Effective Reduction of Industrial GHG Emissions via Energy Integration and Biomass Utilization

Eva Lovelady and Mahmoud El-Halwagi

Process Integration and Systems Optimization Group
Department of Chemical Engineering
Texas A & M University

Motivation

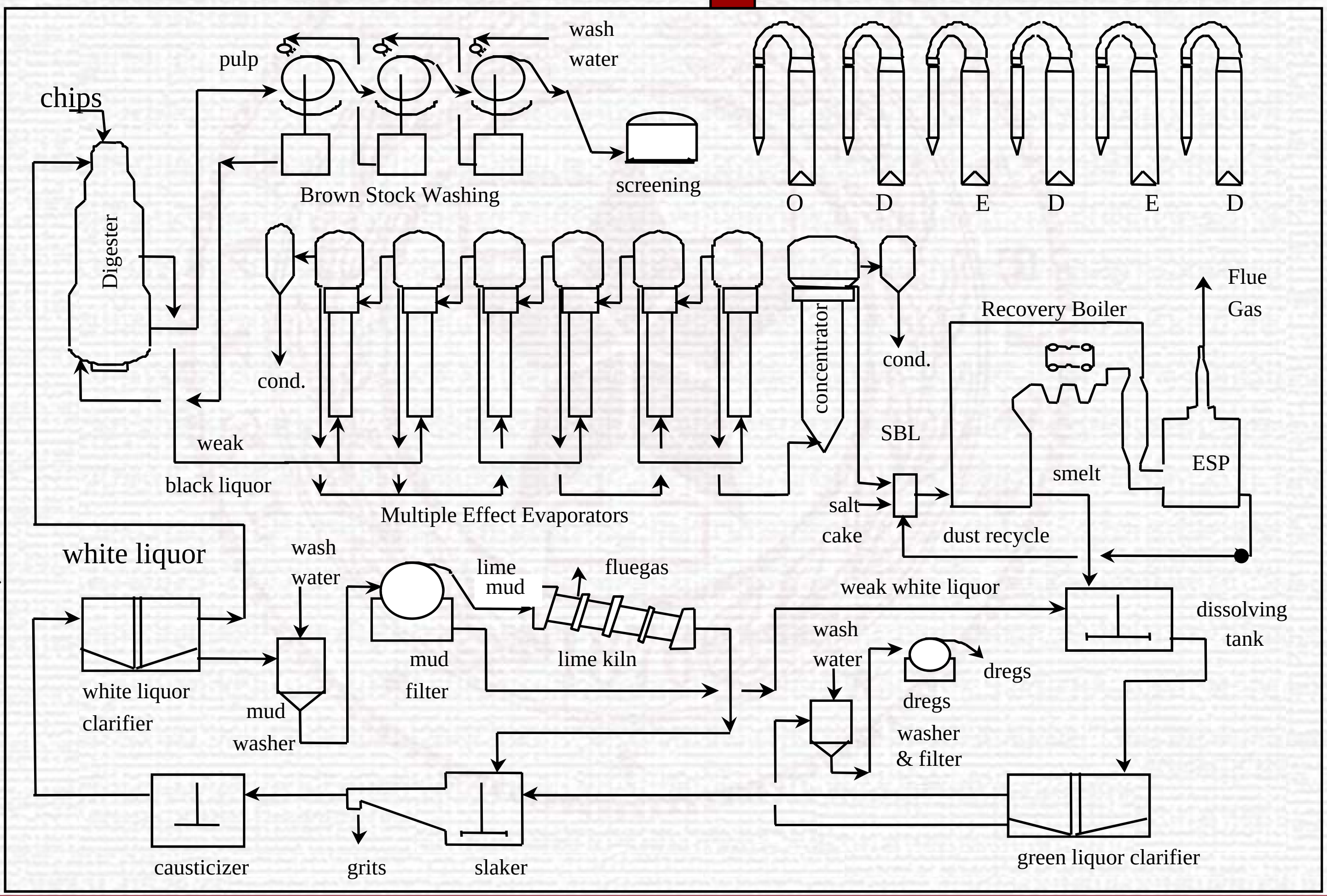
Gaseous Wastes

- **Substantial quantities from energy utilities**
- **GHGs + Precursors for Ozone**

Raw Materials

Fuel/Energy

Material Utilities



Products

Byproducts

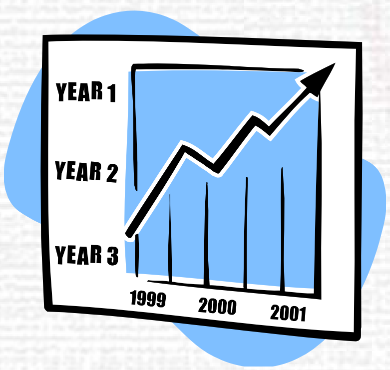
Wastes

Primary Responsibilities/ Goals of Process Engineers

Faster, Better, Cheaper, Safer, & Greener

Specific Objectives:

Profitability Improvement
Yield Enhancement
Resource (mass and energy) Conservation
Pollution Prevention/Waste Minimization
Safety Improvement
Quality Enhancement



How?

Traditional Approaches to Process Development and Improvement

- Brainstorming among experienced engineers

- Heuristics based on experience-based rules

- Evolutionary techniques: Copy (or adapt) the last design we or someone else designed

4

Weaknesses/Limitations of Traditional Approaches

- Time and money intensive
- Cannot enumerate the infinite alternatives
- Not guaranteed to come close to optimum

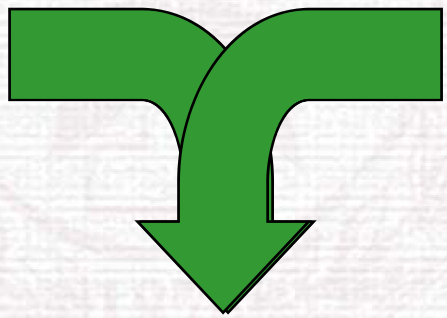
- Does not shed light on global insights & key characteristics of the process
- Limited range of applicability
- Severely limits groundbreaking and novel ideas

5

Solution?

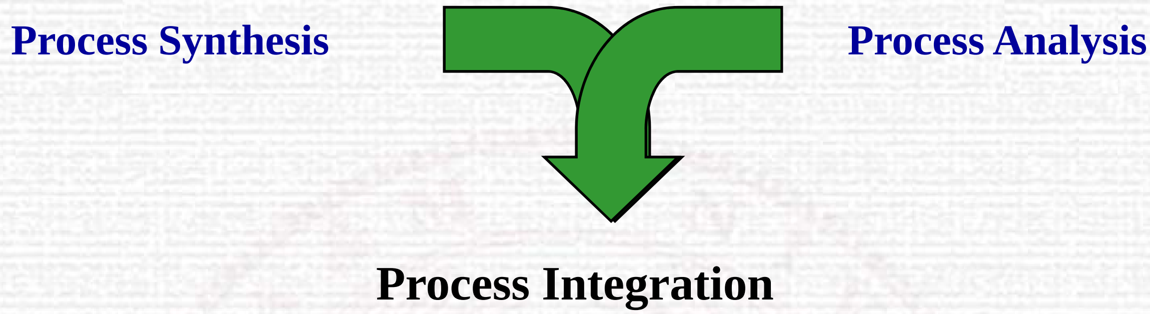
Systematic, fundamental, & generally applicable techniques

