Energy and Information Intensification

Thomas F. Edgar
University of Texas-Austin

NSF Workshop on
Process Intensification

Washington, D.C. 9/30/2014

Coverage of this Presentation

- Focuses on process operation and control (not design)
- Smart manufacturing can assist with process intensification
- Cheap natural gas is a low carbon enabler
- Integrated heat/power and water/power sources
- Thermal energy storage/process control integration

Process Integration (ref. Jeff Siirola)

- Usually results in a decrease in DOF
- Decreases controllability, robustness, flexibility
- Can be mitigated by adding new manipulated variables, sensors, use of model-based control (i.e., Smart Manufacturing or Information Intensification)

What is SMART Manufacturing?

The ability to take action, in real time, to OPTIMIZE your assets in the context of your business strategies and imperatives

SMLC

SMART MANUFACTURING LEADERSHIP COALITION

The infusion of intelligence that transforms the way industries conceptualize, design, and operate the manufacturing enterprise.

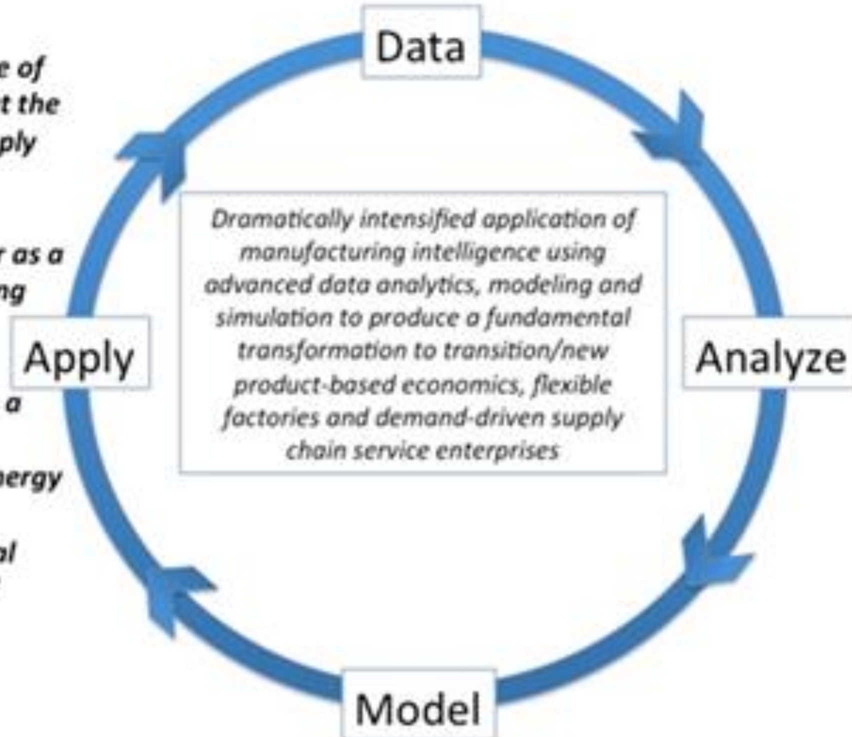
https://smartmanufacturingcoalition.org
http://smartmanufacturing.com

"Internet of Things" Deception

- Connect your smartphone to your digital scale
- Then you will lose weight
- You have to do something else?

21st Century Smart Manufacturing

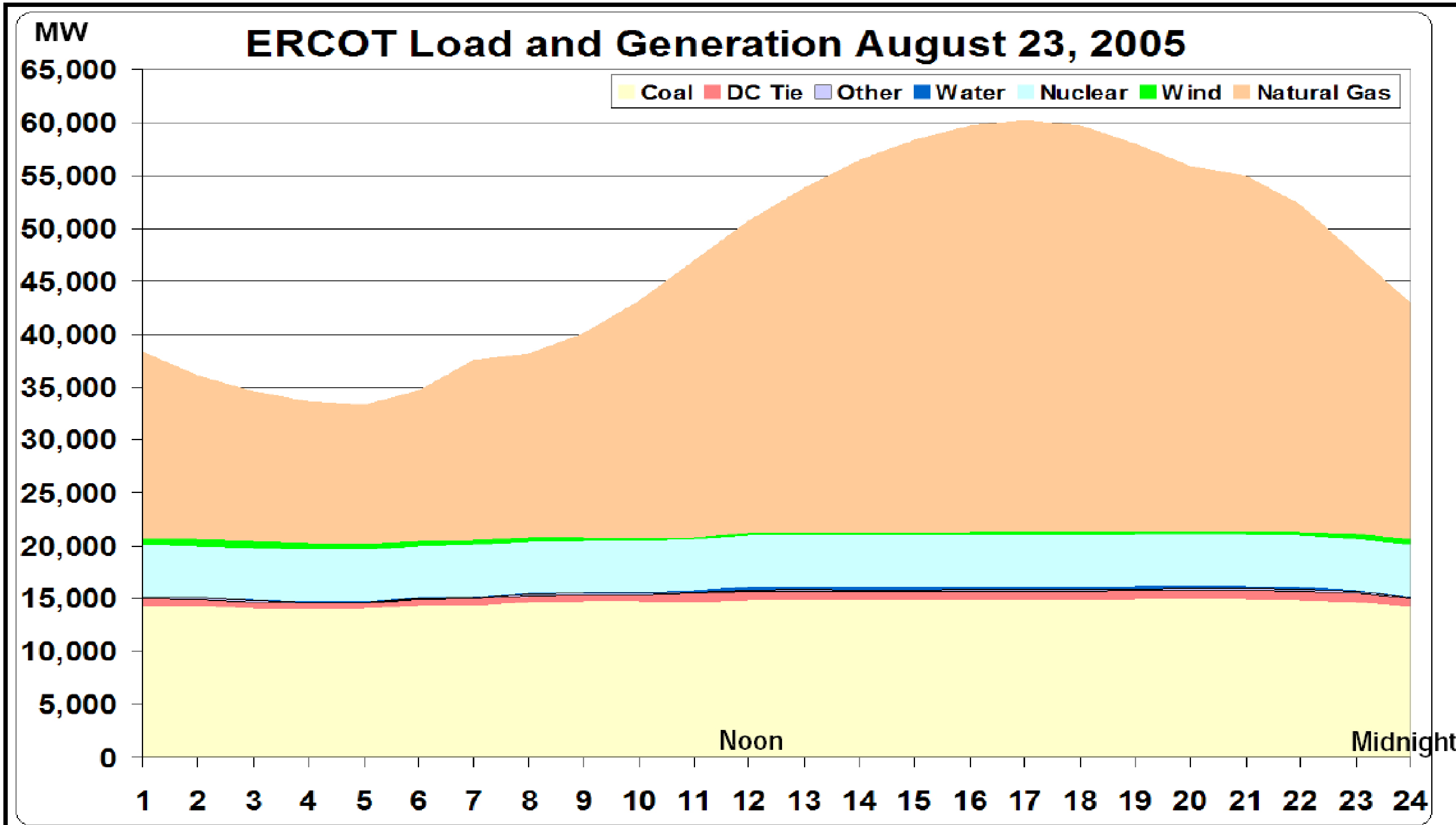
- ***Integrates the intelligence of the 'customer' throughout the entire manufacturing supply chain***
- ***Responds to the customer as a coordinated manufacturing enterprise***
- ***Responds to the public as a performance-oriented enterprise, minimizing energy and material usage and maximizing environmental sustainability, health and safety and economic competitiveness.***



