NATIONAL ENERGY TECHNOLOGY LABORATORY

Design, Analysis, and Optimization of Integrated Power Plant and Water Management Systems

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Outline of Presentation

- **Project Overview**
  - Goals and Objectives
  - Milestones
- **Case Studies**
  - Integrated Power Plant and Water Network
  - PC and IGCC w/ and /wo CO2 Capture
- **Optimal Synthesis Approach**
  - Heat and Mass Exchange Networks
  - Multiobjective Optimization under Uncertainty
- **Conclusions**

Project Overview

- **Goal**
  - Develop a simulation-based tool for the synthesis, design, analysis, and optimization of integrated power plant and water management systems under uncertainties
- **Objectives**
  - Develop water system modeling guidelines, assumptions, and methodologies
  - Algorithm development for the synthesis, design, analysis and optimization of integrated process/water systems
  - Establish process/water simulation baselines for PC and IGCC systems with and without CO_2 capture
  - Study and simulate new water management technologies

Project Milestones (Year 1)

- Generate report summarizing findings on power plant water usage, reuse, recovery, and treatment data
- Deliver detailed three-year project development plan to develop integrated power plant and water management tools
- Develop and exercise Aspen Plus simulations for baseline PC and IGCC power plant /w and /wo carbon capture, including water systems
- Deliver report on Aspen Plus PC and IGCC plant simulations with water network models

Project Milestones (Year 1)

- Deliver plan for development of an Aspen Plus case for water technology developed under the DOE Power Plant Water R&D Program
- Generate Aspen Plus PC plant simulation to evaluate advanced water technology developed under DOE Power Plant Water R&D Program
- Generate report on opportunities for applying APECS to evaluate water mgmt technologies using potential PDE/CFD-based equipment models
- Develop plan for developing probability distributions for uncertainties and variabilities in water management technologies

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Integrated Plant/Water Case Studies
PC and IGCC w/ and wo/ CO2 Capture

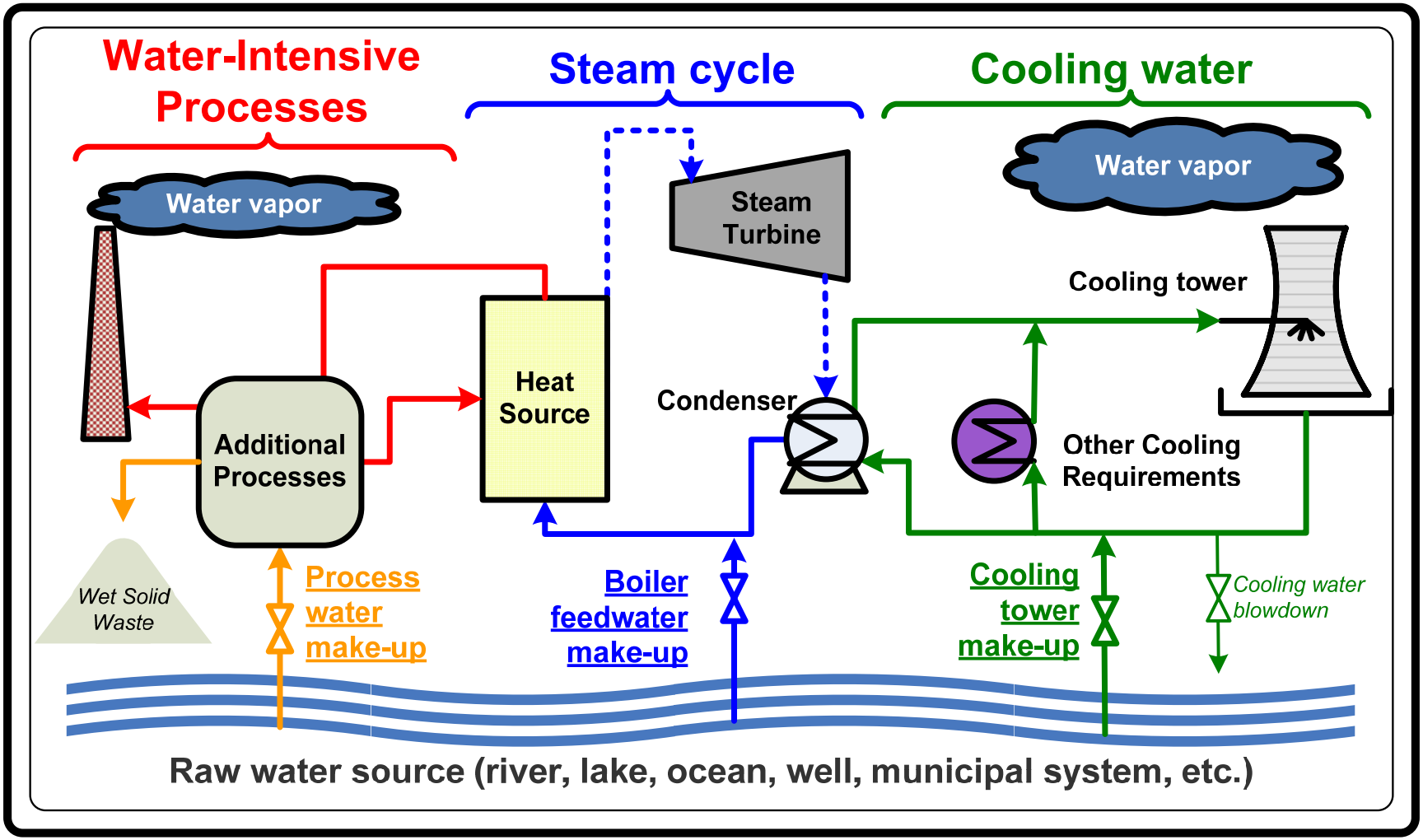
Plant Type	ST Cond. (psig/°F/°F)	GT	Gasifier/ Boiler	Acid Gas Removal/ CO_2 Separation / Sulfur Recovery	CO_2 Cap
IGCC	1800/1050/1050 (non-CO_2 capture cases)	F Class	GE	Selexol / - / Claus	
	1800/1000/1000 (CO_2 capture cases)			Selexol / Selexol / Claus	90%
PC	2400/1050/1050		Subcritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%