Process Synthesis

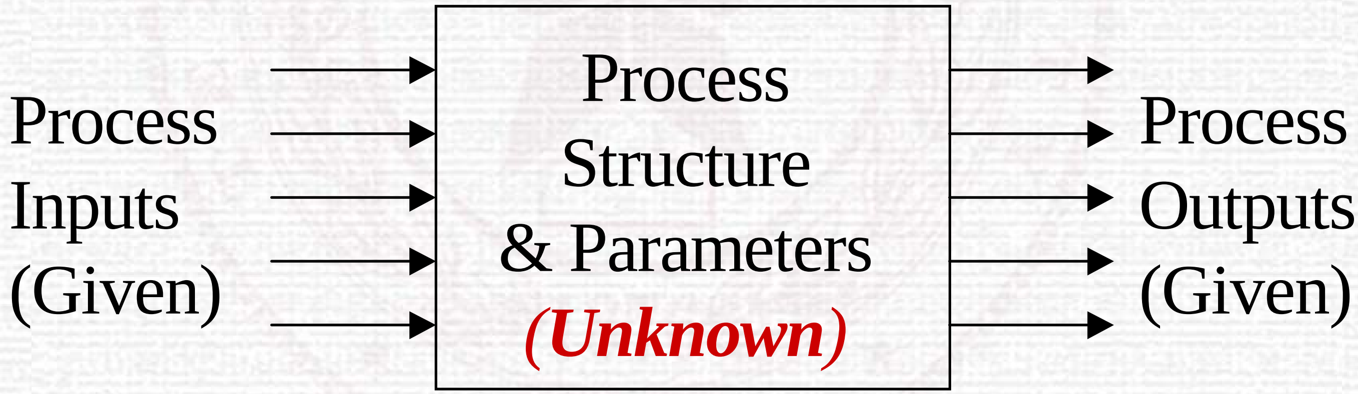


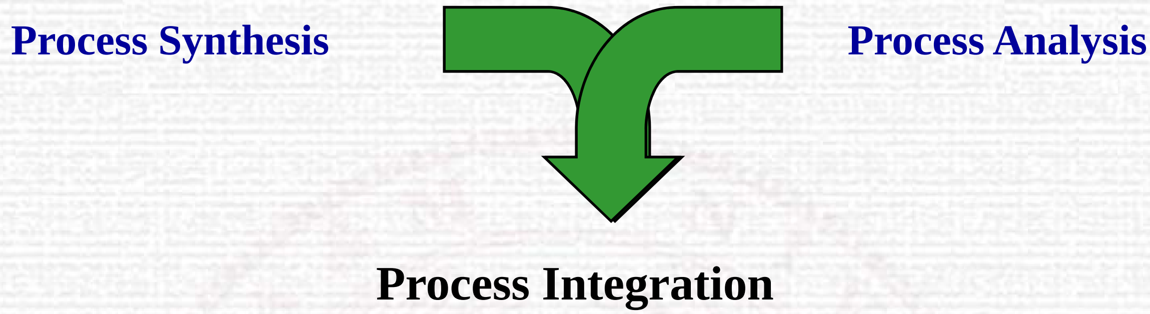
Process Analysis

Process Integration

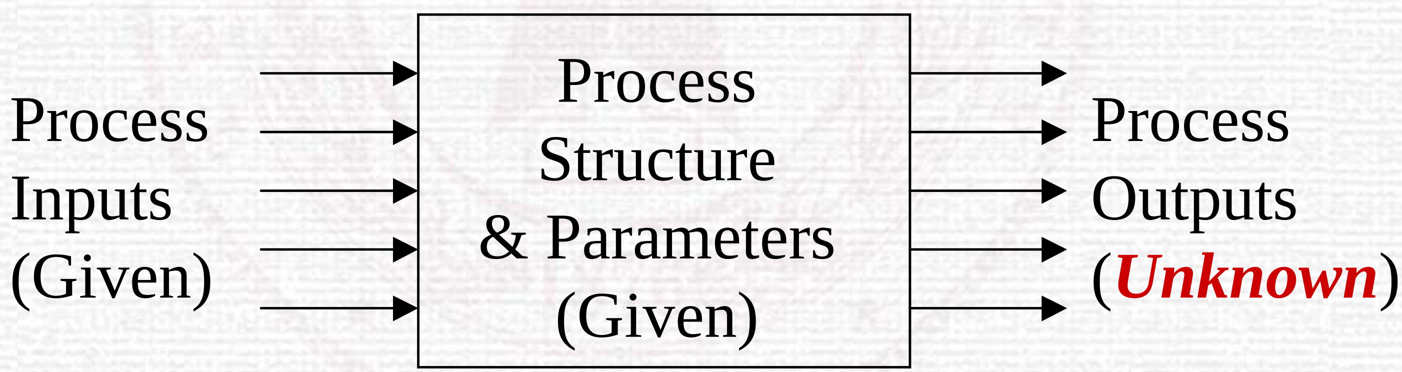


Process Synthesis





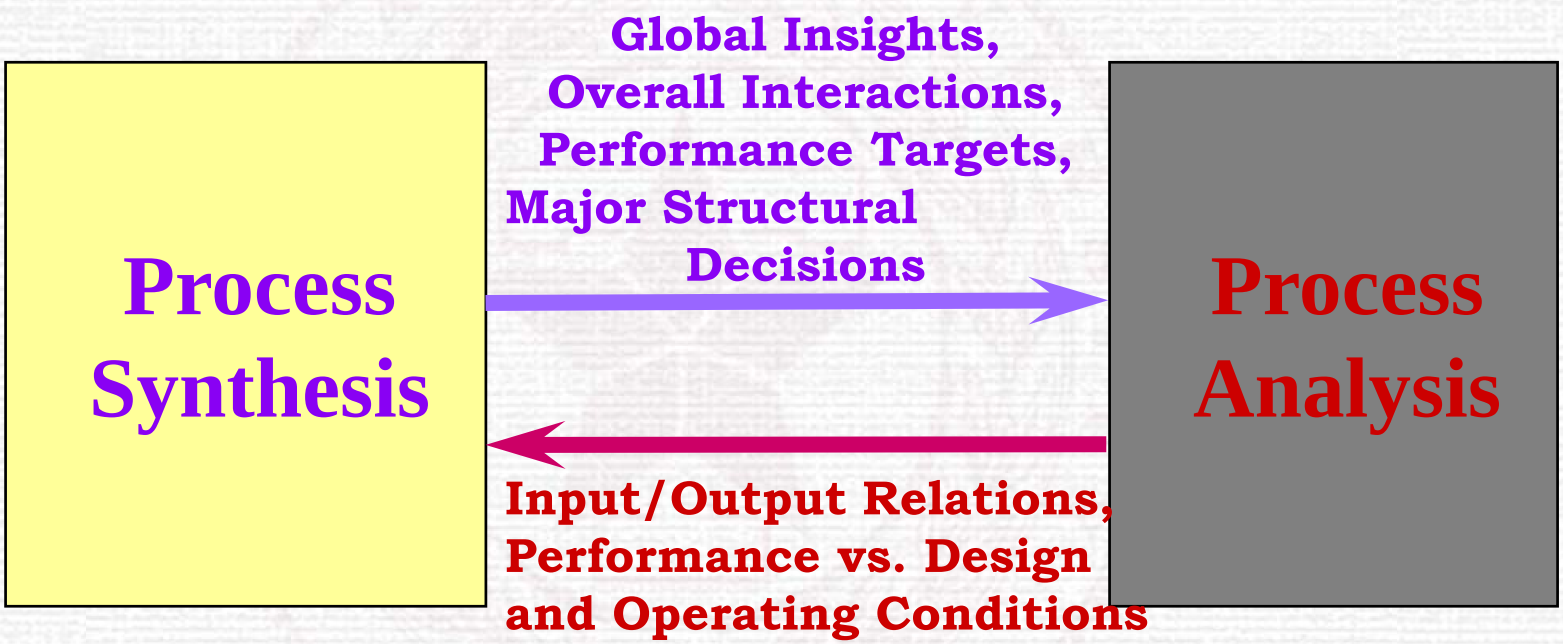
Process Analysis/Simulation



Process Integration

Process Integration =

Process Synthesis + Process Analysis + Process Optimization



Process Optimization: Selection of the best solution from among the set of candidate solutions. Optimization derives the iteration between synthesis and analysis to an optimal closure.

Why Integration?