Energy Intensification Vignettes

- Thermal Energy Storage
- Chiller Optimization
- Water-Energy Integration
- Energy Storage and Process Control
- Combined Solar-Natural Gas Systems

Electricity Demand Varies Throughout the Day

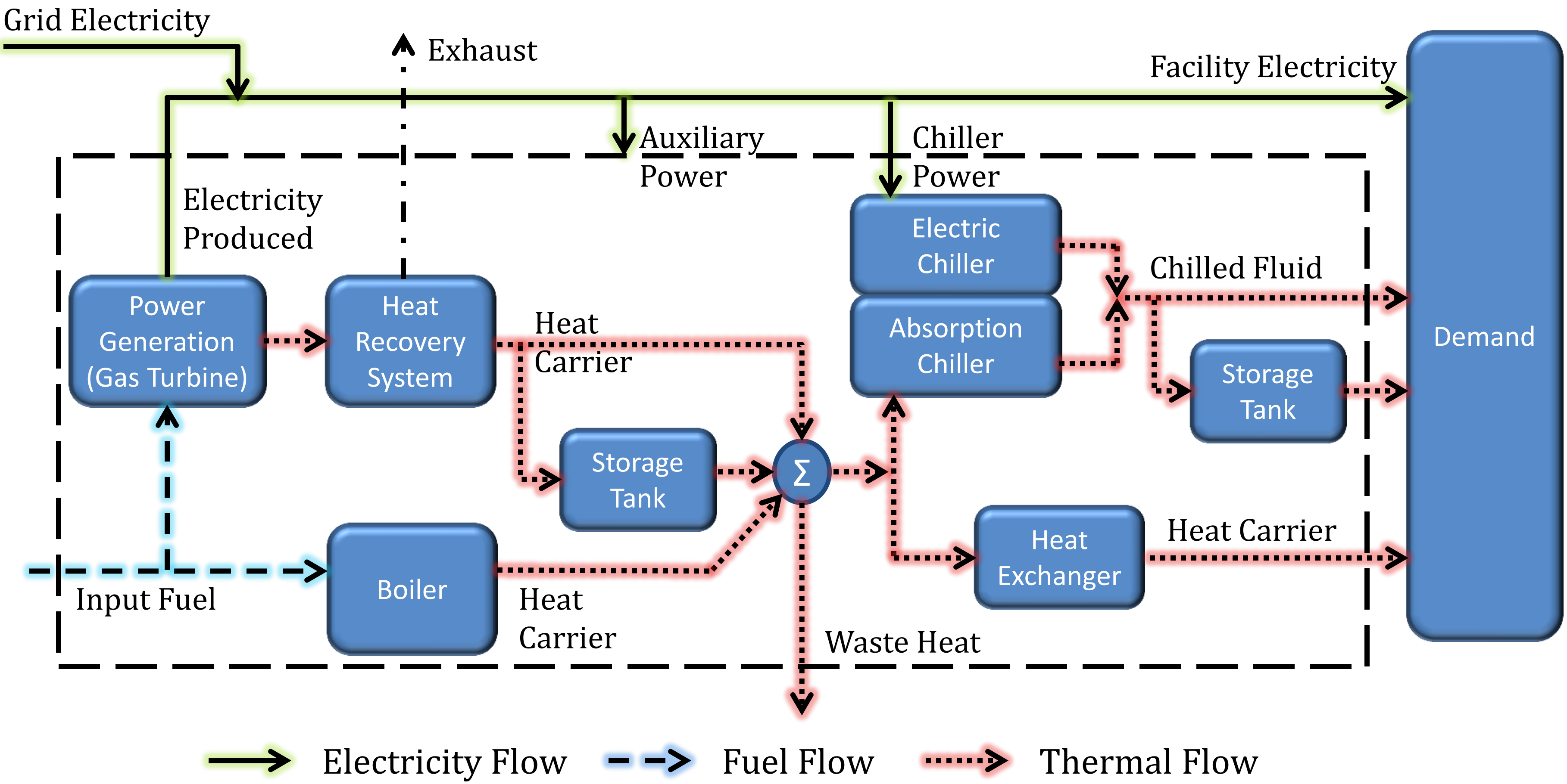


Source: ERCOT Reliability/Resource Update 2006

Thermal Energy Storage

- Thermal energy storage (TES) systems heat or cool a storage medium and then use that hot or cold medium for heat transfer at a later point in time (steam, water, ice).
- Using thermal storage can reduce the size and initial cost of heating/cooling systems, lower energy costs, and reduce maintenance costs. If electricity costs more during the day than at night, thermal storage systems can reduce utility bills further.
- Incentive for thermal storage (NY Con Edison) for building or industrial users: $2,600/KW vs. $2,100/KW for battery storage