Coal-Fired Power Plant

IGCC Power Plant

"Cost and Performance Baseline for Fossil Energy Power Plants Study, Volume 1: Bituminous Coal and Natural Gas to Electricity," National Energy Technology Laboratory, www.netl.doe.gov, August 2007.

Water Flow Schematic for Power Plants



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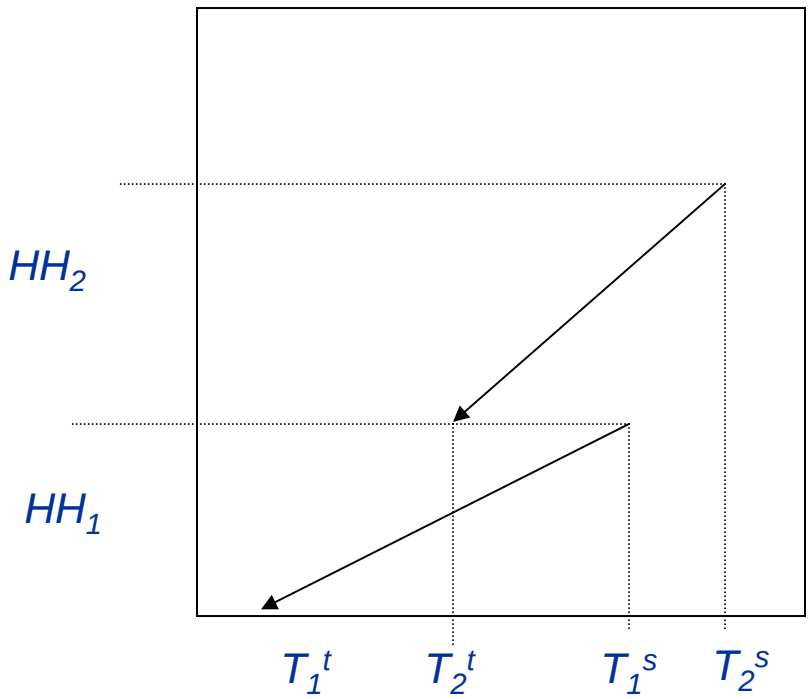
Optimal Synthesis Approach

- **Heat Exchanger Network Synthesis**
  - Minimize use of cooling water
- **Mass Exchanger Network Synthesis**
  - Minimize use of process water
- **Optimization Approach to Process Synthesis**

