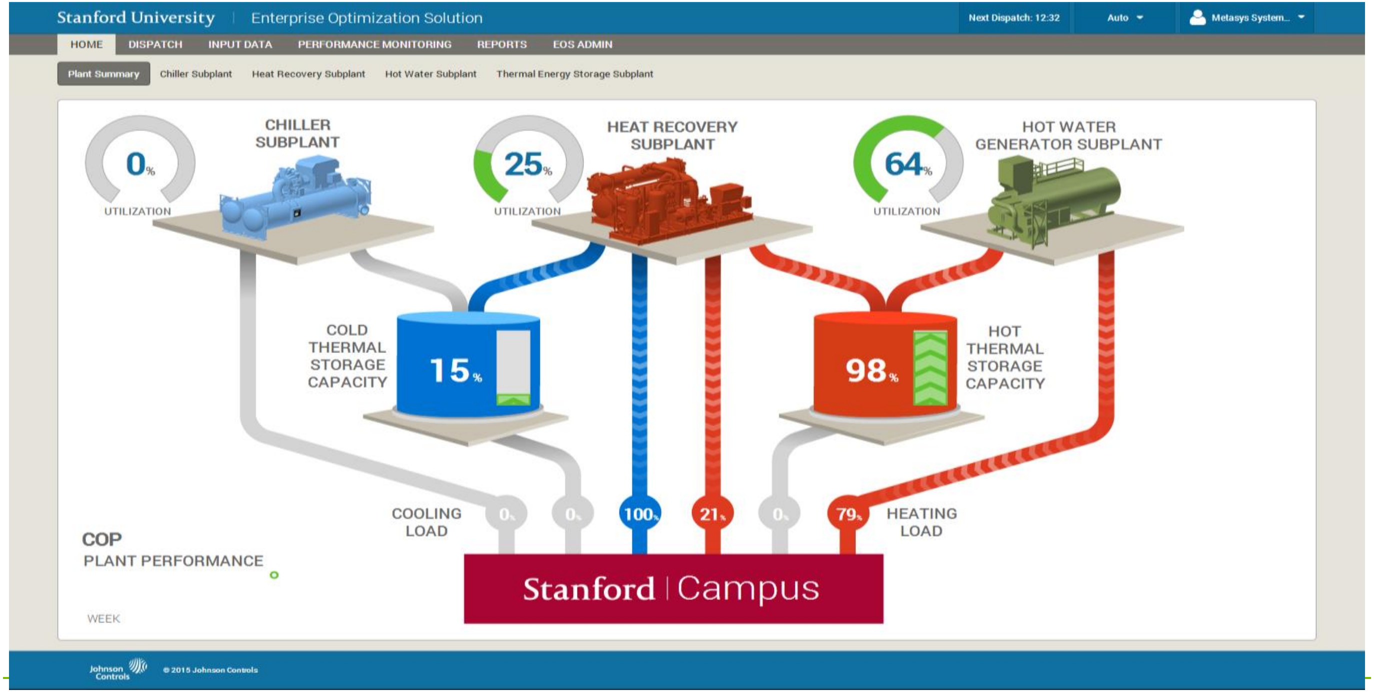
**Renewable Energy Portfolio**
(Purchased electricity)

**Advanced Energy Management Software**
(Predictive cost optimization)


***Benefits -*** *Energy savings, water savings, increased system efficiency, flexibility to adapt to new energy generation technologies, increased safety, reduced operations and maintenance cost, and improved services reliability.*