Energy Flows in a Combined Heat and Power System with Thermal Storage



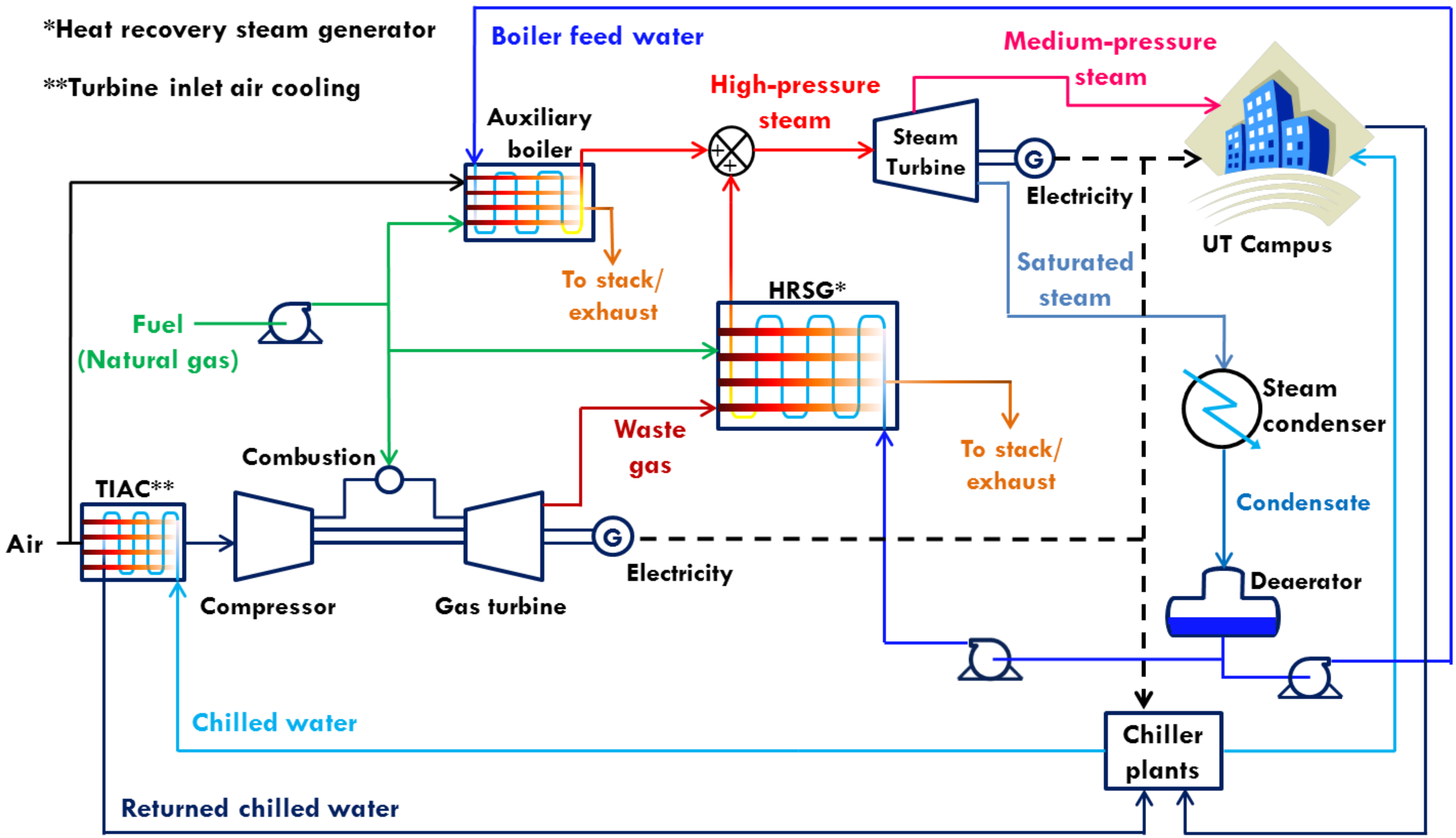
CHP Energy and CO_2 Savings Potential (10 MW)

	10 MW CHP	10 MW PV	10 MW Wind	Combined Cycle (10 MW Portion)
Annual Capacity Factor	85%	22%	34%	70%
Annual Electricity	74,446 MWh	19,272 MWh	29,784 MWh	61,320 MWh
Annual Energy Savings	308,100 MMBtu	196,462 MMBtu	303,623 MMBtu	154,649 MMBtu
Annual CO_2 Savings	42,751 Tons	17,887 Tons	27,644 Tons	28,172 Tons
Annual NOx Savings	59.4 Tons	16.2 Tons	24.9 Tons	39.3 Tons