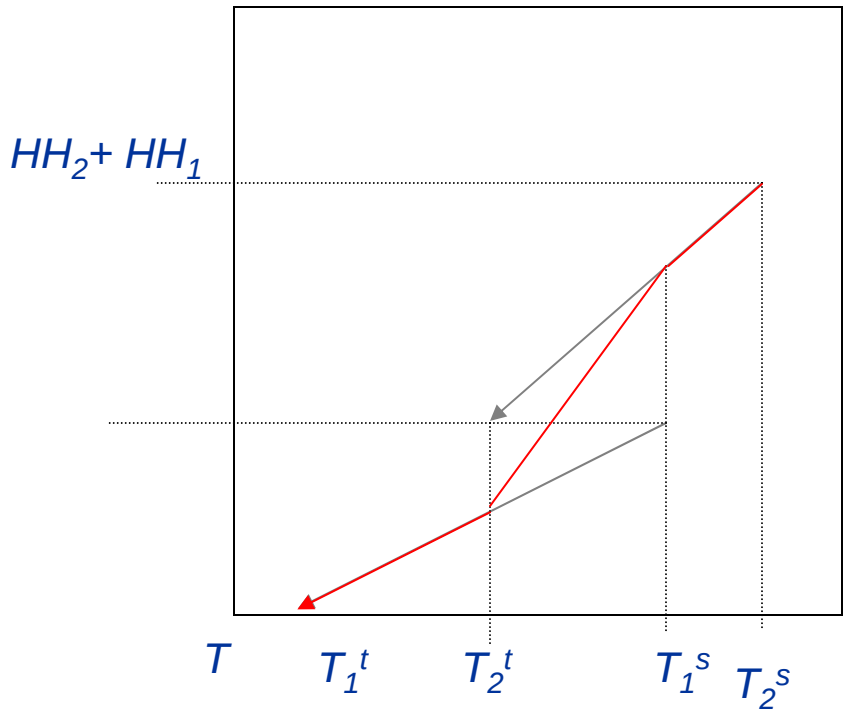
Heat Exchanger Network Synthesis

- **Heat exchange pinch diagrams**

Two hot streams

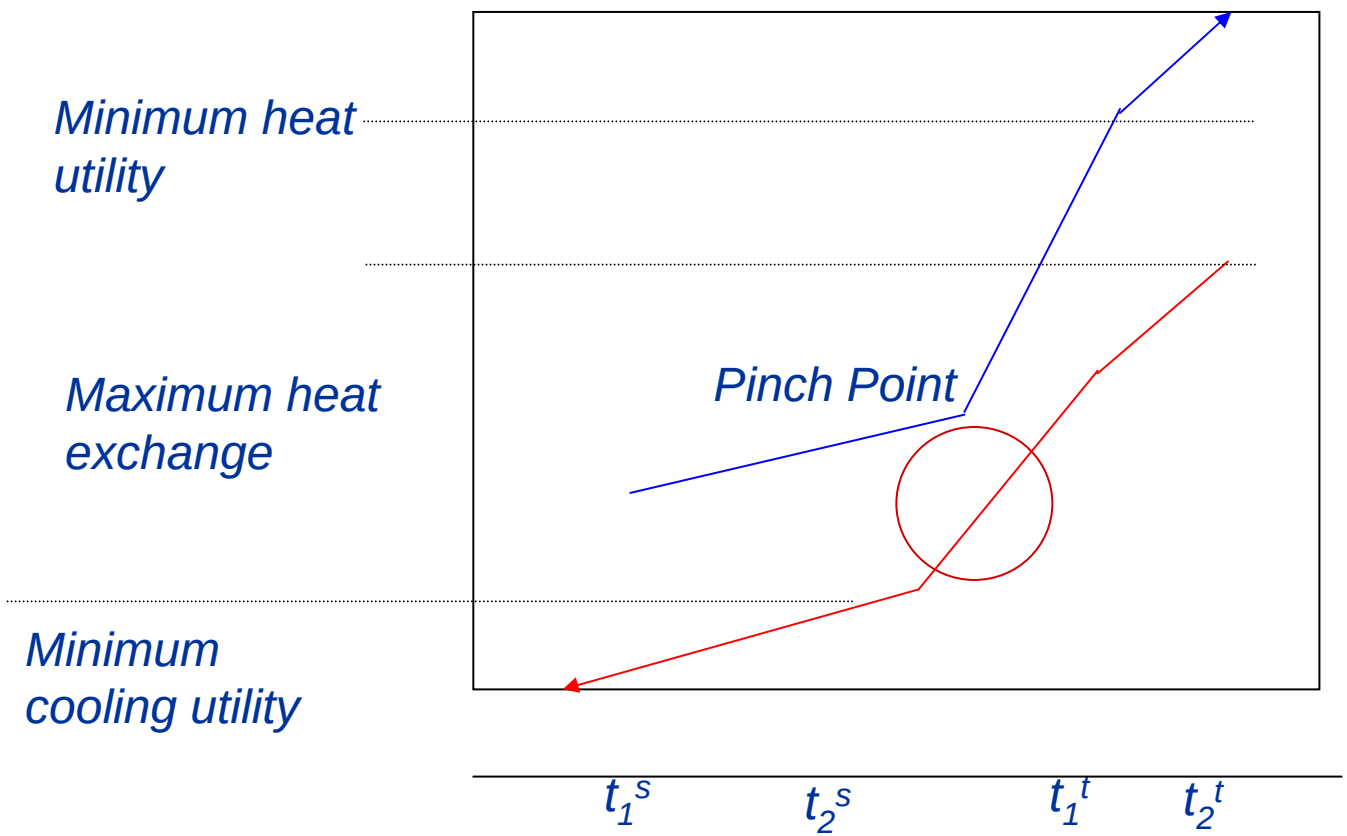


Hot Composite

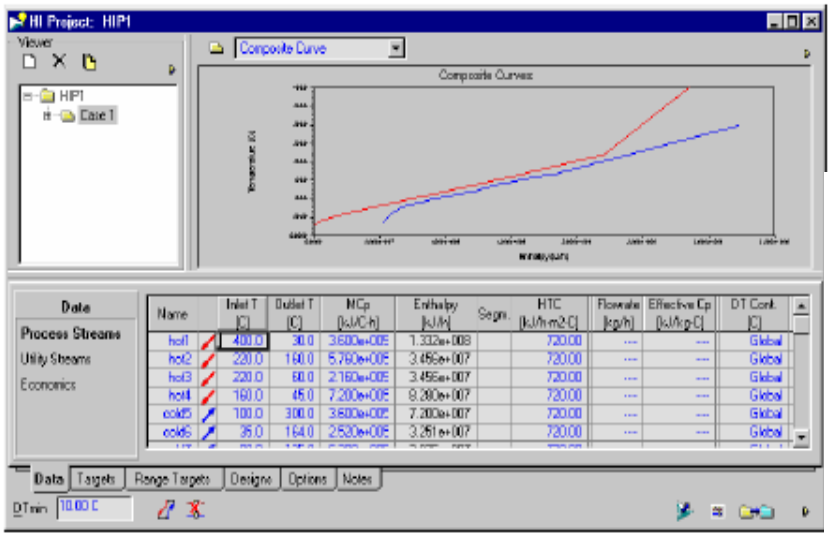


$$HH_u = F_u Cp_u (T_u^s - T_u^t)$$

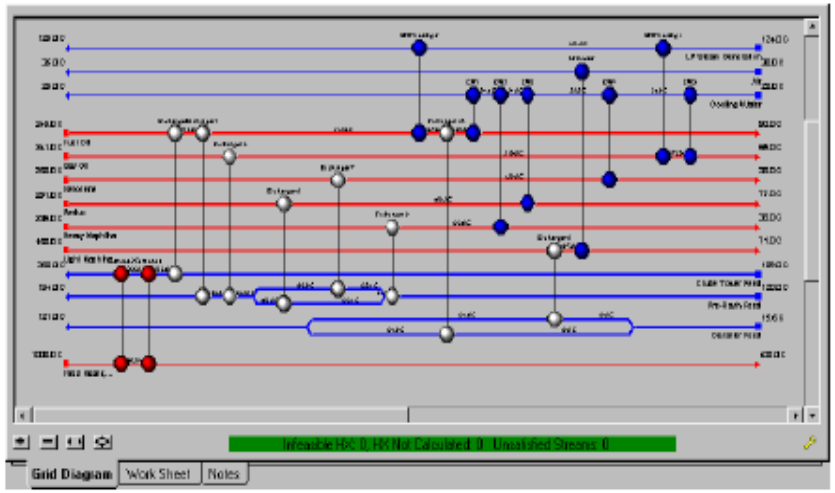
Heat Exchange Pinch Diagram



Optimal Heat Exchange Network Design



Aspen Energy Analyzer