# Advanced Energy Management Software

## UI Abstraction Based on Energy Flows

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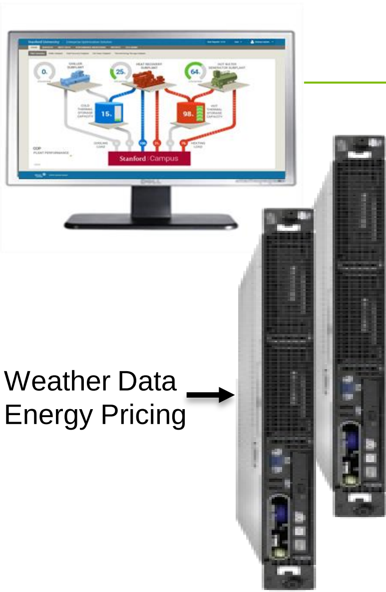
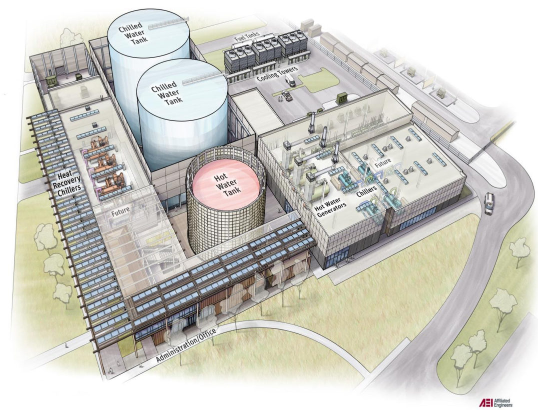
# Optimization & Control System Architecture




Weather Data
Energy Pricing

**BAS / SCADA / PLCs**

**Supervisory**




**Redundant Servers**
Optimization & Data Presentation

**Field Controllers and IO Modules**

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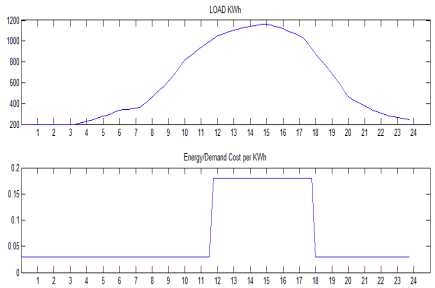
# High Level Optimization Over a Time Horizon

## Predictive Cost Optimization

### Objective Function:

$$\min(J) = \sum C_{ch} P_{ch} \Delta t + \sum C_{gas} F_{gas} \Delta t + \sum C_{tw} P_{tw} + \sum C_{pmp} P_{pmp} + \sum C_{dc} \max(P) + \sum C_{hr} P_{hr} \Delta t$$




### Equality Constraints:

$$Q_{ch} + Q_{hr} = Q_{loadcw\_t_0} \pm Q_{TES\,cw} \qquad Q_{hw} + Q_{hr} = Q_{loadhw\_t_0} \pm Q_{TES_{hw}}$$

$$\cdots\cdots \qquad \cdots$$

$$Q_{ch} + Q_{hr} = Q_{loadcw\_t_1} \pm Q_{TES\,cw} \qquad Q_{hw} + Q_{hr} = Q_{loadhw\_t_1} \pm Q_{TES_{hw}}$$

### Inequality Constraints:

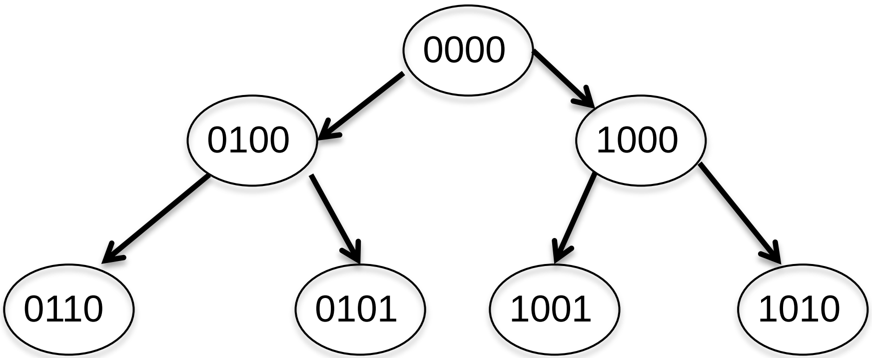
$$Q_{ch} \le \max(Q_{ch}) \qquad Q_{TES} \le \max(Q_{TES}) \qquad Q_{TES} \le \min(Q_{TES}) \qquad \cdots\cdots$$

