IPRO It takes a team
INTERPROFESSIONAL PROJECTS PROGRAM

IPRO 302
CO2 Mitigation: A Techno-Economic Assessment

Sargent & Lundy LLC

Problem

- CO_2 emissions may be contributing to global warming.
- Future governmental regulations are expected.
- Power plants will require CO_2 capture technology.
- Alternate destination for CO_2 must be found

Sargent & Lundy LLC

Our Sponsor:

- Full service provider to public utilities and independent power producers
- Provides global consulting services for:
  - Renewable power
  - Nuclear power
  - Fossil power
  - Design of environmental control systems

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Objectives

- Analysis of CO_2 removal system
  - Computer models of power, steam and flue gas cycles
- Economic analysis
  - Capital and operation costs.
  - Sequestration costs.

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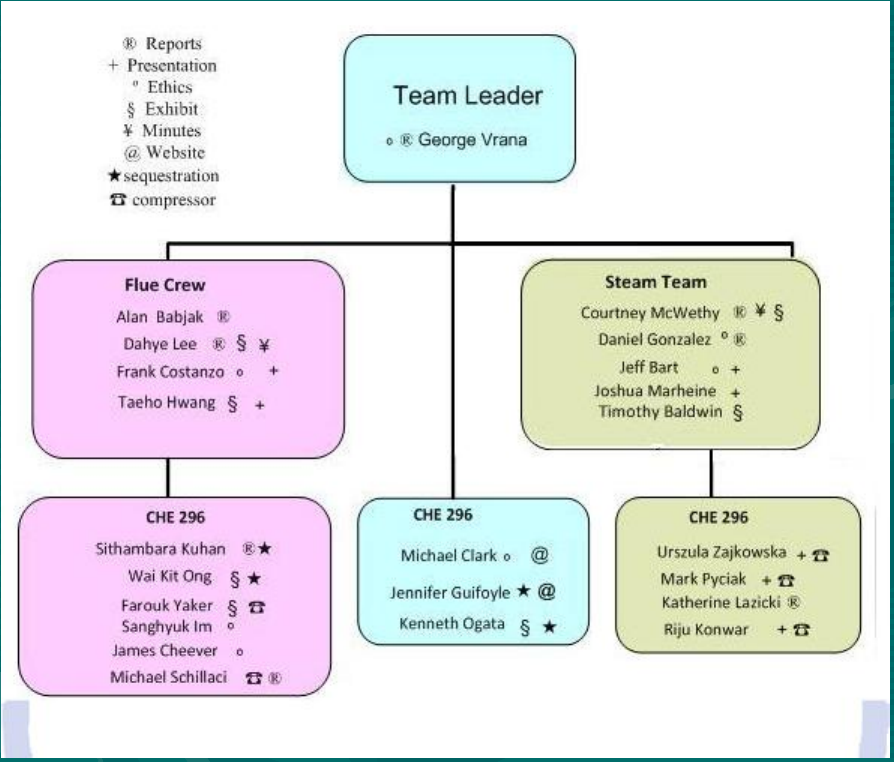
Team