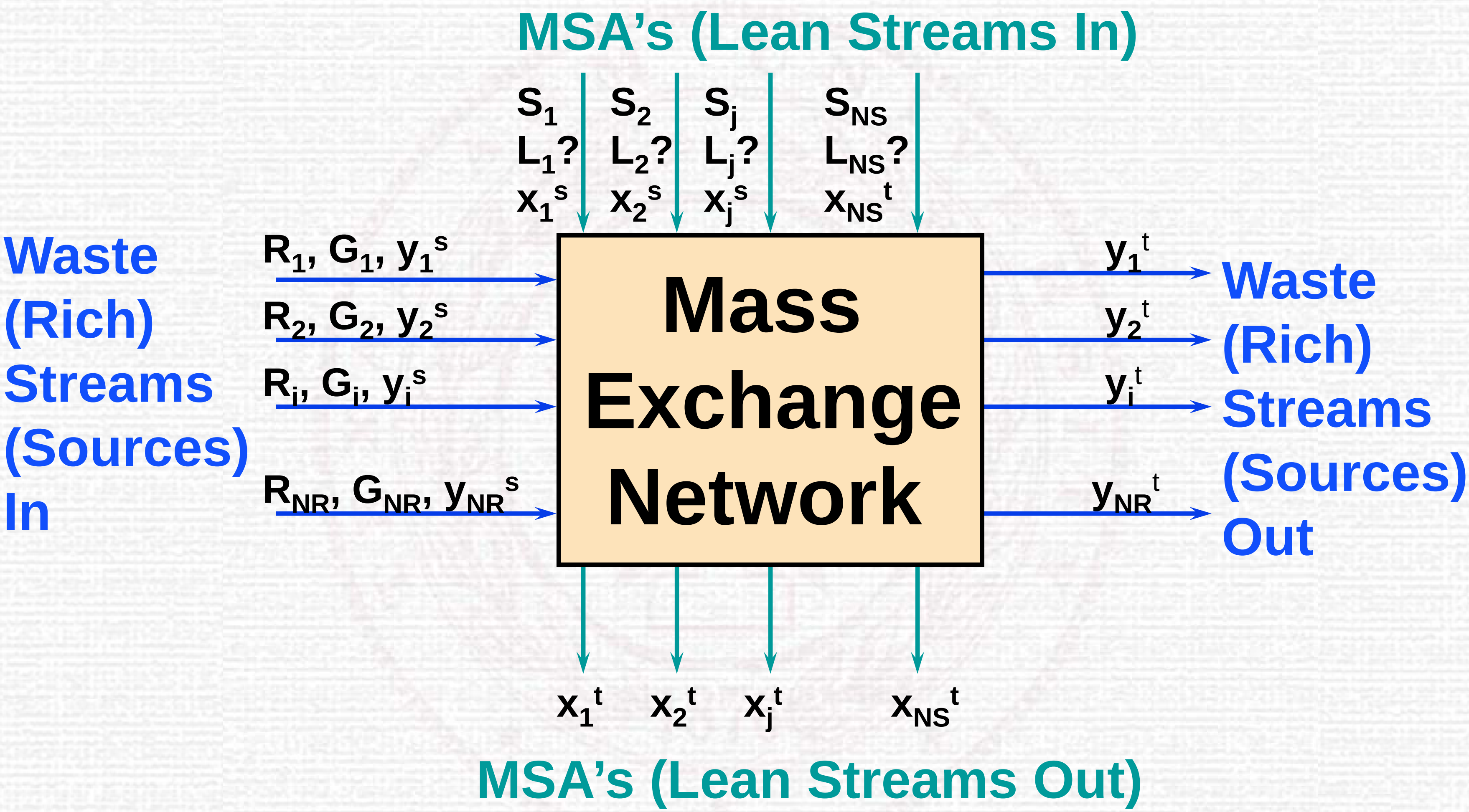
Mass Integration

Energy Integration

A need exists for an integration framework:

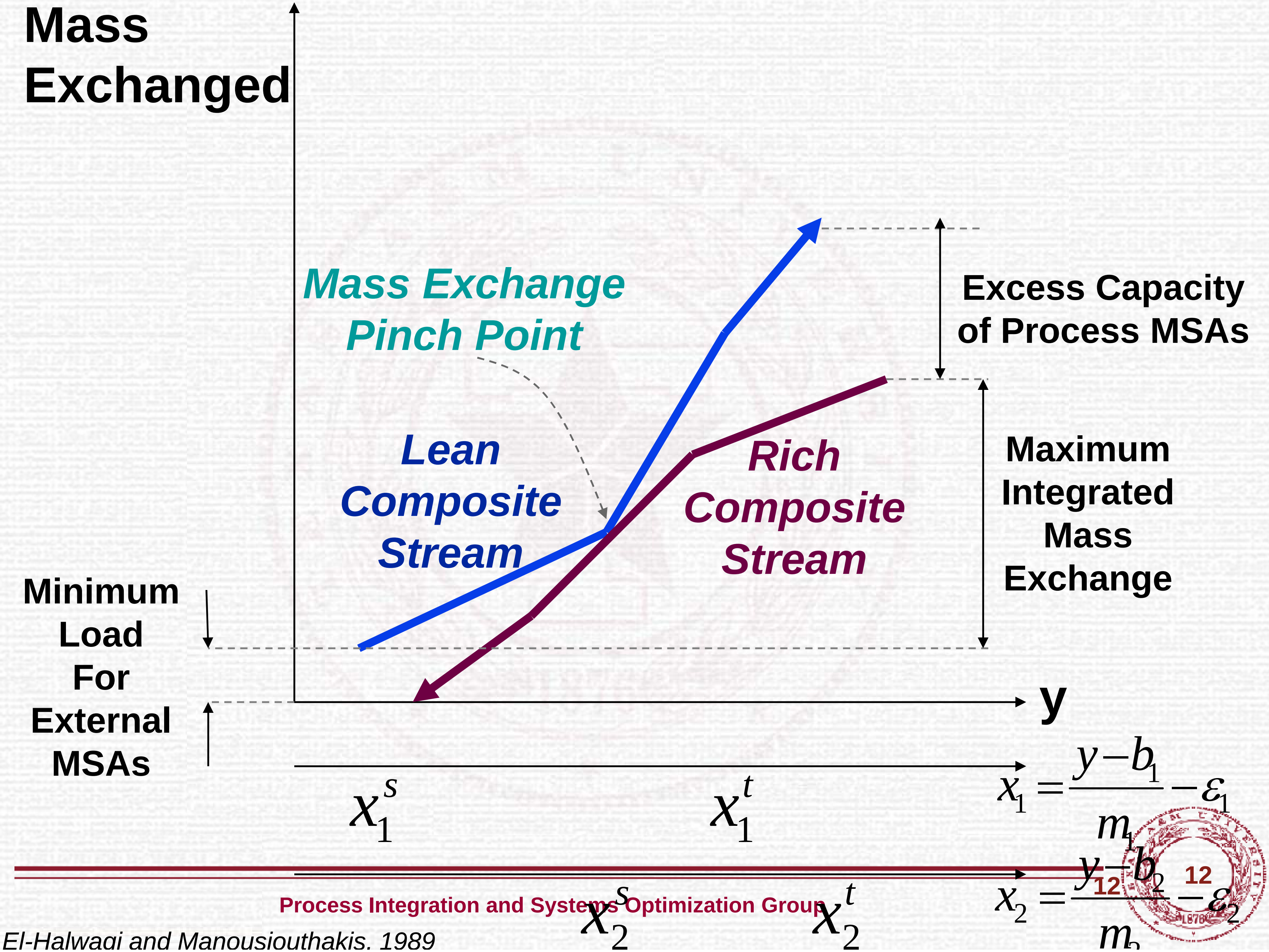
- Guide/assist process synthesis
- Conserve process resources

10



Schematic Representation of the MEN Synthesis Problem

11



El-Halwagi and Manousiouthakis, 1989

DESIGN CHALLENGES

- Which mass-exchange technologies should be used?
- Which MSAs should be used?
- What is optimum flowrate of each MSA?
- Where should each MSA be used (stream pairing)?
- System configuration?

13

What is Process Integration?

A holistic approach to process design, retrofitting, and operation, which emphasizes the unity of the process.