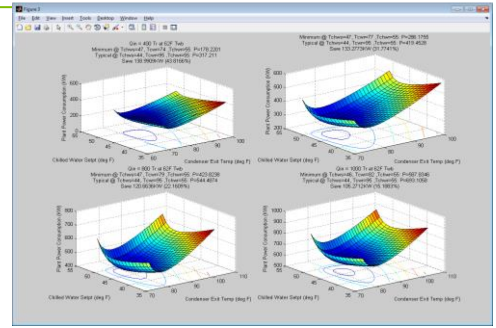
# Low Level Optimization for Min Energy Use

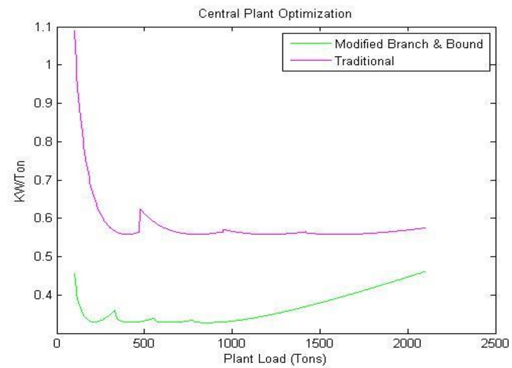
## Equipment Selection & Setpoints

Given: $Q_{ch}$, $Q_{hw}$, $Q_{TES}$ …

Determine equipment selections & setpoints using a Modified Branch and Bound

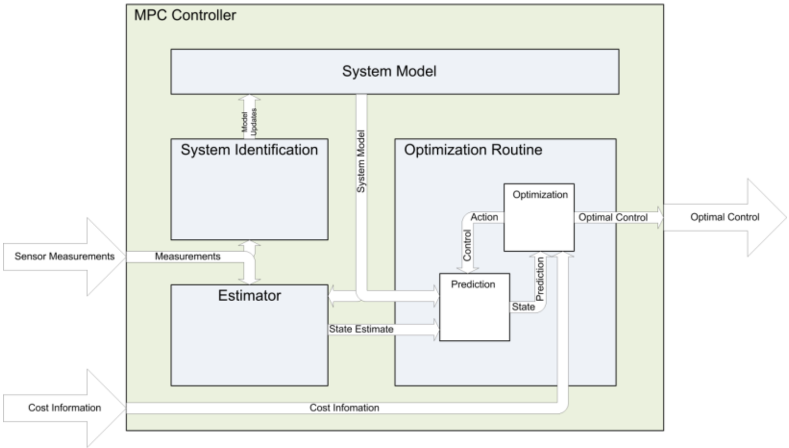


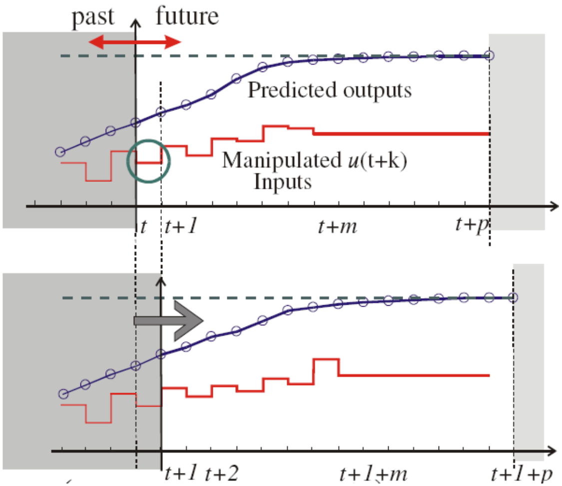