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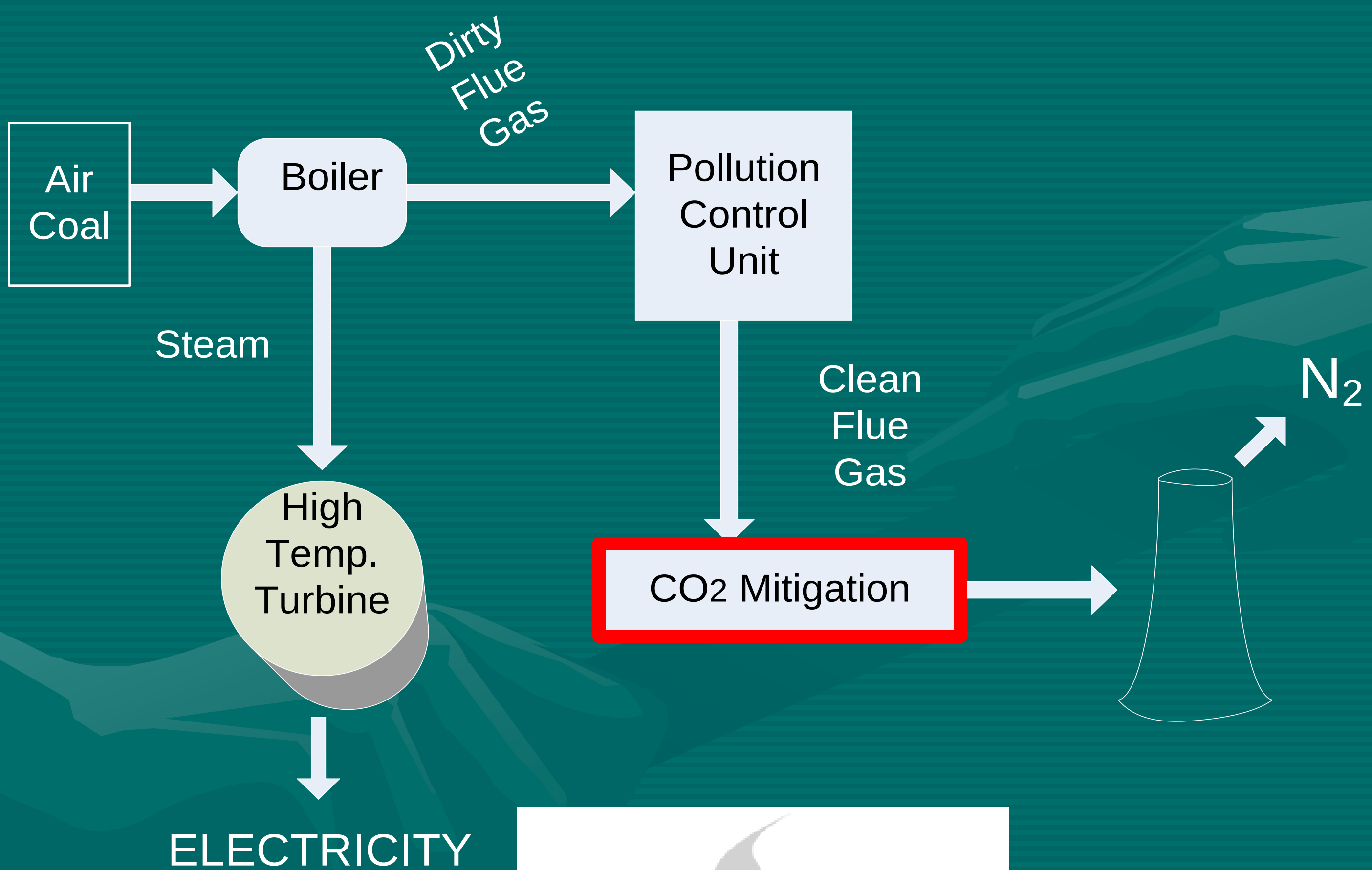
Overall Process



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Steam Team Purpose and Goals

- Analysis of steam cycle and flue gas
- Find values via Matlab simulation and hand calculations
- Determine Flue chemical composition, total mass flow rate, and temperature