Source: U.S. Department of Energy

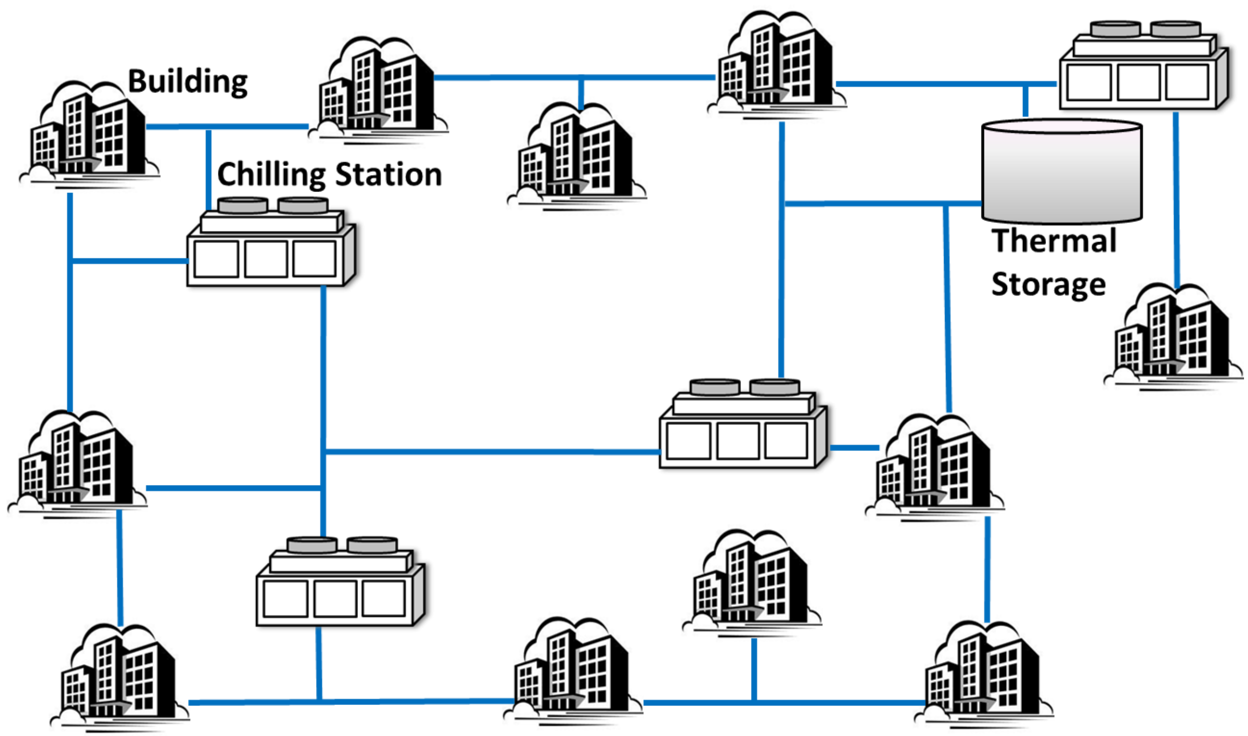
Overview of the CHP Plant at UT Austin

Hal C. Weaver Power Plant (80+ % efficiency)

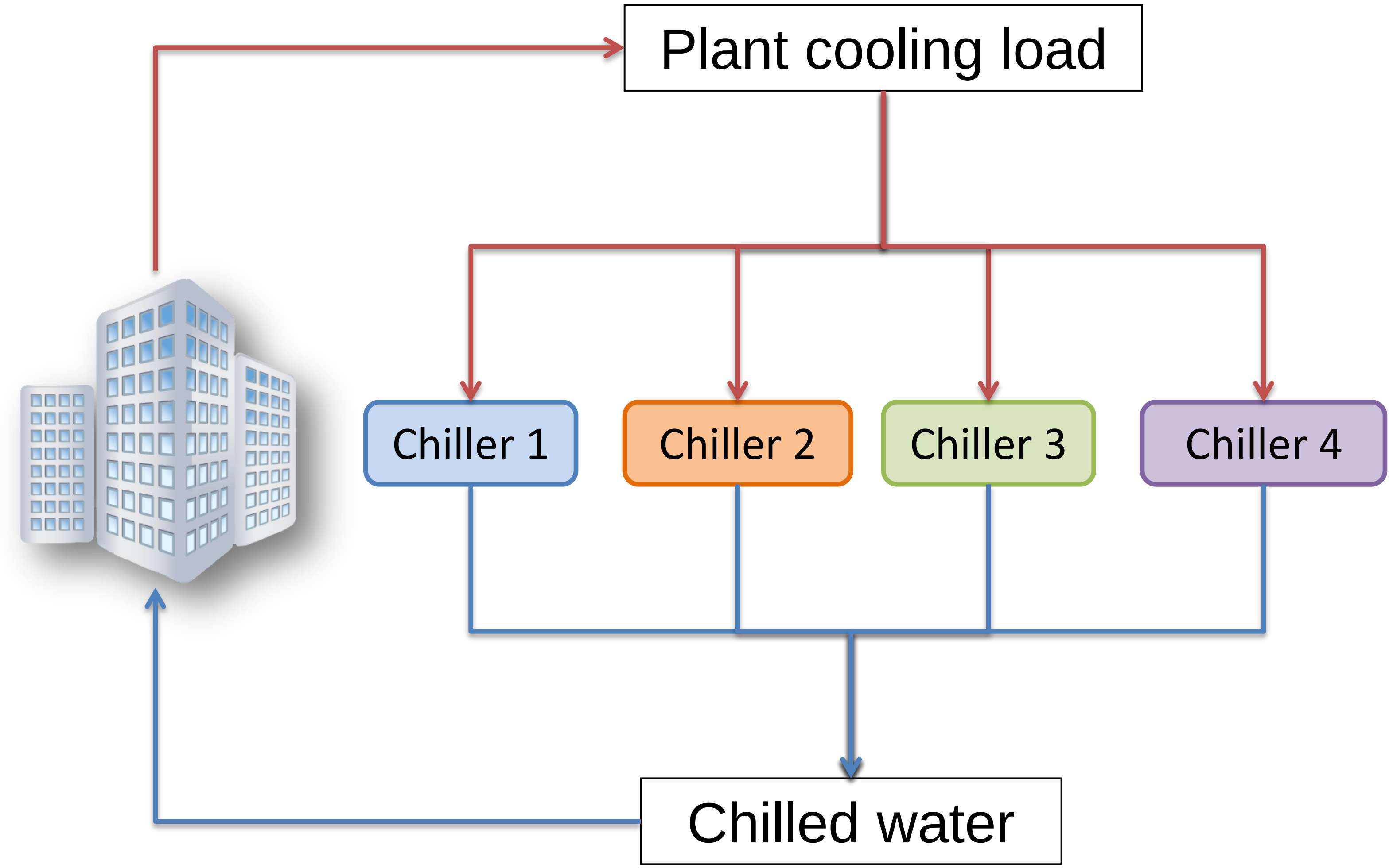


District Cooling

- Chilled water network
- Economy of scale
  - Centralized chillers
  - Thermal energy storage
- Opportunity for optimal chiller loading