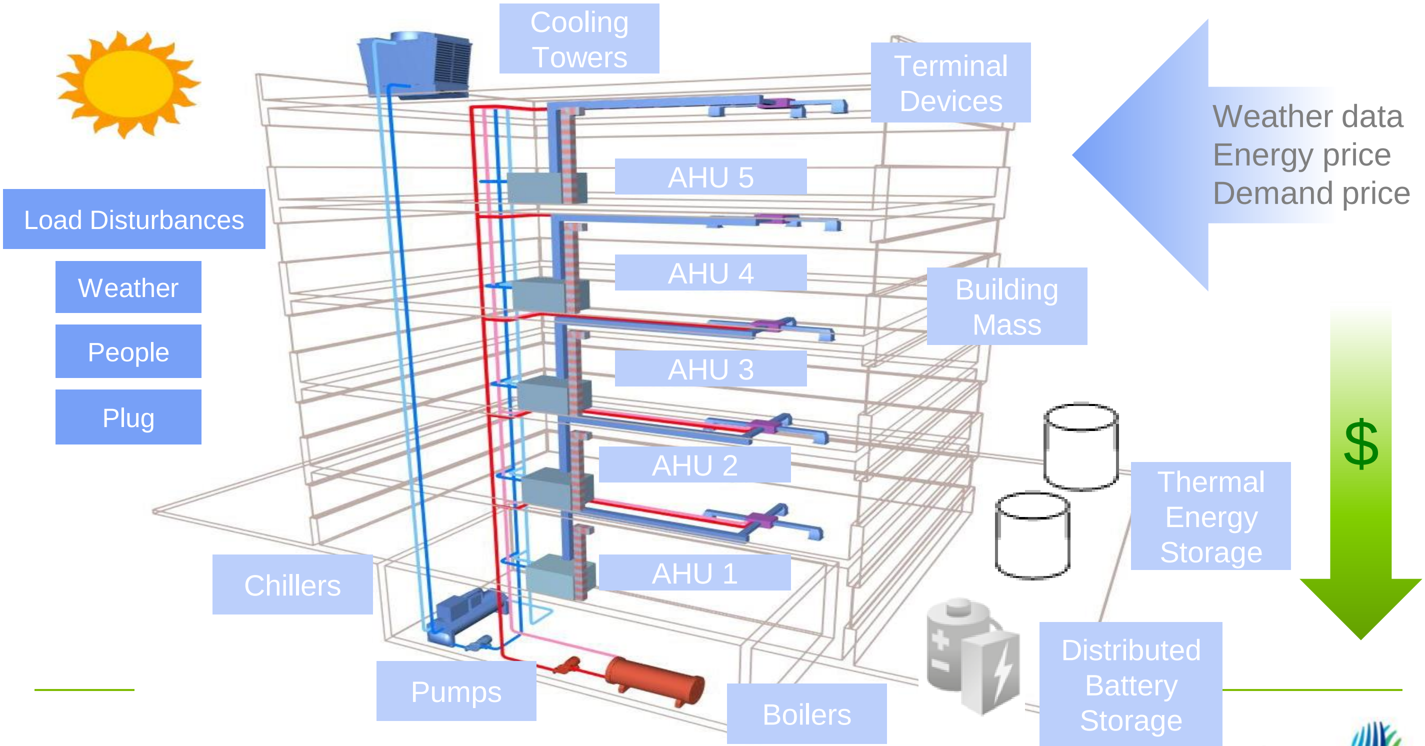
# Model Predictive Control - MPC

## Modern Feedback Control



# Optimization building systems for the lowest operating costs, energy use, water consumption & GHG emissions.

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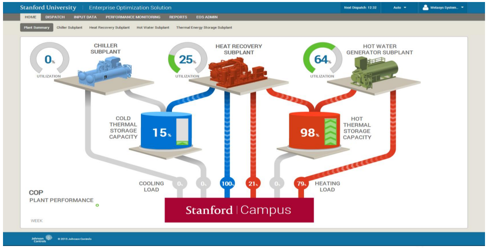
# Thank You

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