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Steam Side

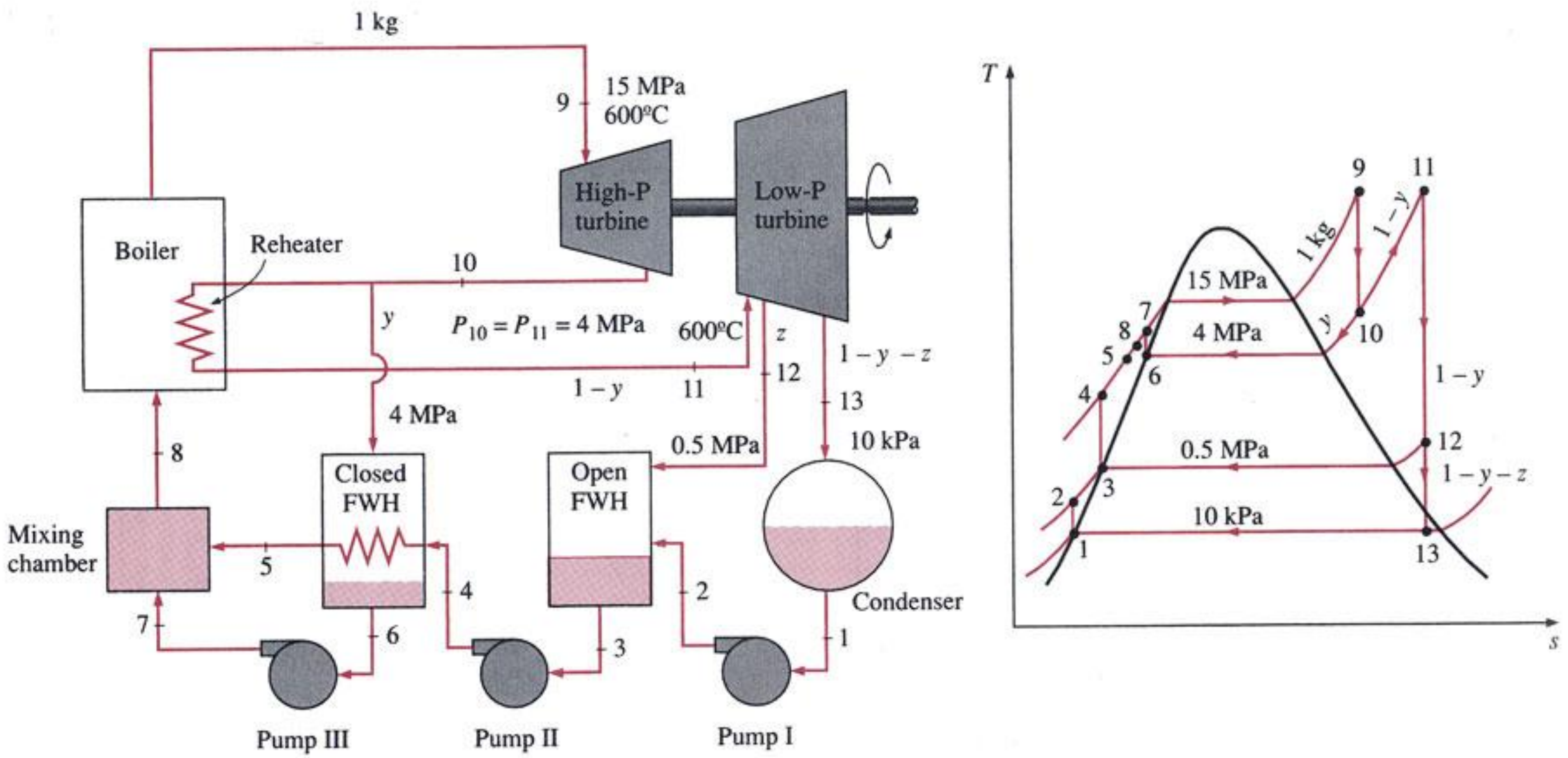


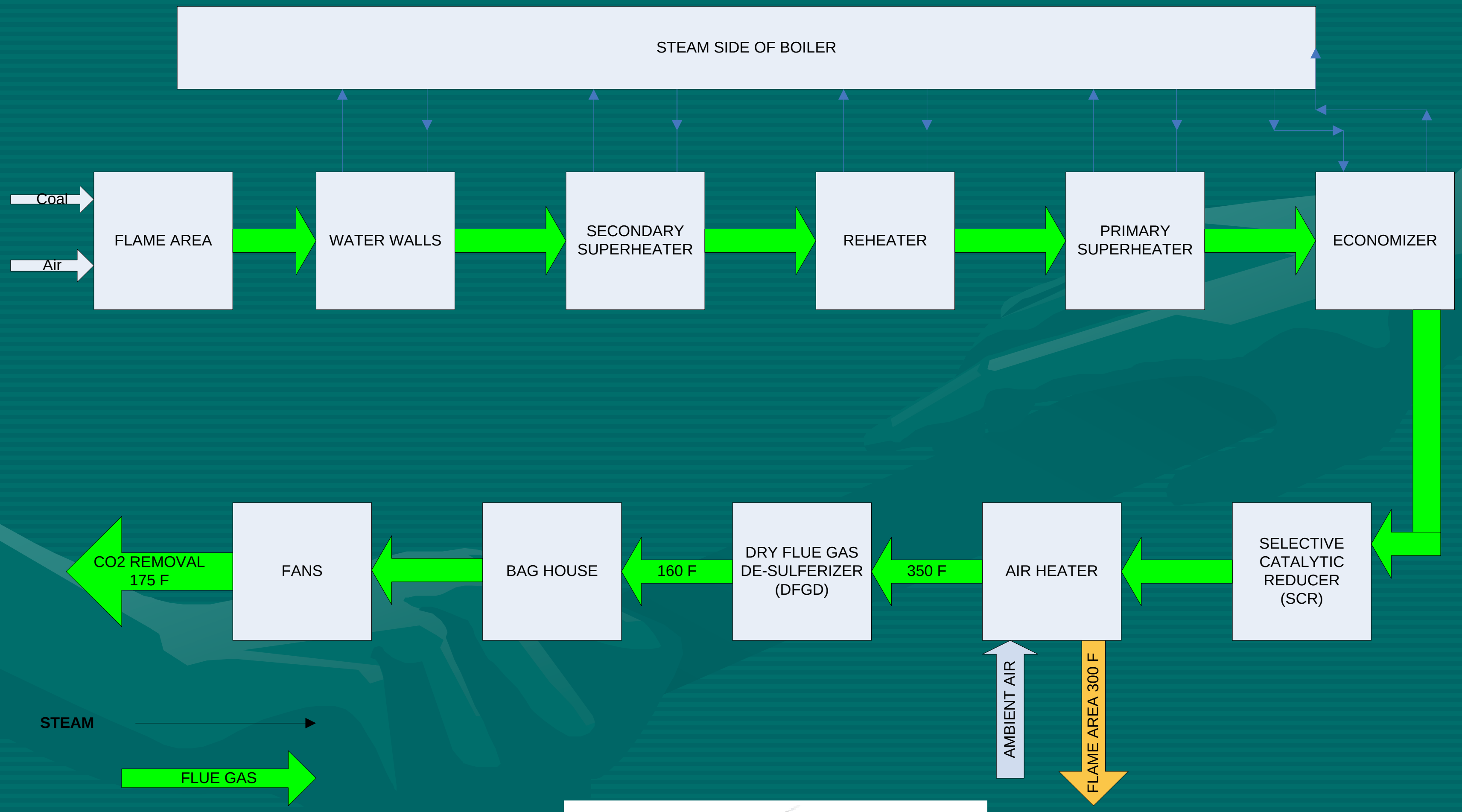
FIGURE 9-19

Schematic and *T-s* diagram for Example 9-6.

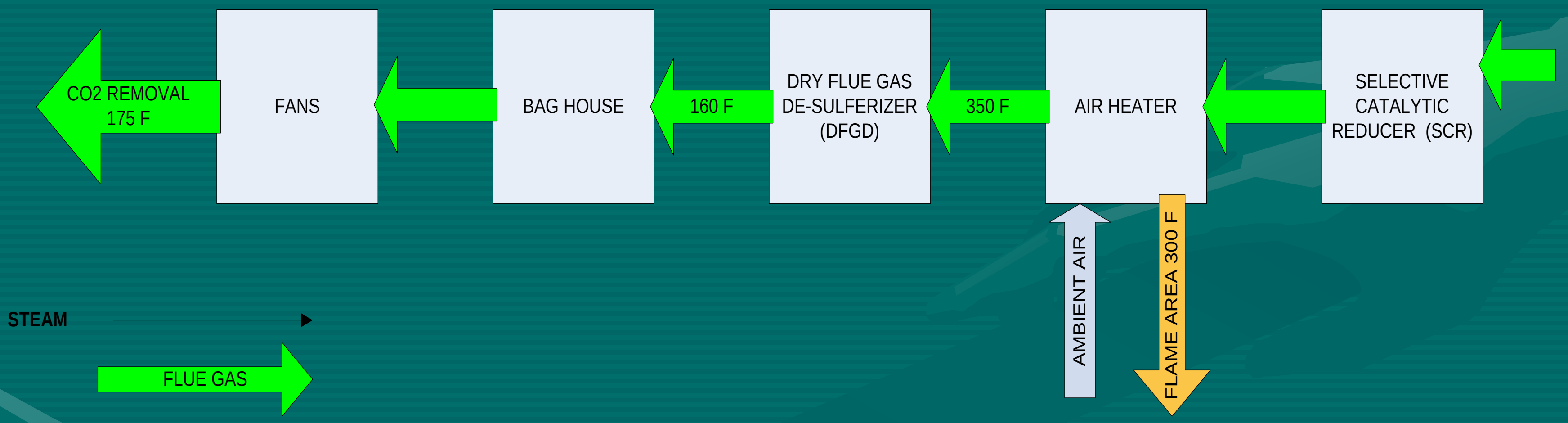
Steam Calculations (MATLAB)

- Gross power
  - Power produced at generator
- Net power
  - Power delivered to transmission lines
    - (Gross power – power consumed in plant)
- Generator and turbine efficiencies
  - Used to determine the steam flow rate at the turbines (gross power known)
- Heat transfer requirements for intermediate stages.
- Boiler specifications given

Steam/Flue Gas Flow



Pollution Control Devices



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Assumptions

- Ideal Heat transfer
- Pollution Control Devices energy losses are neglible
- Baghouse removes all additional components