Involves:

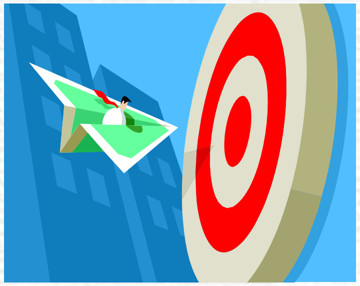
1.) Task identification

2.) Targeting

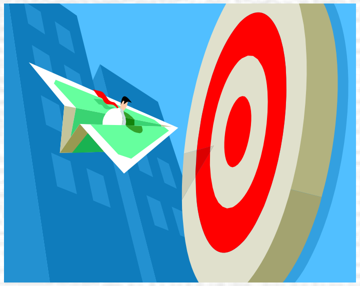
3.) Generation of alternatives (Synthesis)

4.) Selection of alternatives (Synthesis)

5.) Analysis of selected alternatives



Targeting



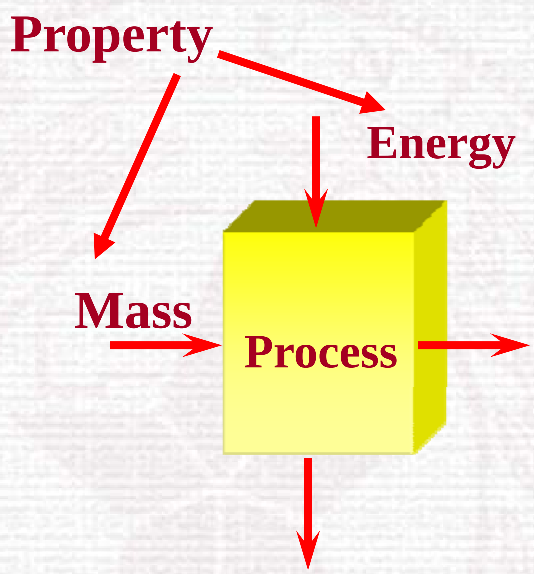
Identification of performance benchmarks for the whole process ***AHEAD*** of detailed design

Specific Performance Targets:

- Profitability improvement (maximization)
- Yield enhancement (maximization)
- Resource (mass & energy) conservation (minimization)
- Pollution prevention/waste minimization (minimization)
- Safety improvement (maximization)

15

Categories of Process Integration



Mass Integration
+
Energy Integration
+
Property Integration

→ Process Integration

Research Theme

Reduction of GHGs and ozone precursors from industrial sources via:

1. **Energy integration**

   ➔ energy conservation, cost savings, NO_x & CO_2 reduction

2. **Incorporation of biomass into utility systems** (e.g., co-firing)

   ➔ Carbon recycling during growth (photosynthesis)
   ➔ Reduction in GHG emissions

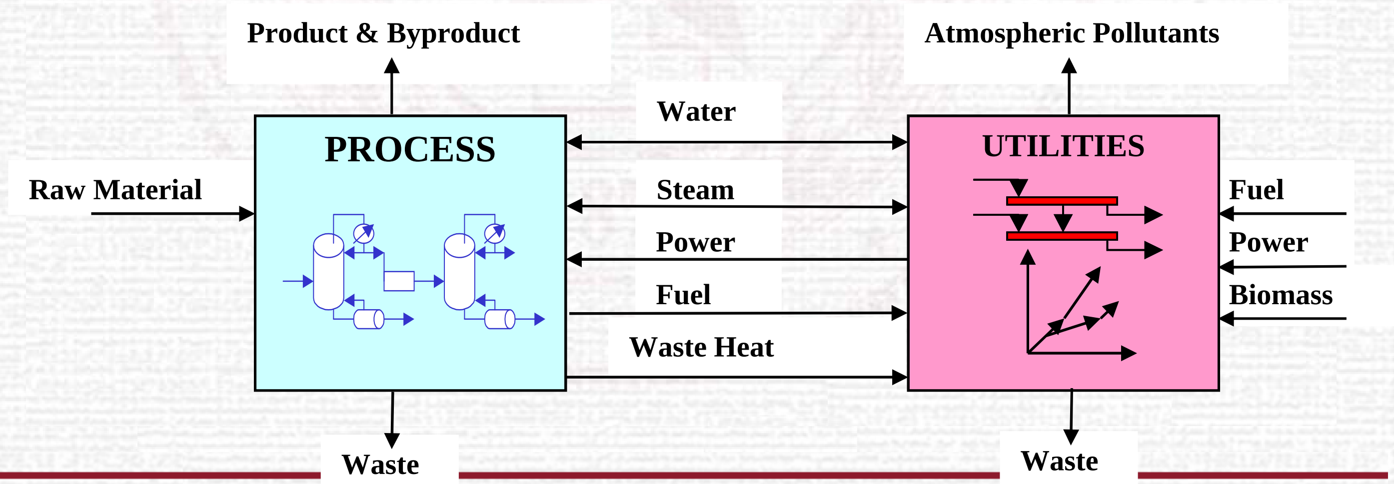
- *In-plant pollution prevention not end-of-pipe pollution control*
- *Environmental benefit + cost and energy savings: win-win*

17

Problem Statement

Consider a process with:
- A set of specific heating and cooling demands
- Steam demands for non-heating purposes such as tracing, blanketing, stripping, etc.
- A certain requirement of electric power
- A header system with steam generated by process operations and external fuel
- A set of fossil fuels and biomass streams that may be used as energy sources in the process

The objective is to develop a systematic and generally applicable approach to target process cogeneration that effectively uses process sources and external biomass and biowaste streams while satisfying the process heating and non-heating steam demands, and to determine the GHG pricing options required to compete with fossil fuel cogeneration or electricity bought from external sources.



Research Questions

- What are the optimum quantities and levels of heating and cooling utilities?
- At what pressure level should steam from the external fuel be generated?
- Is there a potential for power cogeneration? What is the cogeneration target?
- What is the optimum scheme for recycling/reusing process sources for energy purposes?
- Can some of the combustible wastes be used instead of fresh fuel? To what extent? Where?
- What refrigeration technologies may be used (e.g., cooling towers, refrigeration cycles, absorptive refrigeration, etc.)?

Research Questions

- What are the necessary process modifications that are required to trade off the core-process units with the utility system?
- What cofiring ratio of biomass to fossil fuel should be used for external fuel steam generation?
- What is the benchmark for maximum cogeneration potential by utilization of biomass and biowaste streams and minimum usage of external thermal utilities?
- What is the benchmark for minimum emission of GHGs and ozone precursors (on a lifecycle basis) for the scenarios of using current technologies, new technologies, and incorporating biomass into the utility system?
- What are the sound policy recommendations that will enable market penetration of biomass-based cogeneration in the process industries? What are the corresponding technical and economic issues? What are the net reductions in ozone precursors and GHG emissions?

Project Objectives

- Develop a systematic and generally applicable approach to the optimization of design and operation process combined heat and power as well as integration with the core processing units ➔ Cost reduction + energy savings + reduction in GHGs and ozone precursors

- Determine the various feasible pathways and technologies for utilizing biomass in processing facilities, specially for cogeneration

- Provide an economic, energy and environmental evaluation of the prospects for biomass utilization in processing facilities

- Examine how potential GHG emission pricing alternatives might influence the relative efficiencies of alternative technologies and other strategies as well as the power generation market penetration of biomass.