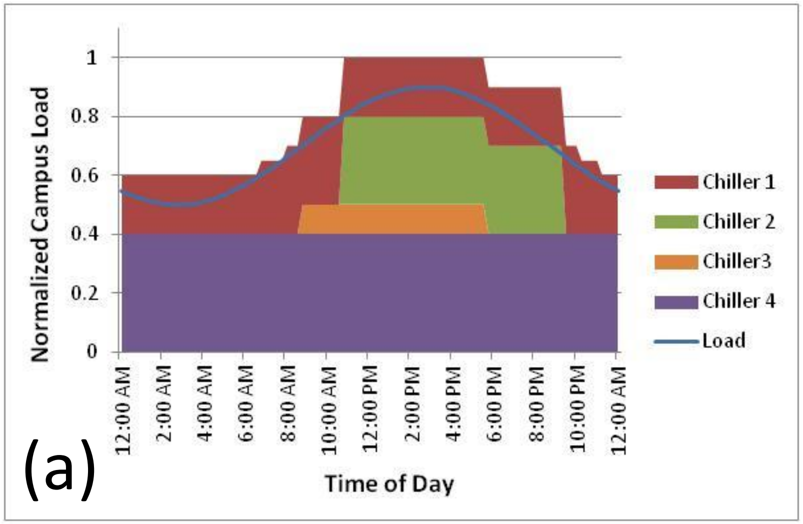
Optimal Chiller Loading to Save Energy

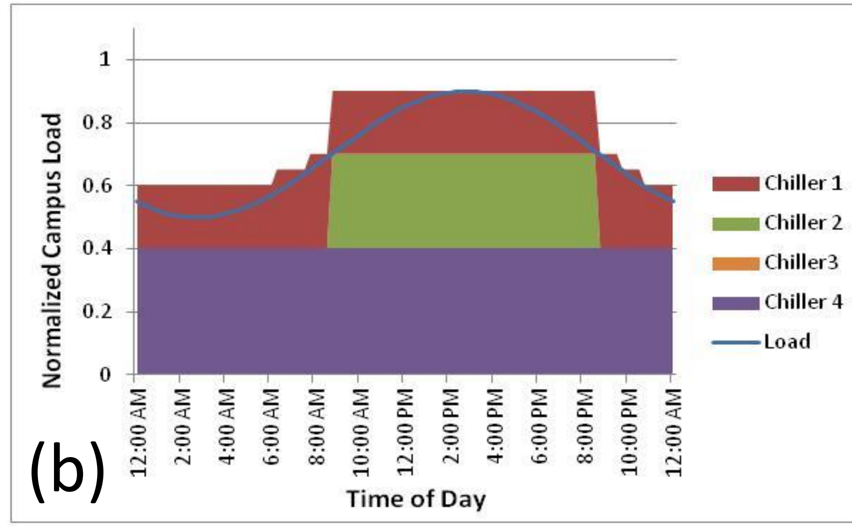


Optimal Chiller Loading

- A chiller cools the water for air conditioning buildings
- Multiple chillers in a facility are often different from one another in terms of efficiency, age, and/or capacity.
- Allocating cooling load among chillers minimizes the power consumption
- Thermal energy storage (TES) stores chilled water to be used later (24 hour cycle)

Thermal Energy Storage Operating Strategy with Four Chillers





-Chillers 1& 4 are most efficient, 3 is least efficient

-Chiller 1 is variable frequency

(a) Experience-based (operator-initiated)

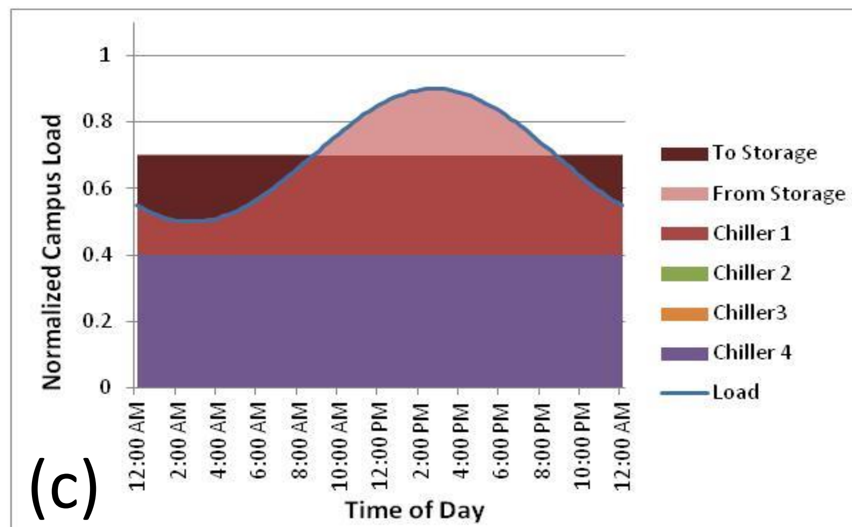
- -No load forecasting
- -Uses least efficient chiller (Chiller 3)

(b) Load forecasting + optimization

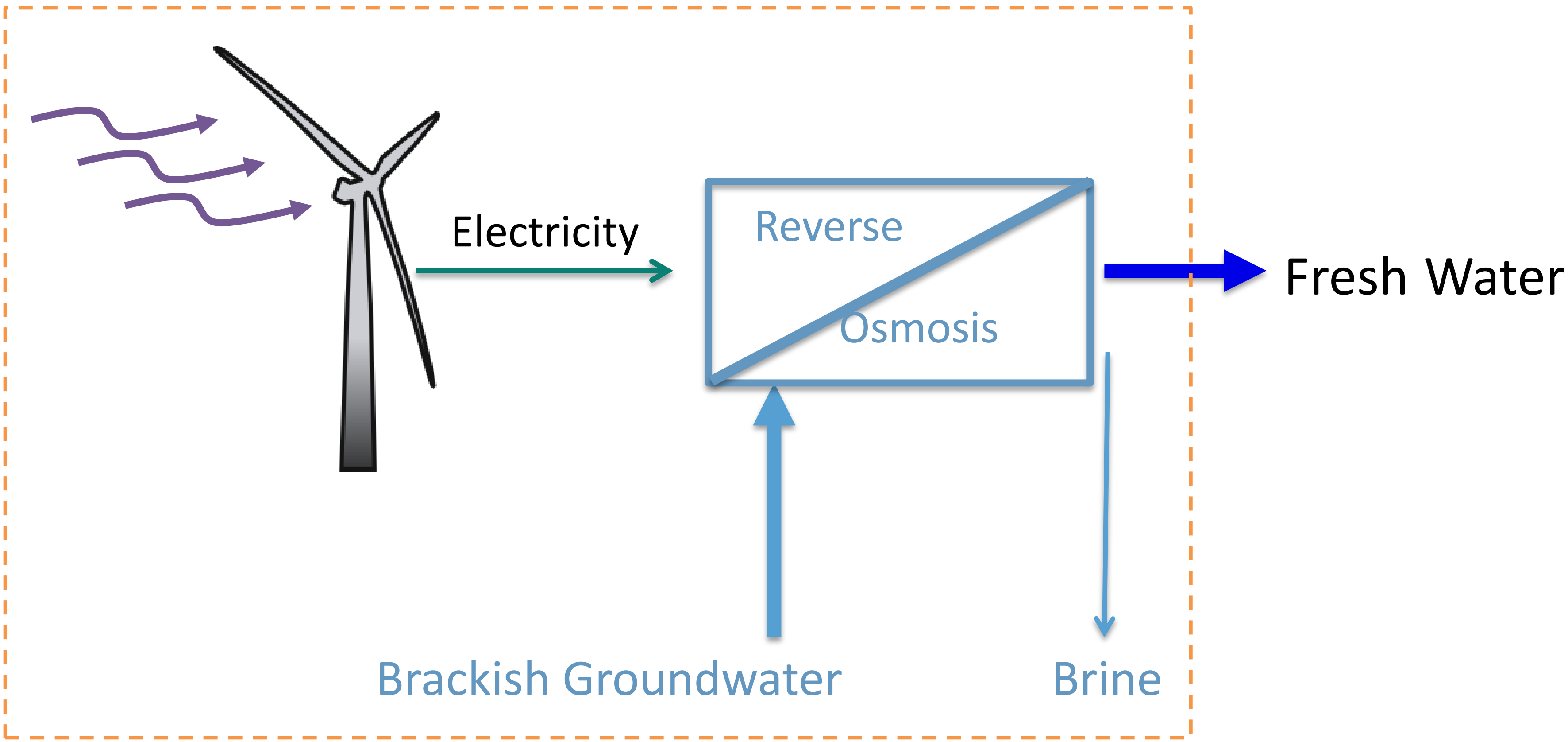
- -Uses most efficient chillers (avoids Chiller 3)