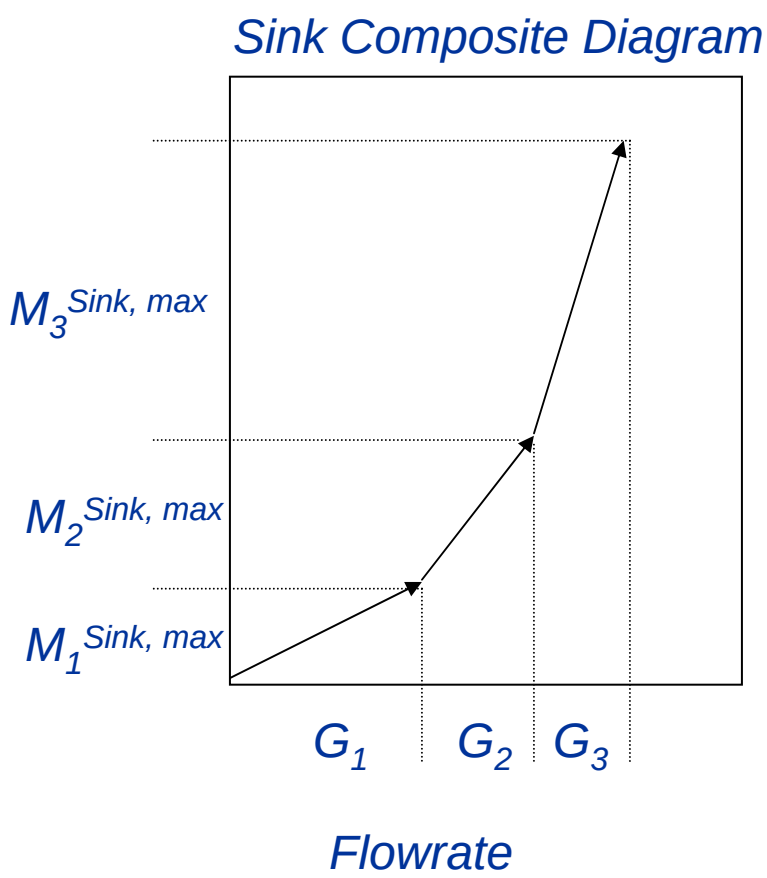


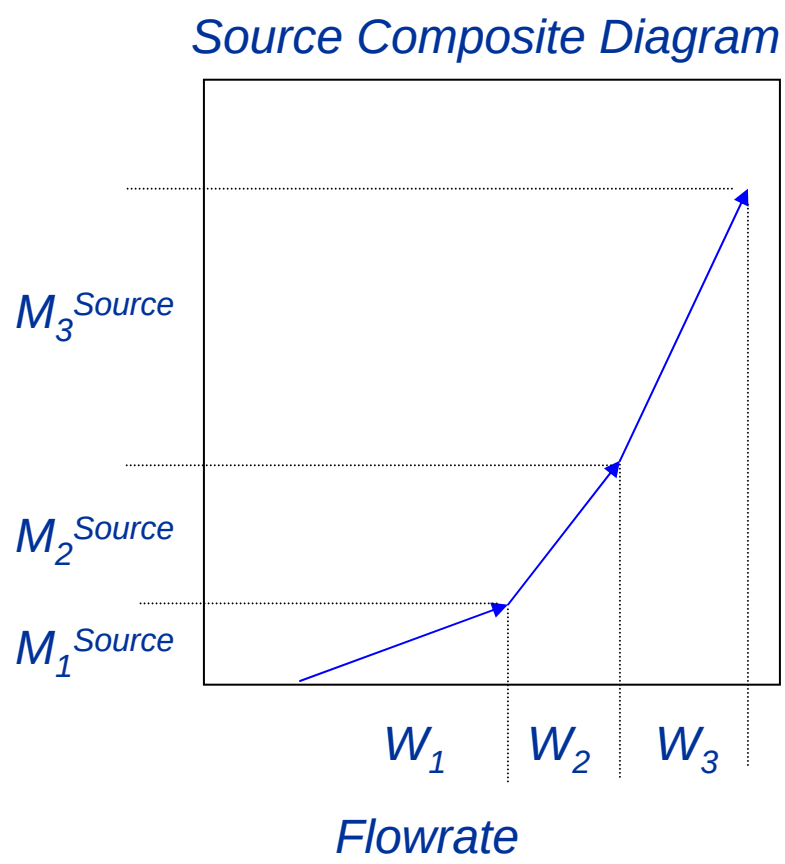
- Calculates targets for energy and capital investment
- Enables the development of improved heat integration projects, significantly reducing operating, capital, and design costs, and minimizing energy-related emissions
- Provides tools for performing process optimization