- Examine the sensitivity of the findings in the face of a wide spectrum of possibilities for variables pertaining to processing characteristics, biomass availability, attributes and pricing, relative costs of power and heat, GHG trading markets and pricing, evolution of new environmental regulations, and technological advancements

21

Approach

- Process Cogeneration: energy integration, design, operation, and optimization
- Biomass Utilization for Energy: integration, design, operation, and optimization
- Techno-Economic-Environmental Analysis and Policy Recommendations

22

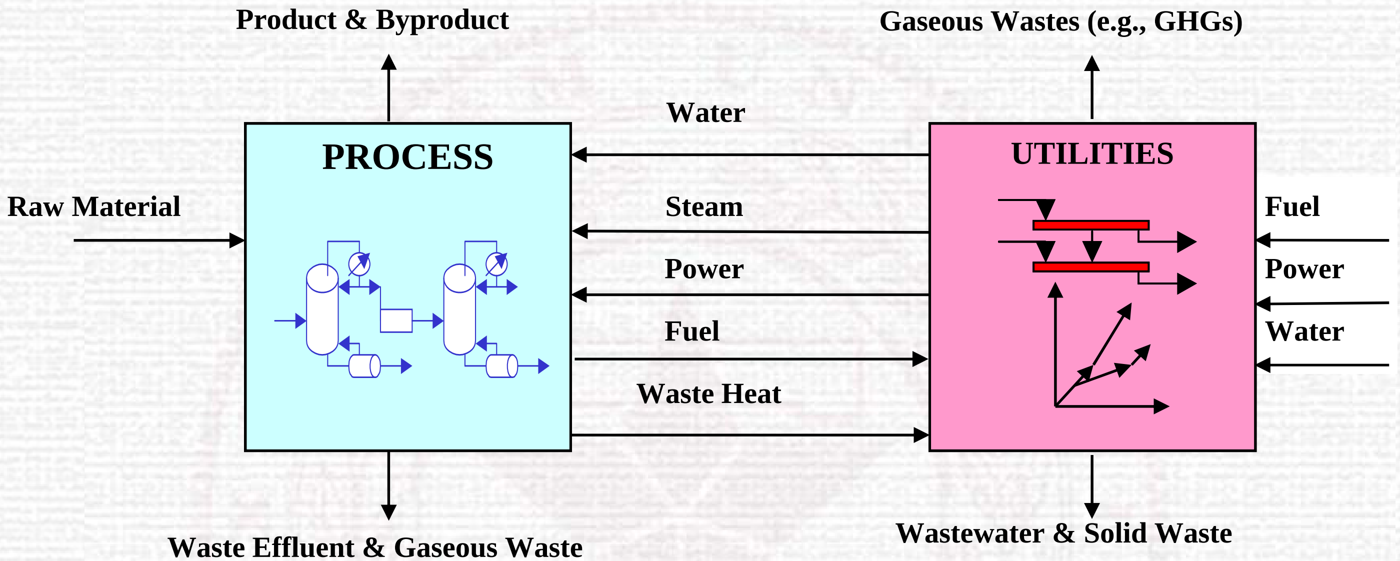
Energy Integration and Combined Heat and Power

SCOPE

- Energy conservation
- Heat exchange networks
- Process cogeneration
- Optimization of steam and utility systems

23

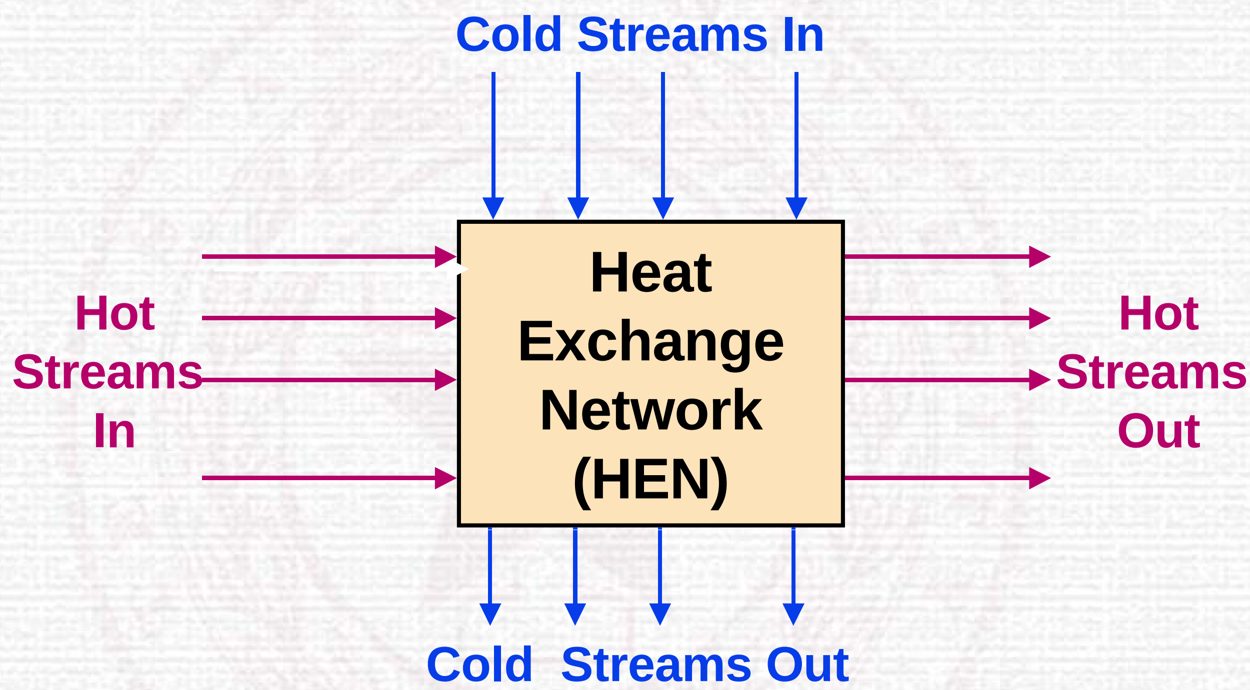
Motivation



Optimize

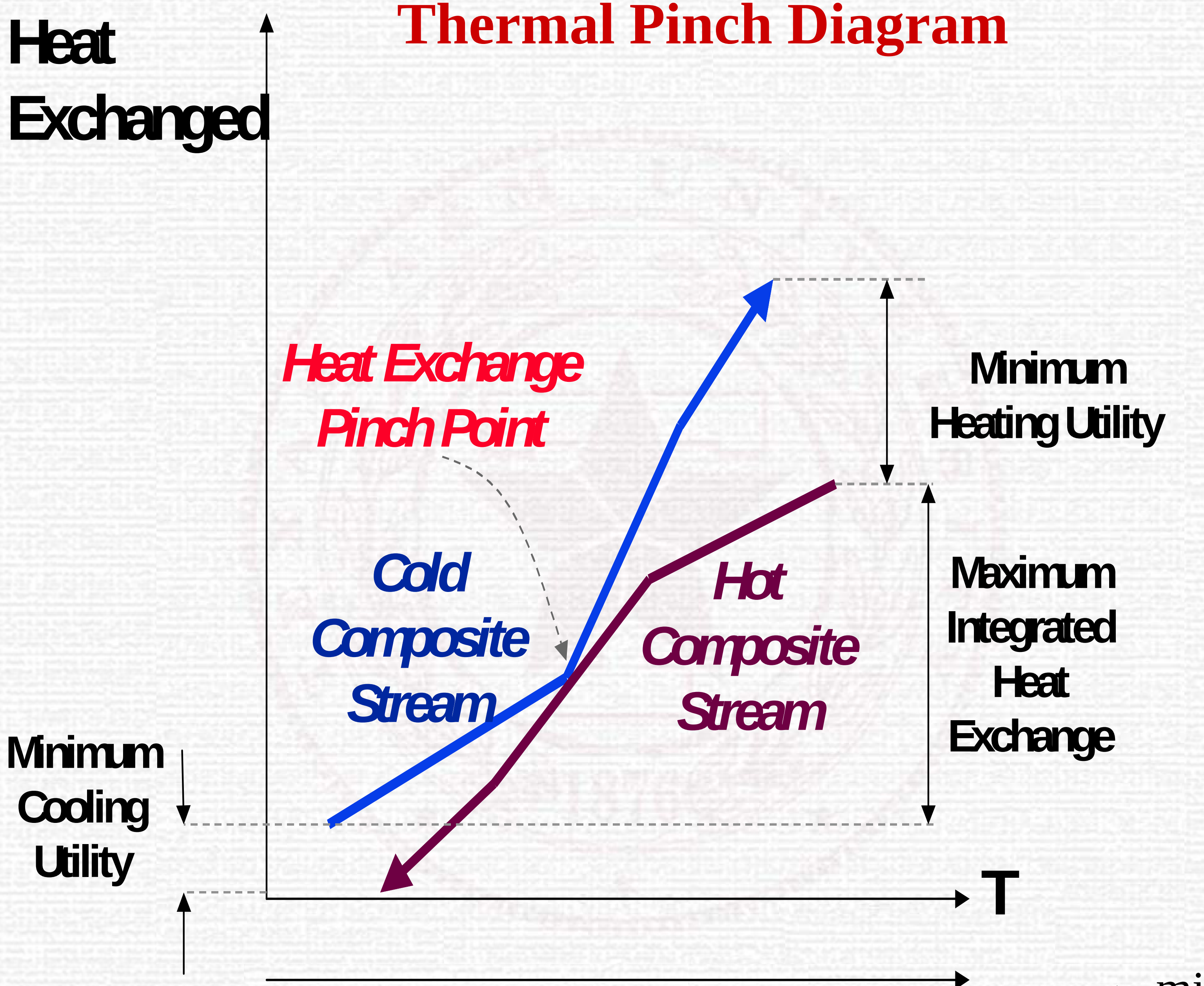
- Process production and operation
- Fuel
- Power
- Steam (purchased & generated)
- Water
- Waste Gas (e.g., GHG) Discharge