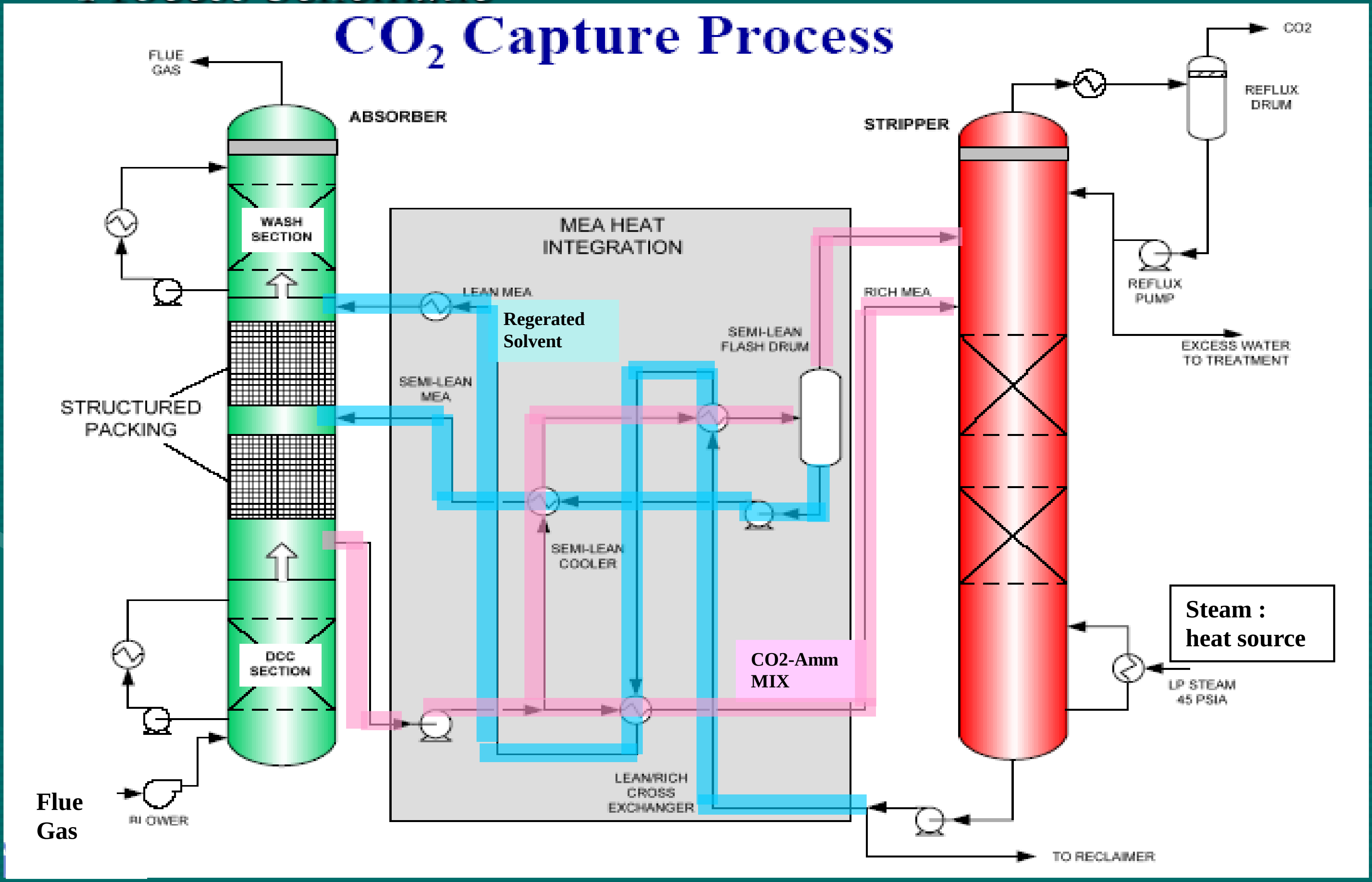
Results

- 76 kg/sec of coal
- 708 kg/sec air into furnace
- 730 kg/sec out of flue
- 152 kg/sec of CO_2 out of flue
- 82.7 Degrees C

Resulting Power Losses

- 30 MW loss for steam removal prior to entering intermediate turbine for use by CO_2 removal process
- 30 / 53 MW loss depending on 100 F or 35 F temp requirement respectively

- Process Schematic



- Absorber
  - Absorption : Operation when liquid & gas phases contacts
  - Diffusion or mass transfer of solute to Solution
  - Solute : CO_2 – absorbed from flue gas into stagnant liquid

- Stripper
  - Separate and regenerate CO_2 from solution
  - Separation Property : Relative Volatility --- 30 times volatility difference

- Reaction

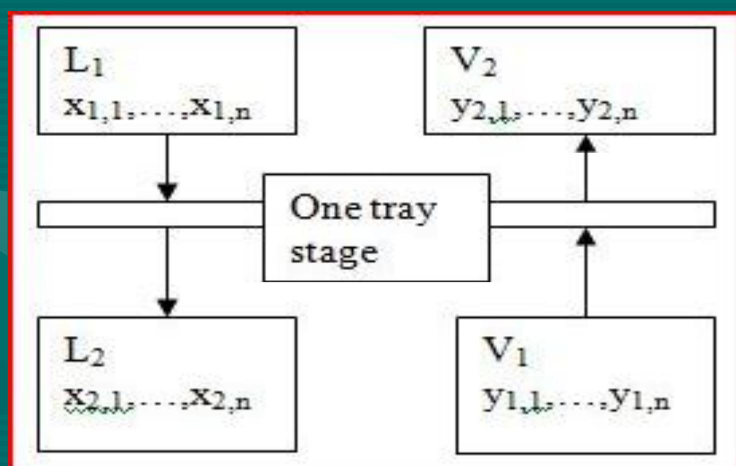
$$(NH_4)_2CO_3 + H_2O + CO_2 \underset{\text{stripper}}{\overset{\text{absorber}}{\rightleftharpoons}} 2\, NH_4HCO_3$$