- Provides both graphical and algorithmic methods

Analogy between MENs and HENs

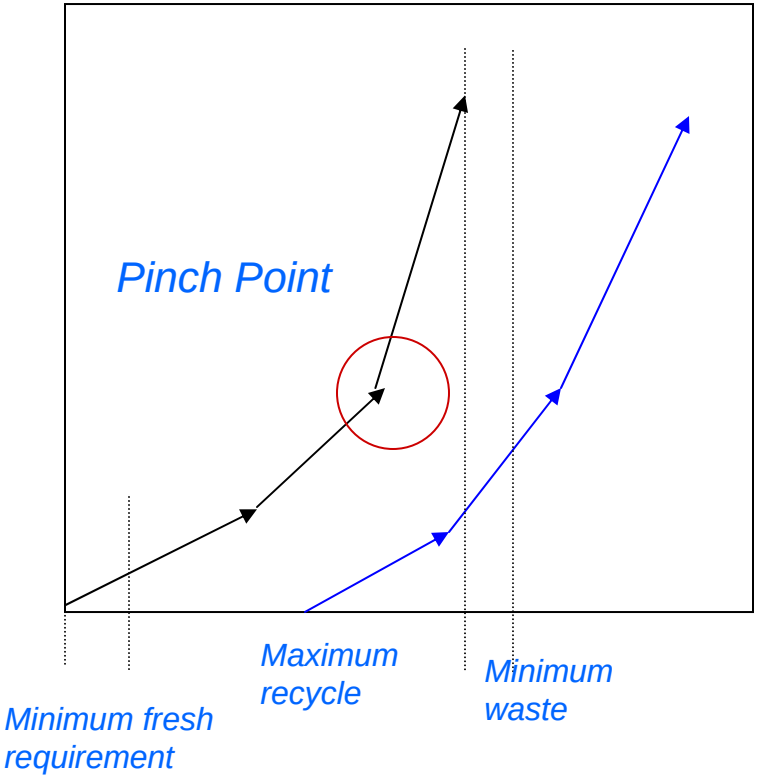
Category	MENs	HENs
Transferred Commodity	Mass	Heat
Donors	Rich streams	Hot streams
Recipients	Lean streams	Cold streams
Rich variable	Composition y	Hot temperature T
Lean variable	Composition x	Cold temperature t
Slope of equilibrium	m	1
Intercept of equilibrium	b	0
Driving force	e	ΔT^{min}