Heat Integration



- Which heating/cooling utilities should be employed ?
- What is the optimal heat load to be removed/added by each utility?
- How should the hot and cold streams be matched (i.e., stream pairings)?
- What is the optimal system configuration (e.g., how should the heat exchangers be arranged? Is there any stream splitting and mixing ?)

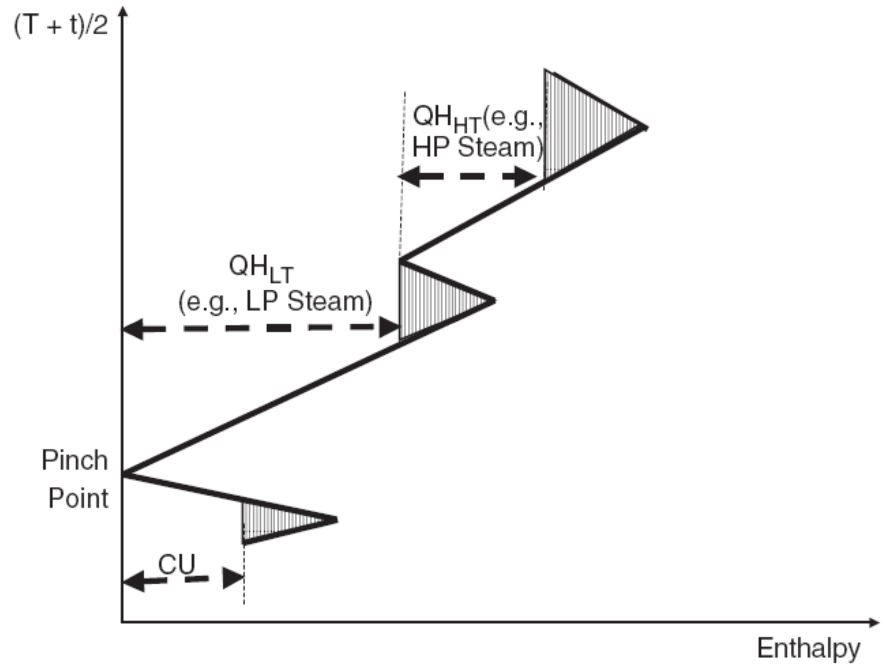
Thermal Pinch Diagram



$t = T - \Delta T^{min}$

Grand Composite Curves

- Site-wide heat integration
- Targeting and selection of each utility

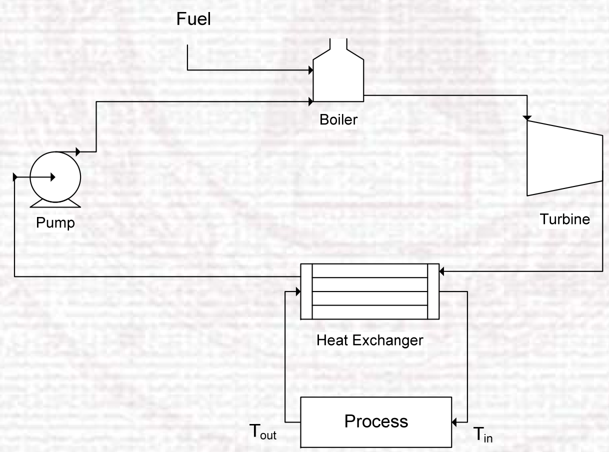


Linnhoff, B., Townsend, D. W., Boland, D., Hewitt, G. F., Thomas, B. E. A., Guy, A. R., and Marsland, R. H. (1982). "User Guide on Process Integration for the Efficient Use of Energy," Warwickshire, UK.

27

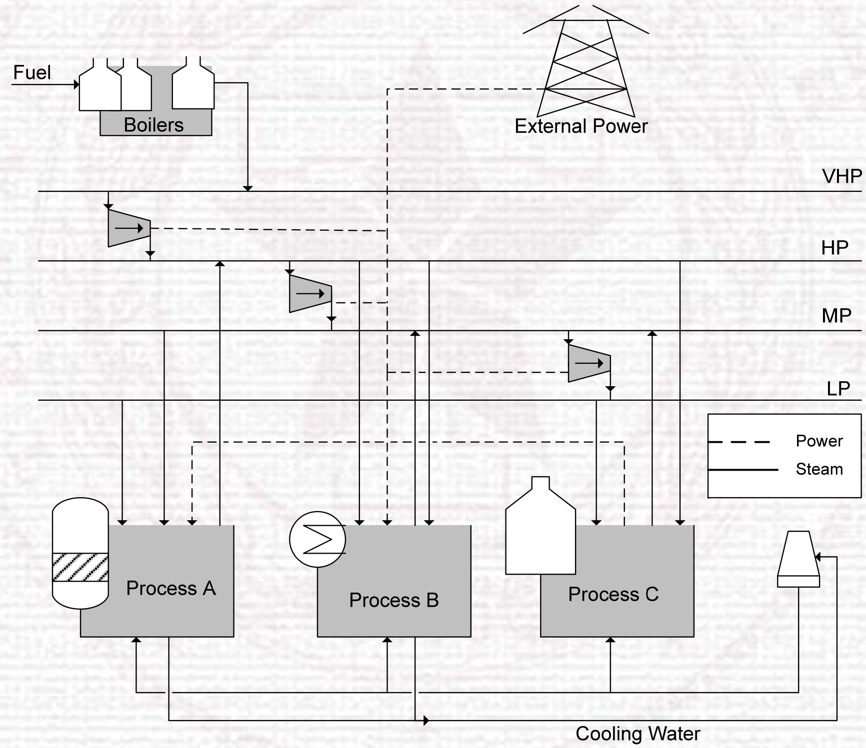
Cogeneration in a Chemical Plant

- In the chemical Plant's utility system, cogeneration can be implemented by:
  - Cogenerating Power with heat
  - Integrating heat/power requirements within the thermodynamic cycle