Ammonia Carbonate — Ammonia Bicarbonate

- Counter-Current packed Absorber
  - The highest *theoretical* efficiency.
  - Driving force : concentration difference
  - Pressure Drop

$$f_p = \frac{150}{\mathrm{Re}_p} + 1.75 \Rightarrow f_p = \frac{\Delta P}{L}\frac{D_p}{\rho V_s^2}\frac{\varepsilon^3}{1-\varepsilon}$$

- Stripper



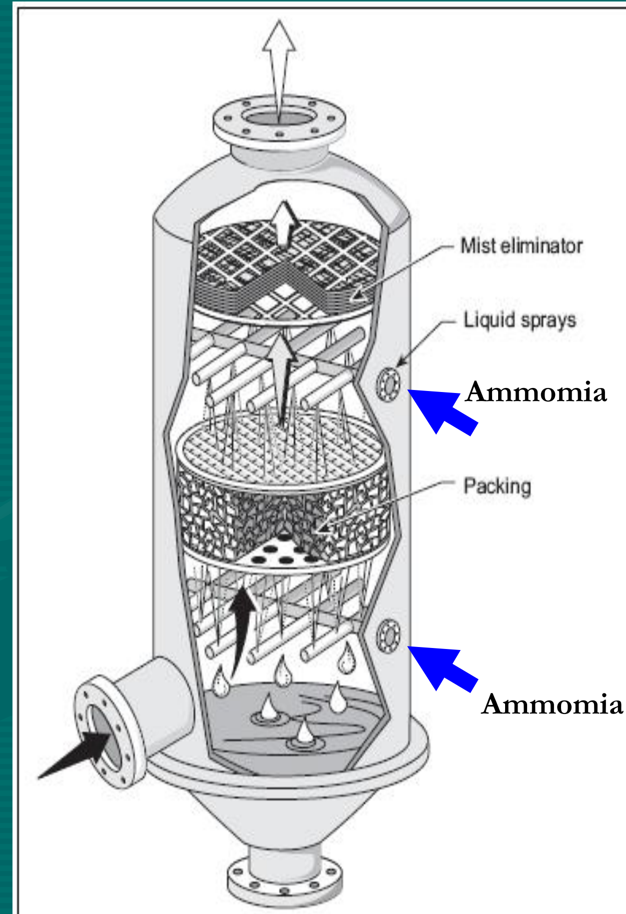


Figure 5-1. Countercurrent-flow packed tower

- Operating Condition for Chilled Ammonia Process
  - Reagent composition : **25% Ammonia, 75% Water**
  - CO2 Removal Efficiency : **1.29 lb CO_2 / lb Reagent**
  - Heat of Reaction : 260 Btu/lb

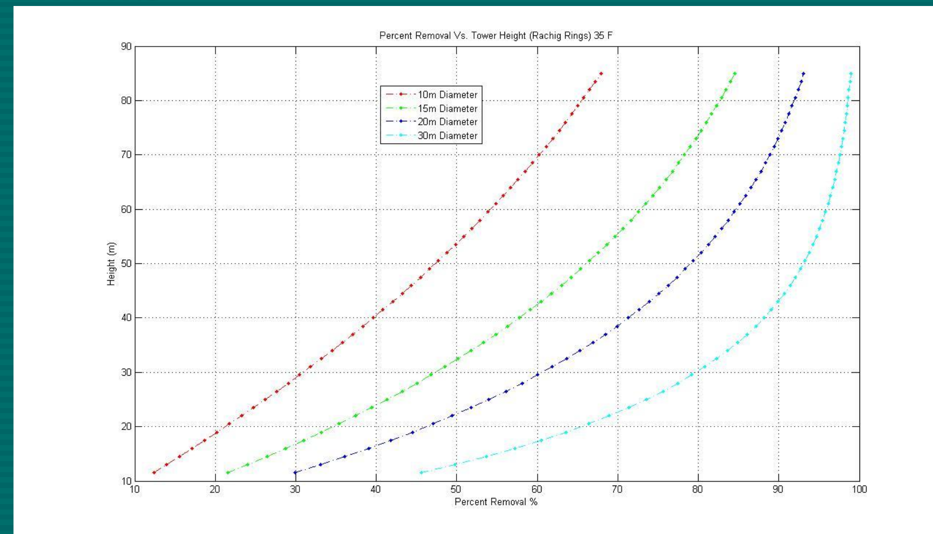
  - Absorption Temp. : 35~60°F (2 ~ 16 °C)
  - Absorption Pressure : Atmospheric