(c) Load forecasting + TES + optimization

- -Uses only two most efficient chillers



Inclusion of a Brackish Groundwater Desalination Plant Could Utilize the Electricity to Produce Fresh Water



Source: Michael Webber and Michael Baldea (UT-Austin)

Integration of Wind Energy and Water Desalination

- Provide an alternative source of water for water-strained areas
- Transform low-value products (brackish groundwater and intermittent electricity) into a high-value product (treated water for municipal/industrial use)
- Alternative use of a carbon-free, domestic, renewable source of energy
- Provide solutions to challenges of each technology
  - Desalination can load-follow intermittent, off-peak nature of wind power
  - Excess low cost wind power addresses high energy requirements of desalination

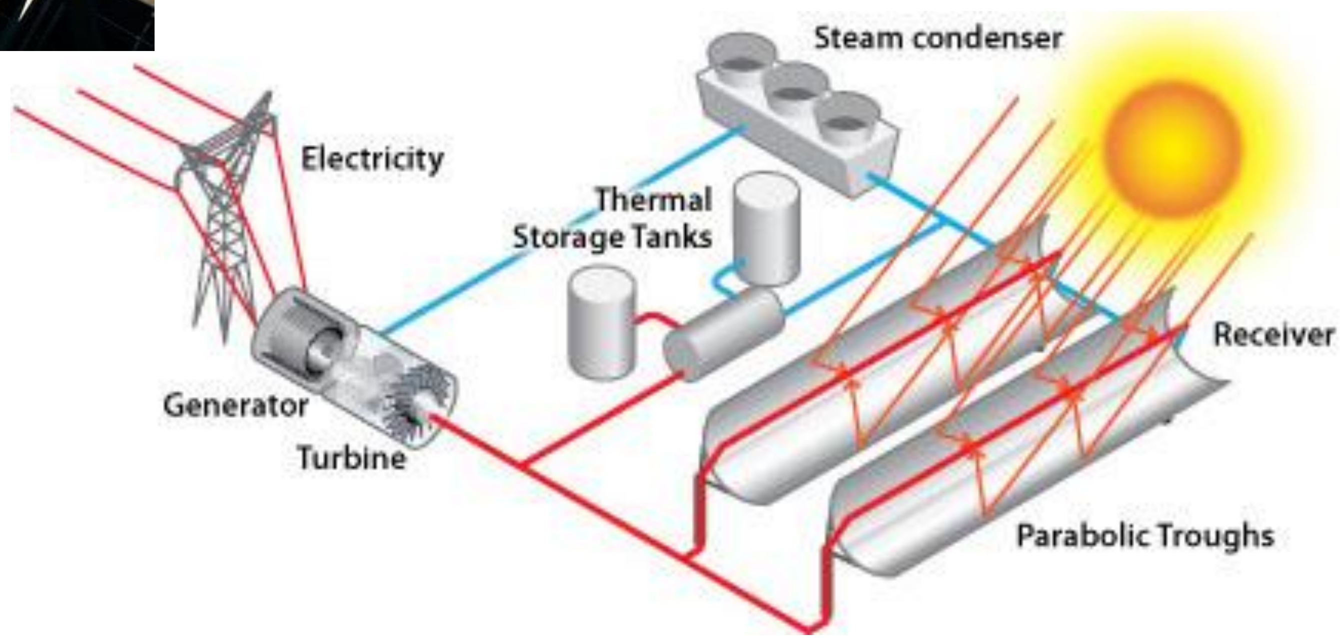
Integrated Wind Energy and Water Desalination-Other Benefits

- Water requires energy and energy requires water
- 40% of new U.S. power production is from wind
- Cost for brackish water cleanup 3-10x cost of surface water (if it is available); desalination easier than using RO for seawater.
- Water is easier to store than electricity