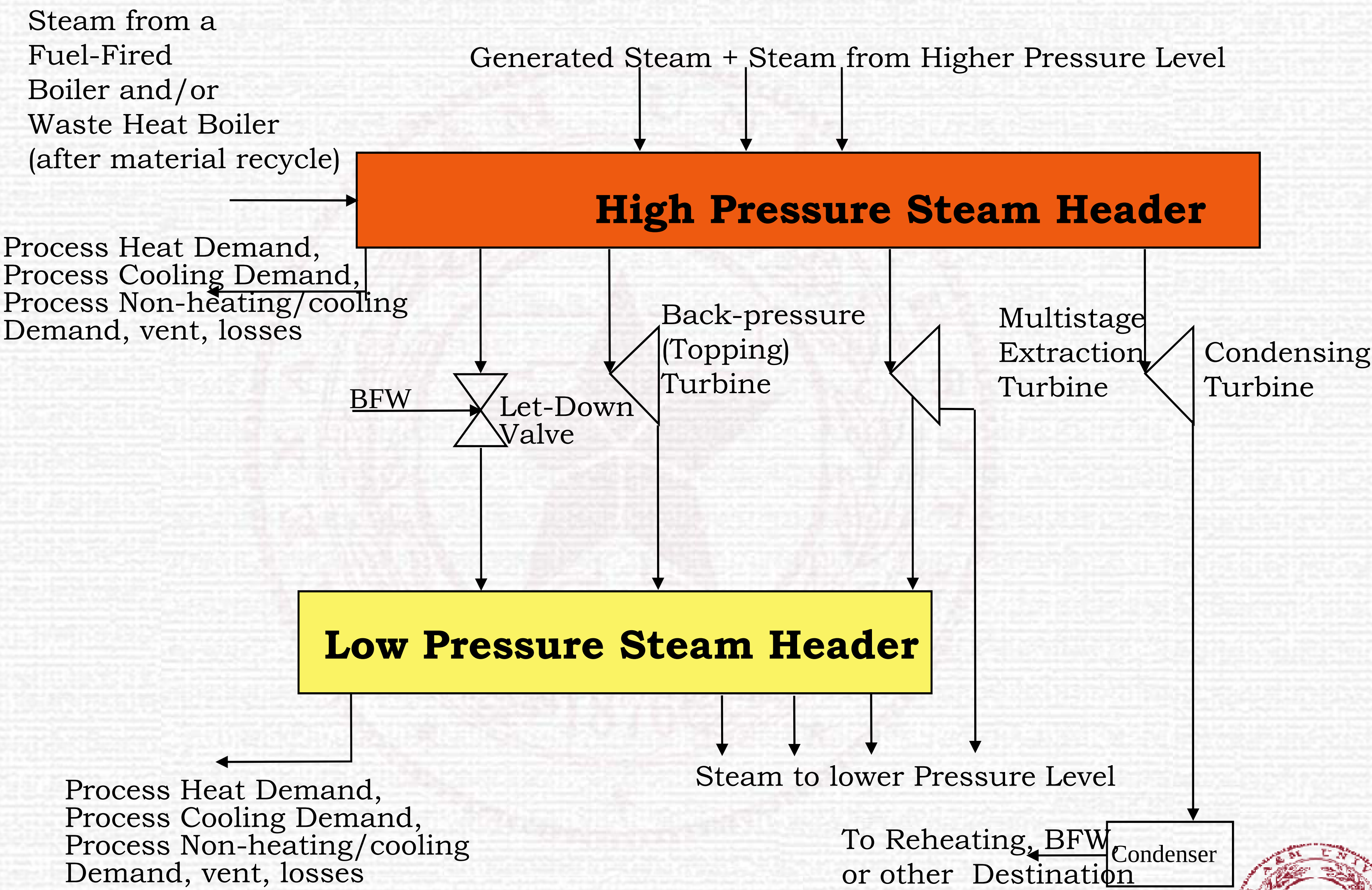
Cogenerating Power with Heat

- Power cogeneration with heat is utilized when expanding steam from a pressure level to another.