  - Regeneration Temp. : 200 ~ 250°F
  - Regeneration Pressure : 300 ~ 600 psia

  - Pressure Drop : 0.1 psia / tray

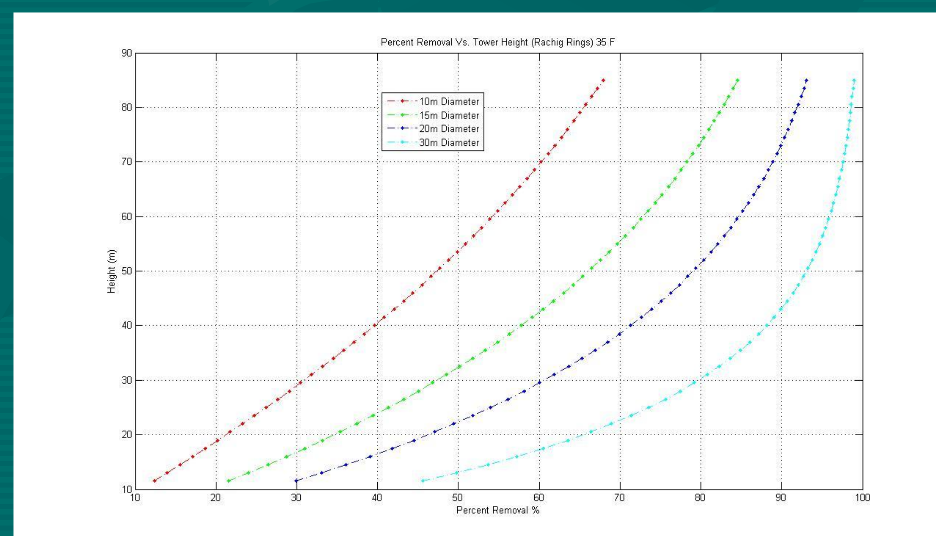
- Absorber Design with Matlab

Berl Saddles



  - 20 meter diameter chosen as best compromise of cost and efficiency.

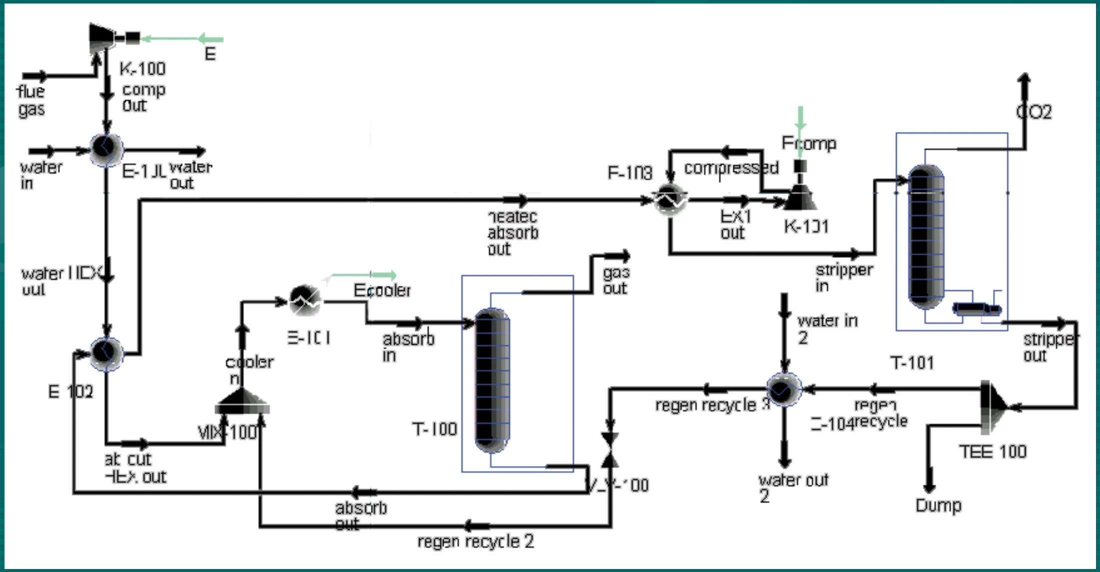
Raschig Rings



  - Higher cost
  - Lower Void fraction
  - Higher Surface Area

- Stripper Design with Matlab

- Heat integration Design
  - HYSYS simulation
  - Obstacle : system does not have ammonium carbonate (AC) and ammonium bicarbonate (BC)
  - Assumptions
    - majority of streams between Stripper and Absorber consists of Ammonia and Water.
    - HYSYS design model with H_2O, NH_3, CO_2 estimates the most similar heat integration process including heat exchangers and compressors.