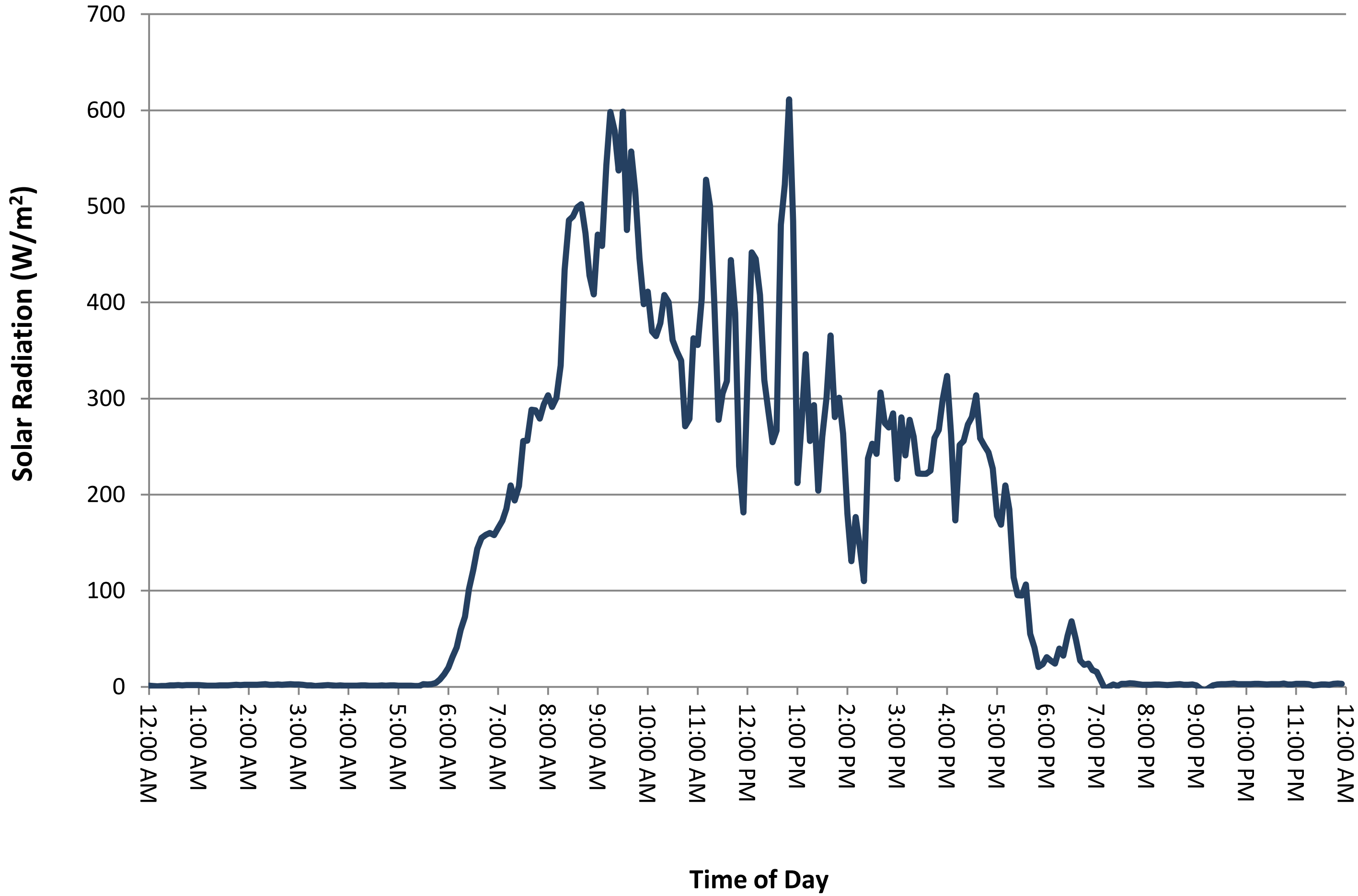
TES with Concentrated Solar Power (CSP)

- CSP technologies concentrate sunlight to heat a fluid and run a generator

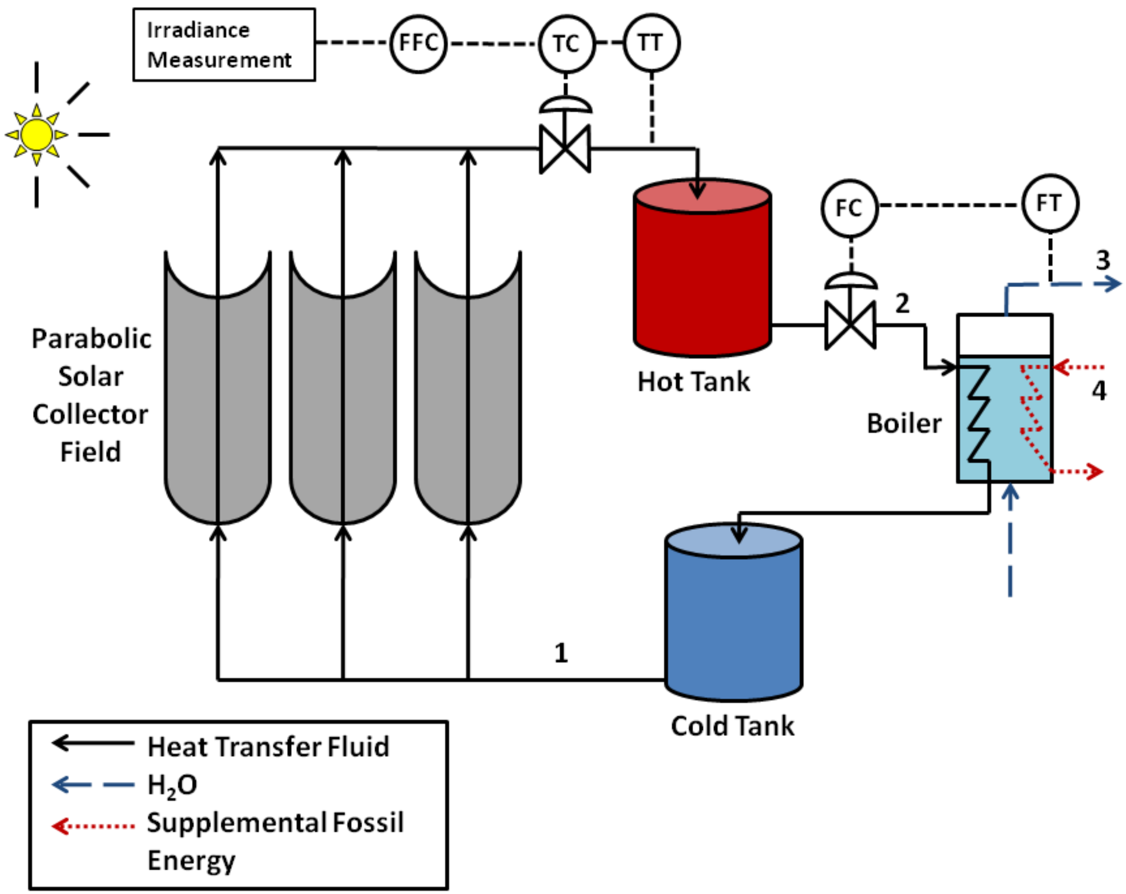
- By coupling CSP with TES, we can better control when the electricity is produced