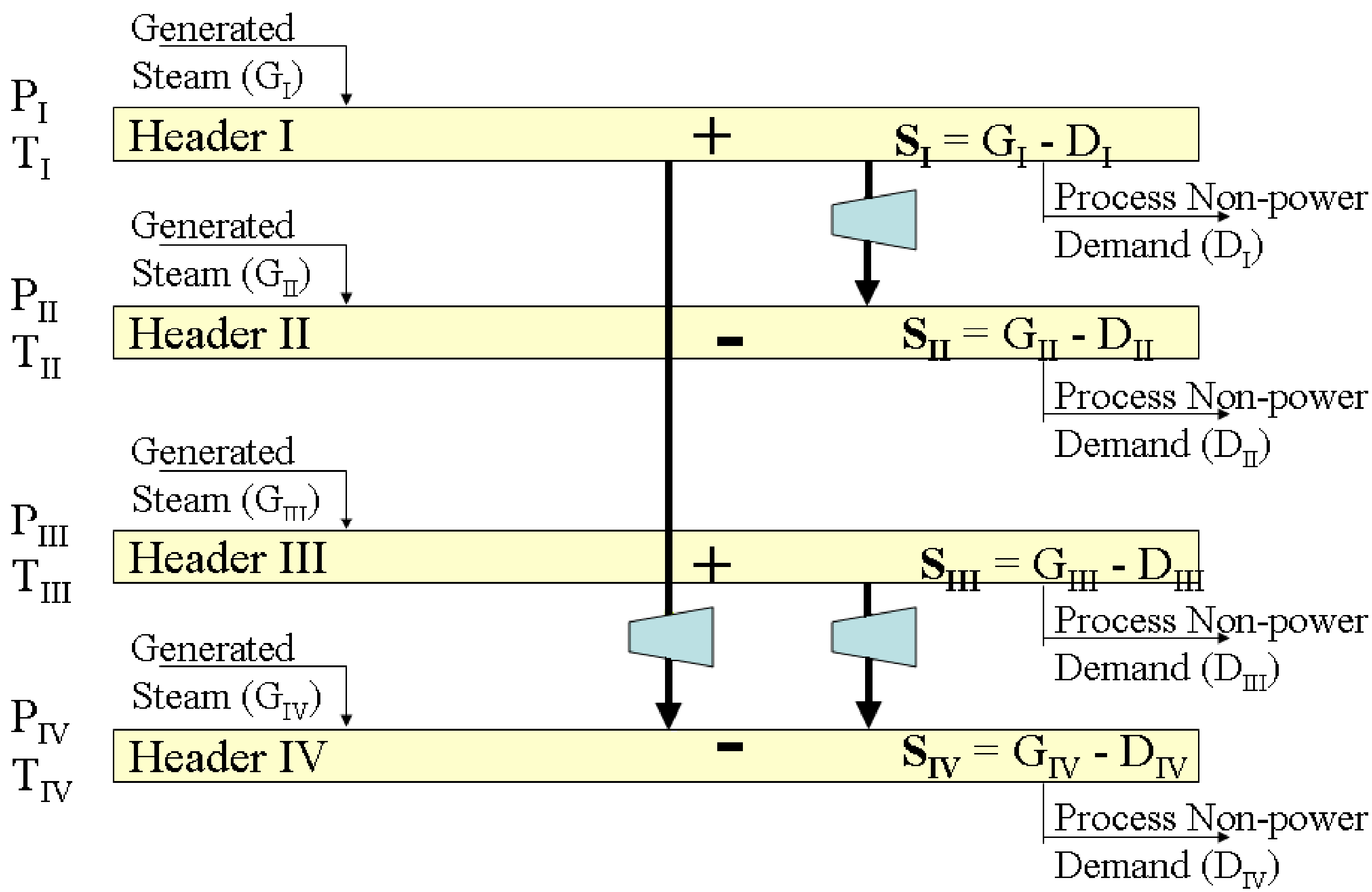


29

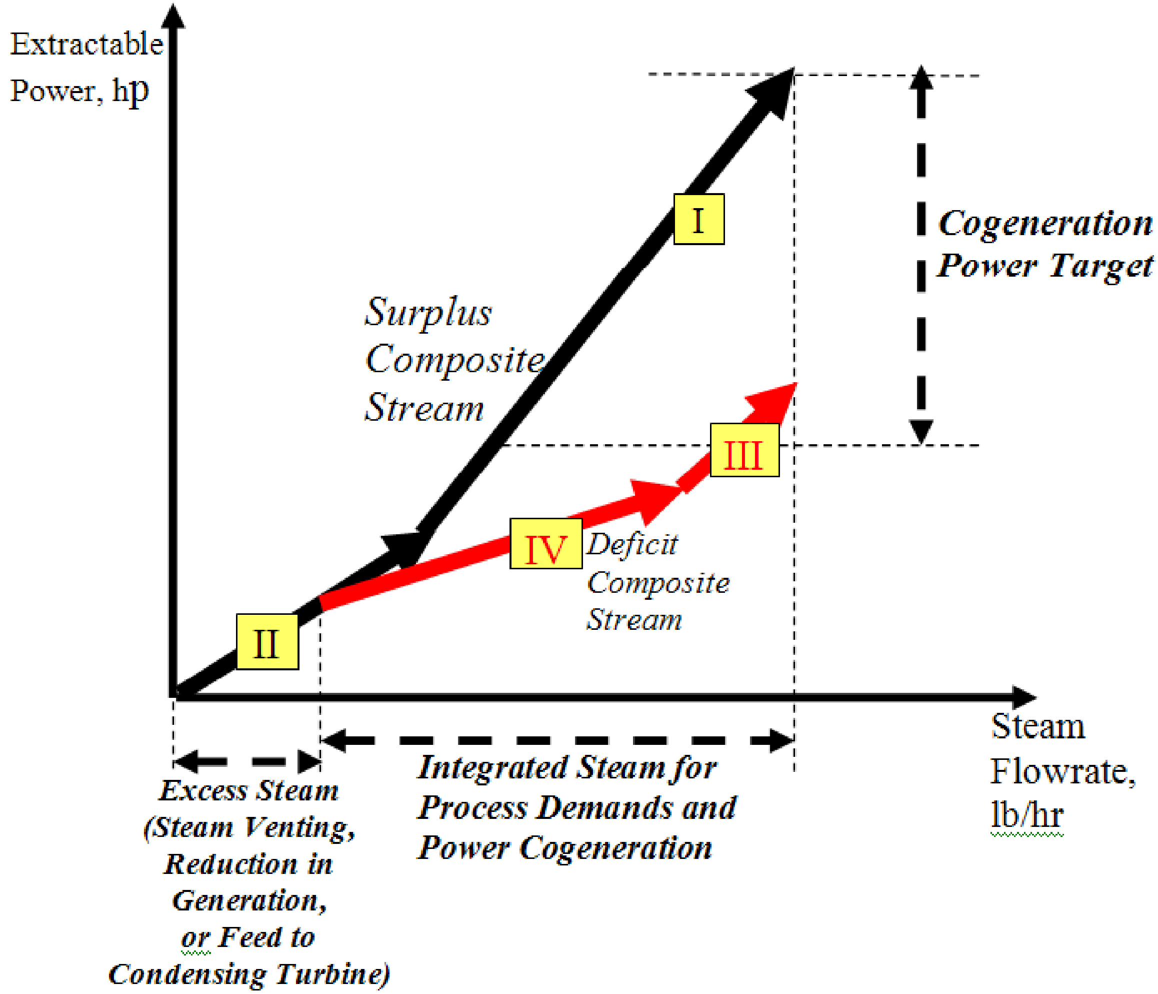
Steam Headers and CHP



Managing Steam Headers



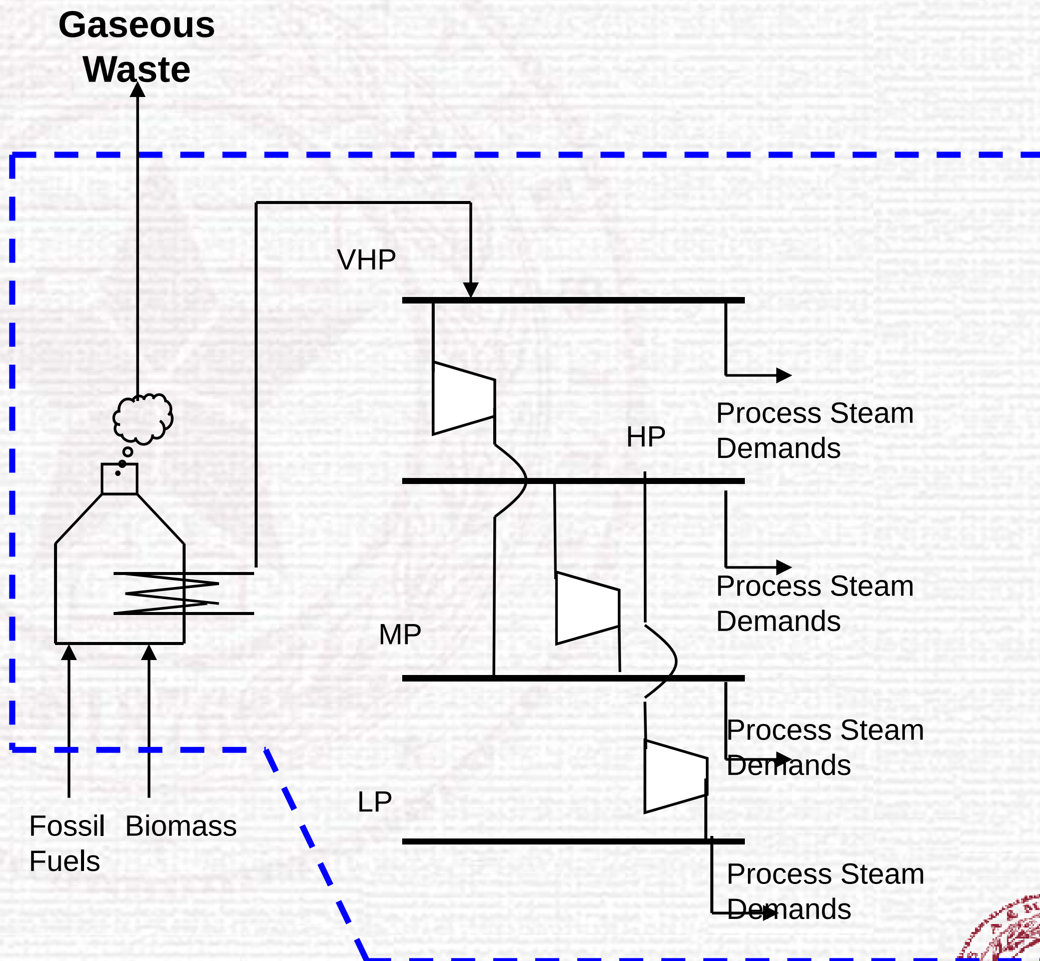
Cogeneration Power Pinch Diagram



Harell D., and El-Halwagi M., "Design Techniques and Software Development for Cogeneration Targeting with Mass and Energy Integration," AIChE Spring Meeting, New Orleans, March 2003

Biomass in Utility Systems

- Cost reduction, efficiency improvement, and NO_x/CO_2 reduction through combined heat and power (CHP) in process industries
- Capturing power generation potential through pressure reduction in steam systems: "cogeneration"
- Utilization of biomass or biowaste for partial/total cogeneration



33

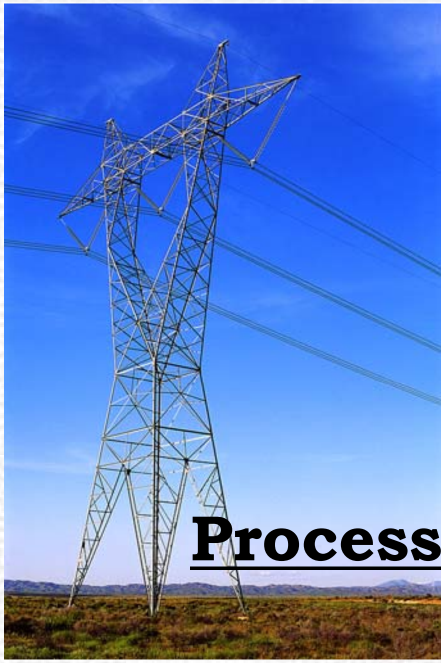
Conclusions

- Systematic and generally-applicable procedures for the design and operation of optimum cogeneration and biomass utilization ➔ reduction in GHGs and ozone precursors (+ cost and energy savings)
- An integrated approach for analysis of technical, economic and environmental aspects of cogeneration and biomass utilization.
- In-process modifications leading to cost savings, energy conservation, and reduction in GHGs and ozone precursors.
- Strong interaction with industry.
- Dissemination via publications, workshops, monograph, and software.
- Insights on short- and long-term solutions and recommendations to policymakers.

34

QUESTIONS?

35



Process Integration & Systems Optimization

El-Halwagi Research Group
Department of Chemical Engineering
Texas A&M University