Source Sink Mapping





Mass Exchange Pinch Diagram



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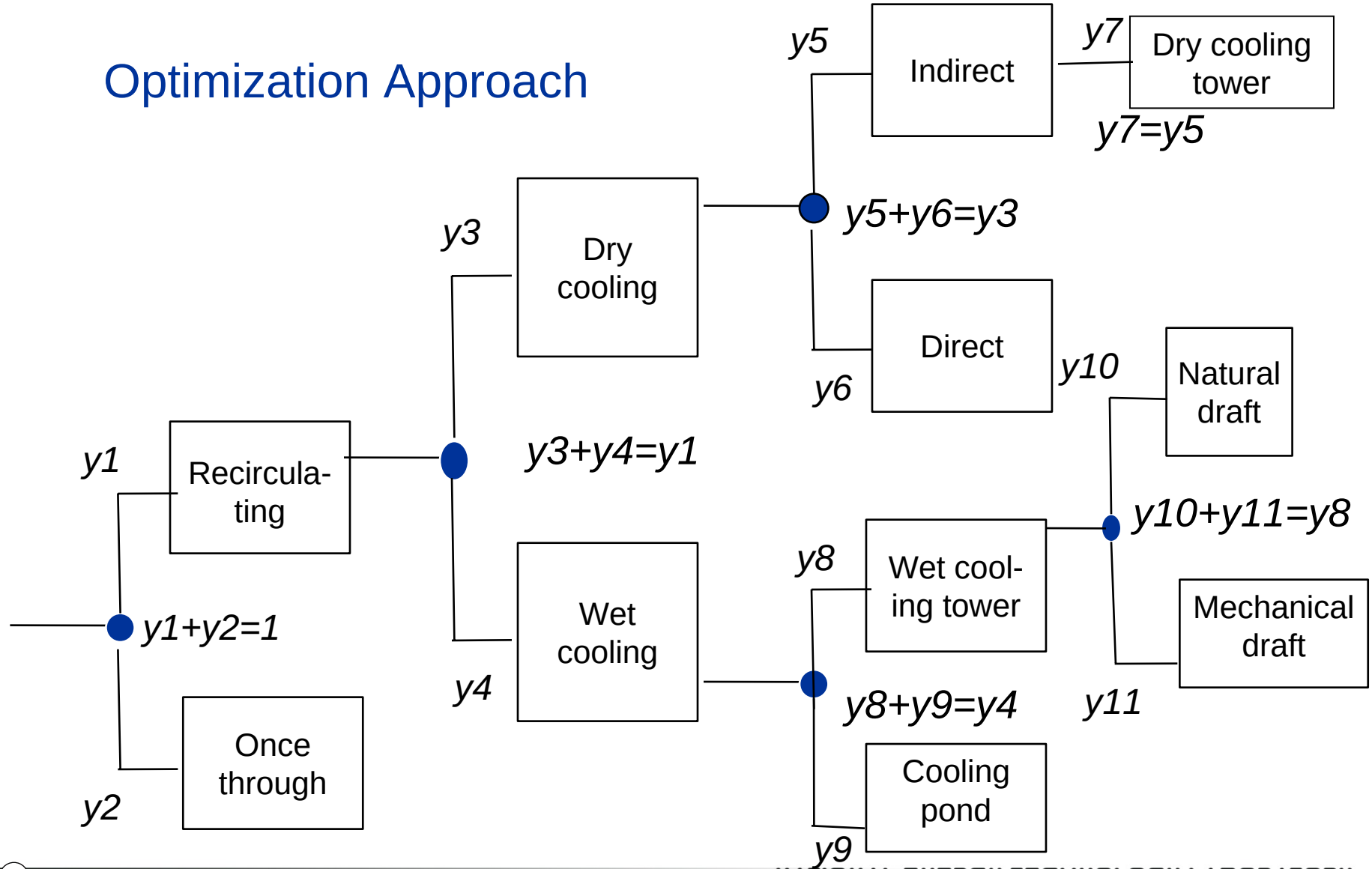
Cooling Water System Configurations

Optimization Approach



Mixed Integer Nonlinear Programming (MINLP)