Solar Energy and the Need for Storage



Solar Heating Augmented by Natural Gas Firing



- Feedforward + Feedback (PID) temperature control
  - Uses FF measurements of solar irradiance
  - Flow rate of stream 1 is manipulated variable
- Feedback control (PID) used for steam flow (power) control
- Supplemental gas used when solar energy is not sufficient (stream 4)

Summary of Results

	Sunny Day: System without Storage	Sunny Day: System with Storage	Cloudy Day: System without Storage	Cloudy Day: System with Storage
Solar Energy Delivered to Load	16.48	16.82	8.40	8.49
Supplemental Fuel Required (MWh)	12.58	7.18	15.78	15.51
Solar Share	47.6%	70.1%	34.3%	35.4%

- Solar Share increased by 47% on sunny day, 3% on Cloudy day
- Power quality much better with storage
- Dynamic optimization with weather forecasts can further improve solar share

Minimization of Nonrenewable Energy Consumption in Bioethanol Production Using a Solar-assisted Steam Generation System

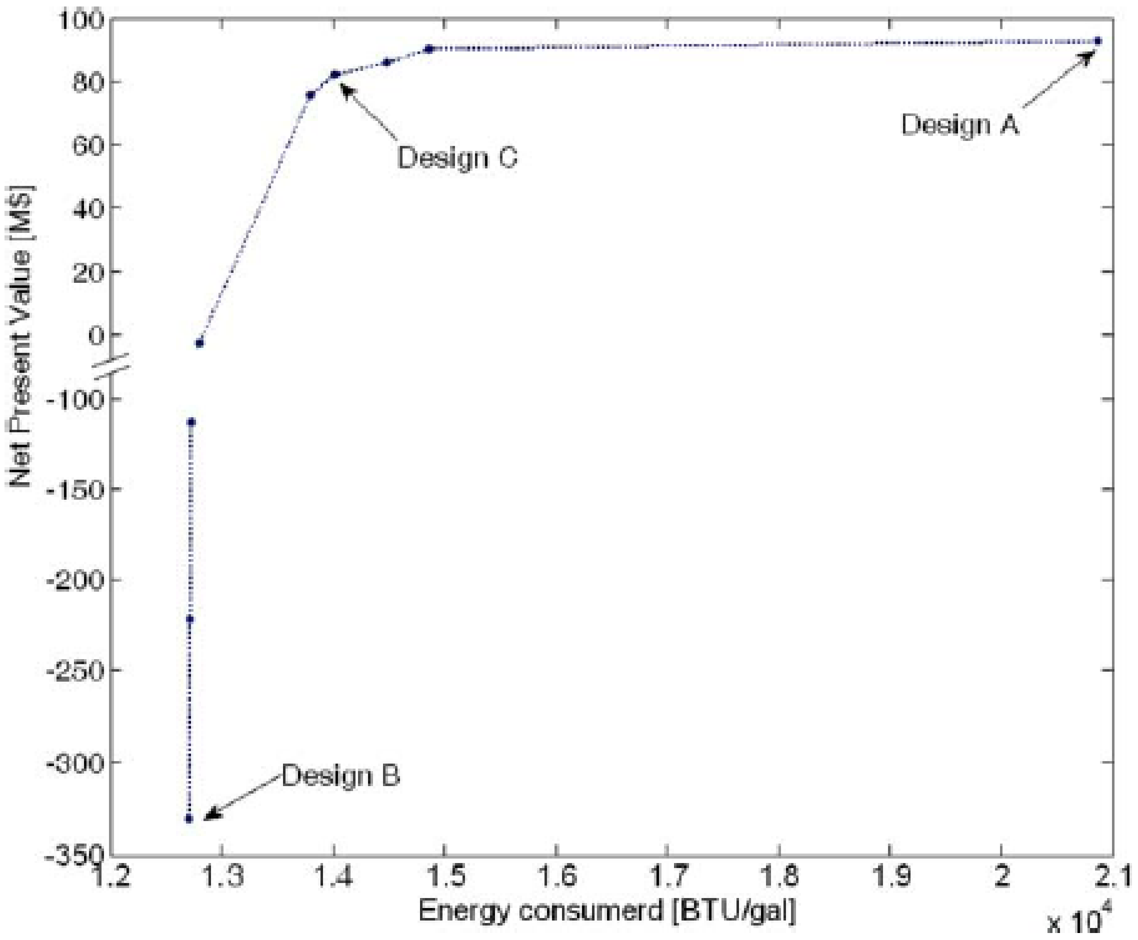


Figure 3. Pareto set of optimal solutions in the bioethanol production plant

AIChE Journal

Brunet, Robert, Gonzalo Guillén-Gosálbez, and Laureano Jiménez. "Minimization of the nonrenewable energy consumption in bioethanol production processes using a solar-assisted steam generation system." *AIChE Journal* 60.2 (2014): 500-506.

Table 5. Economic and Energetic Summary of the Bioethanol Process

Item	Design A	Design B	Design C
Net Present Value ($)	92,752,281	−328,817,003	75,610,887
Energy consumed (Btu/gal)	20,968	12,838	13,903
Total Capital Investment ($)	37,159,397	316,441,020	44,862,192
Operating Cost ($/yr)	63,021,995	79,893,062	62,606,124
Production Rate (kg/ yr)	119,171,463	119,171,463	119,171,463
Unit Production Cost ($/kg)	0.67	1.12	0.68
Unit Selling Price ($/kg)	0.69	0.69	0.69
Total revenues($)	81,826,000	81,826,000	81,826,000
Area solar panels (m^2)	0	5,430,794	71,053
Natural gas consumed (kg/yr)	22,066,980	10,570,180	12,102,040

AIChE Journal
Brunet, Robert, Gonzalo Guillén-Gosálbez, and Laureano Jiménez. "Minimization of the nonrenewable energy consumption in bioethanol production processes using a solar-assisted steam generation system." *AIChE Journal* 60.2 (2014): 500-506.

Conclusions

- Many opportunities to improve energy efficiency in the process industries by combined use of natural gas and renewables
- Water-energy nexus is a new opportunity for process intensification
- Smart manufacturing tools will be critical technologies to deal with this dynamic environment