$$\underset{x,y}{Optimize}\ Z = z(x,y) = a^T y + f(x)$$

$$h(x) = 0$$

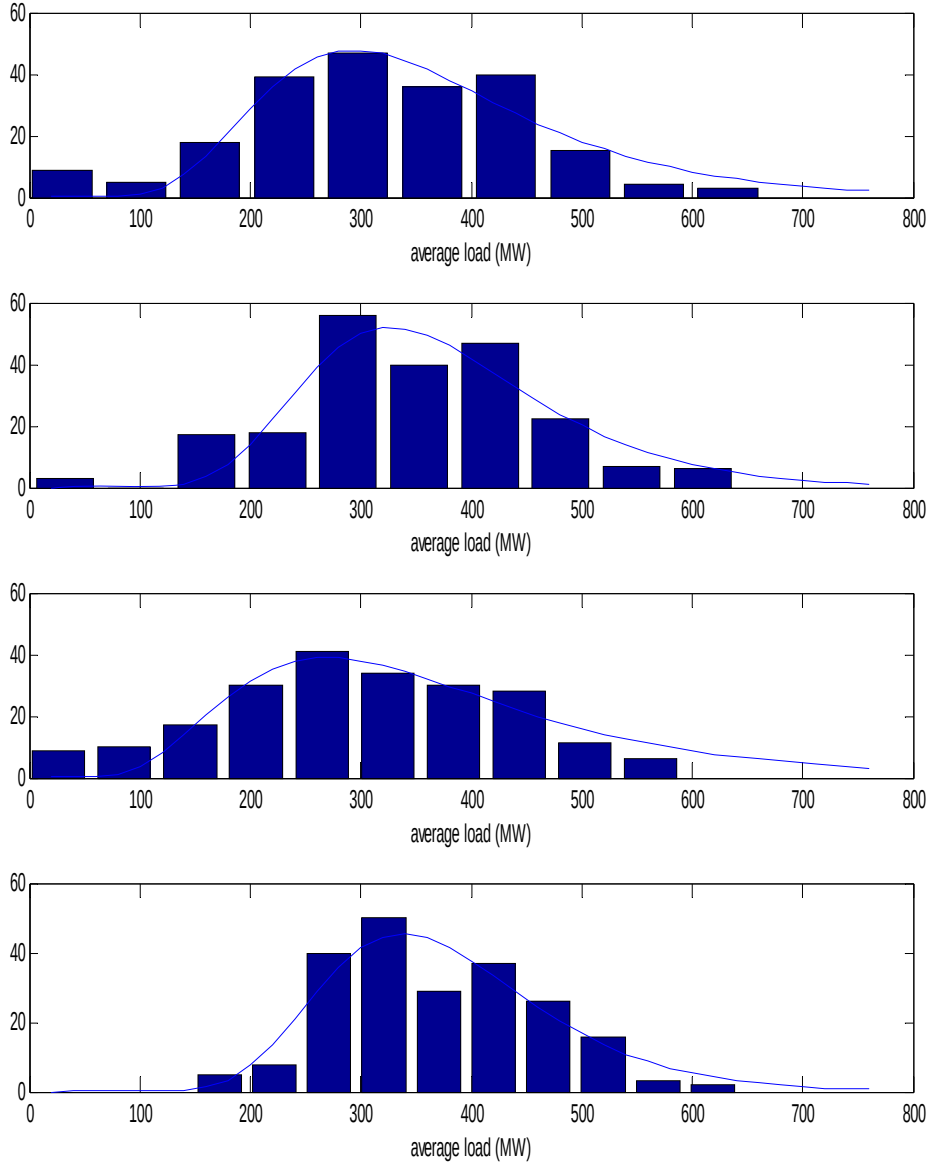
$$g(x,y) = -B^T y + g(x) \leq 0$$

Where x represents continuous variables

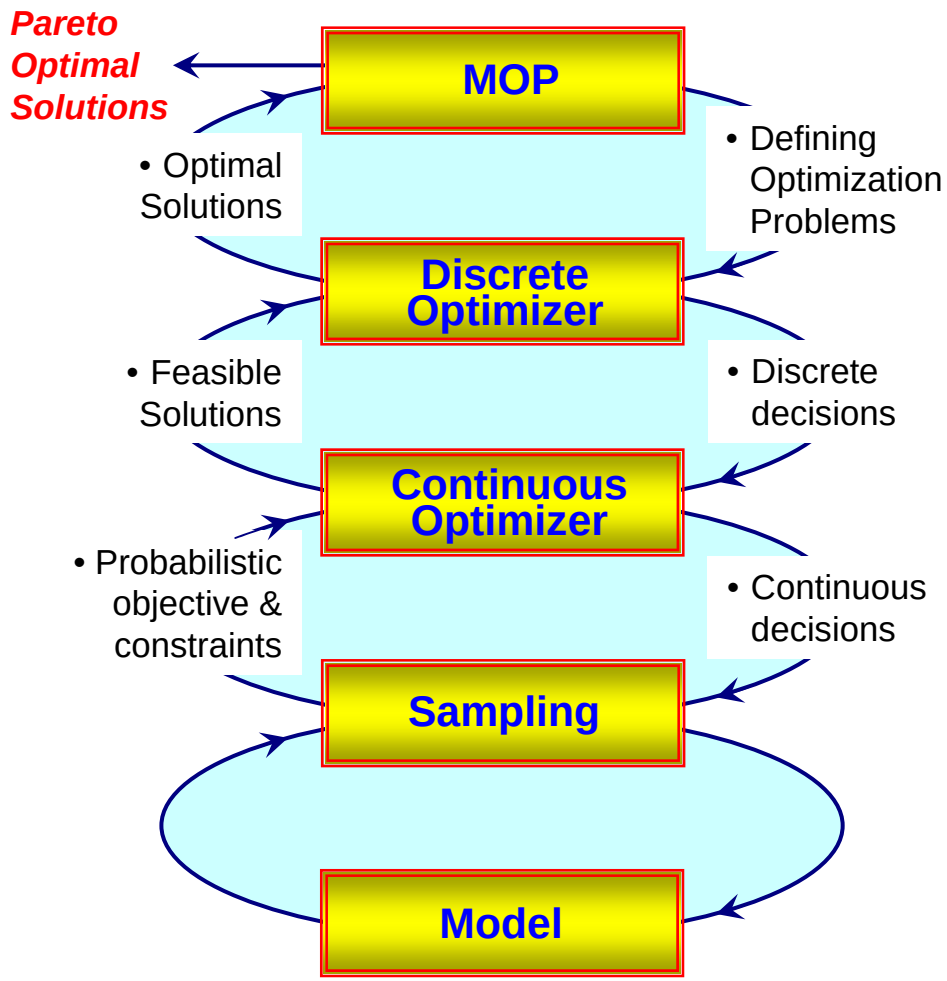
y represents binary variables, 0 or 1.

Uncertainties

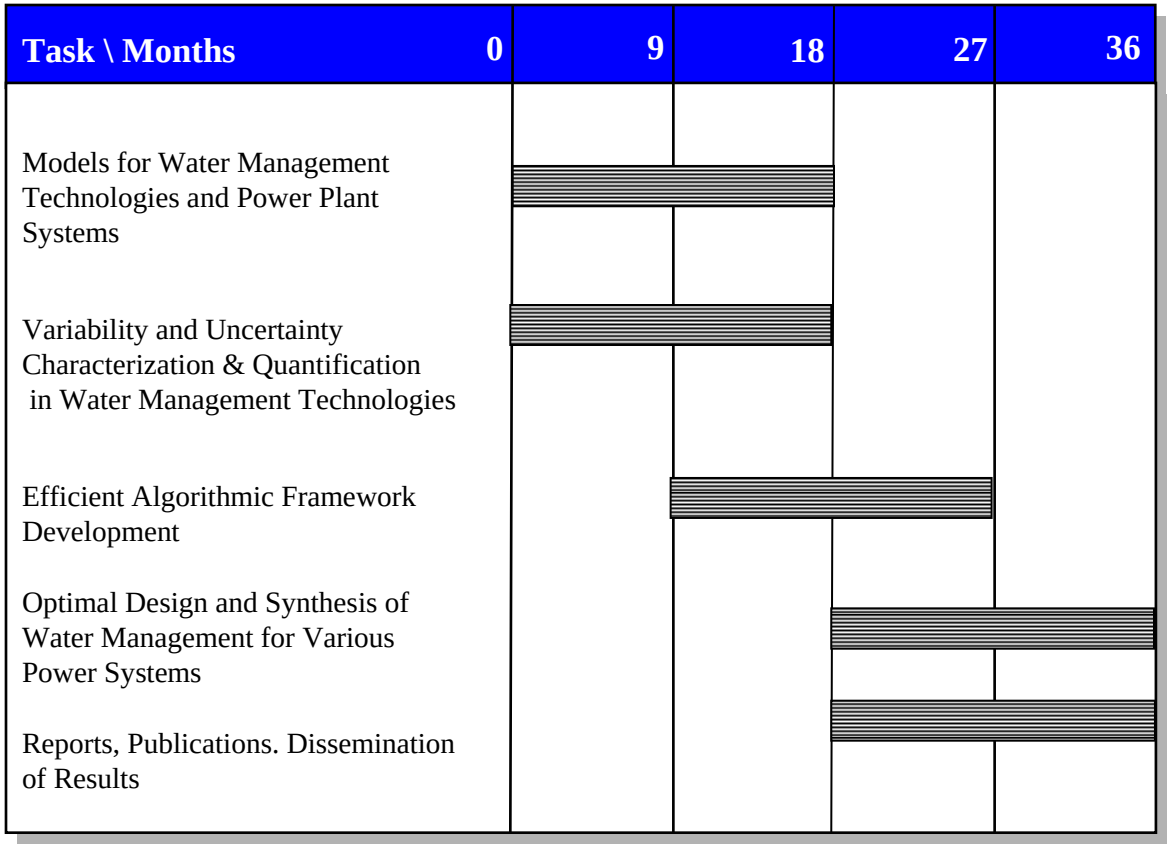
- Frequency distribution of average load for plants with an estimated peak capacity between 400 and 700 MW for four seasons: from top to bottom fall, winter, spring and summer



Multiobjective Optimization under Uncertainty



Scope of Work and Timetable



Conclusions

- **Heat exchanger network synthesis provides assessment of minimum heat and cooling utilities**
- **Mass exchanger network synthesis will reduce process water requirements**
- **Optimization of the process structures and process design will provide:**
  - cost effective and reduced water power plants in the face of uncertainties
  - trade-offs between cost and water requirements
  - optimal water networks