- Economical Analysis
  - Assumptions : interest rate, labor fee, Land cost, etc.

Challenges with CO_2 Compression

- Corrosive – water + CO_2
- Iron Carbonyl formation – water + CO
-

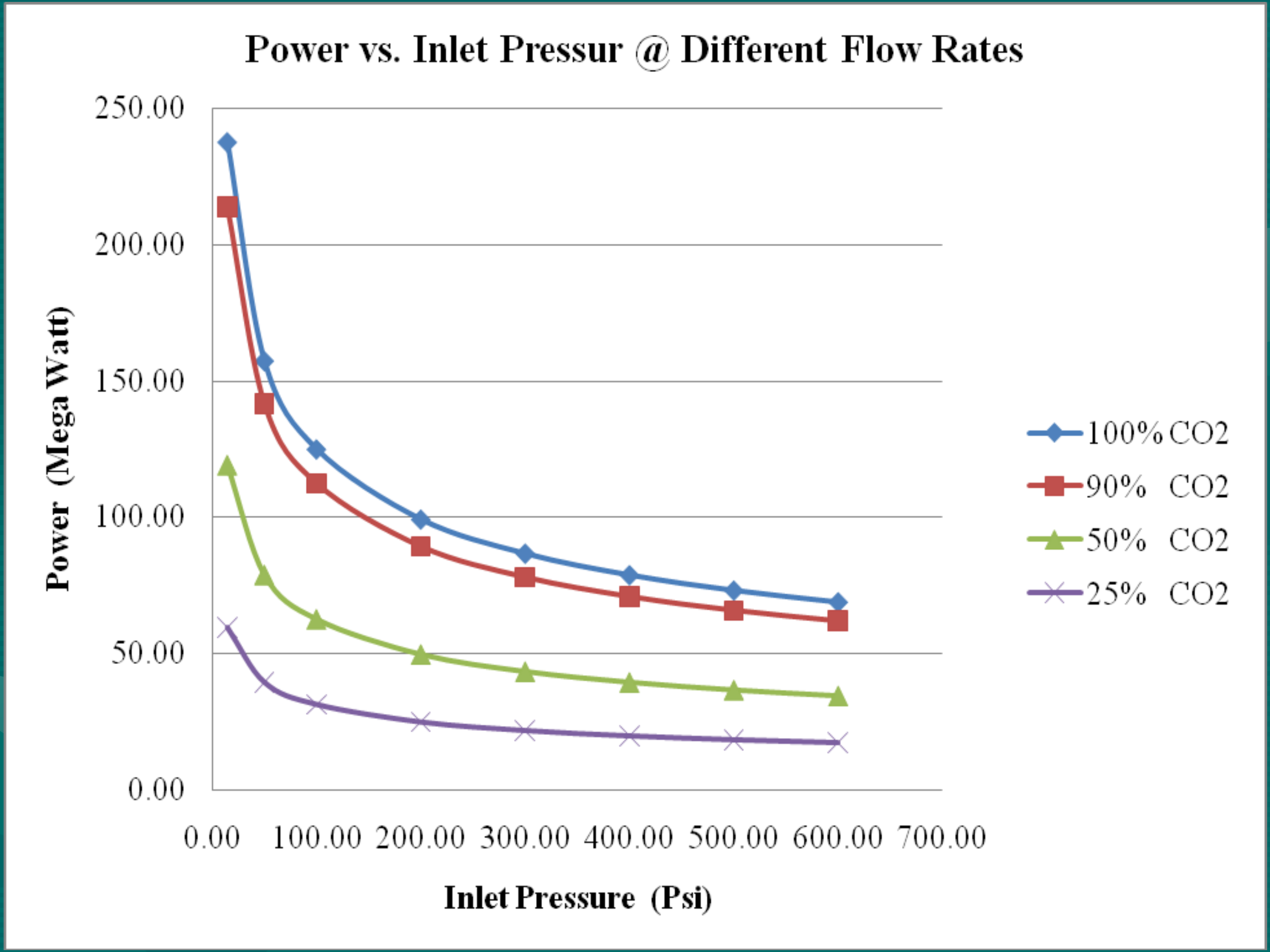
Centrifugal Compressors

- Superior efficiency
- Oil-free compression
- Less maintenance-intensive
- Higher speed, commonly used in the 10-40MW range

MOST VIABLE COMPRESSOR

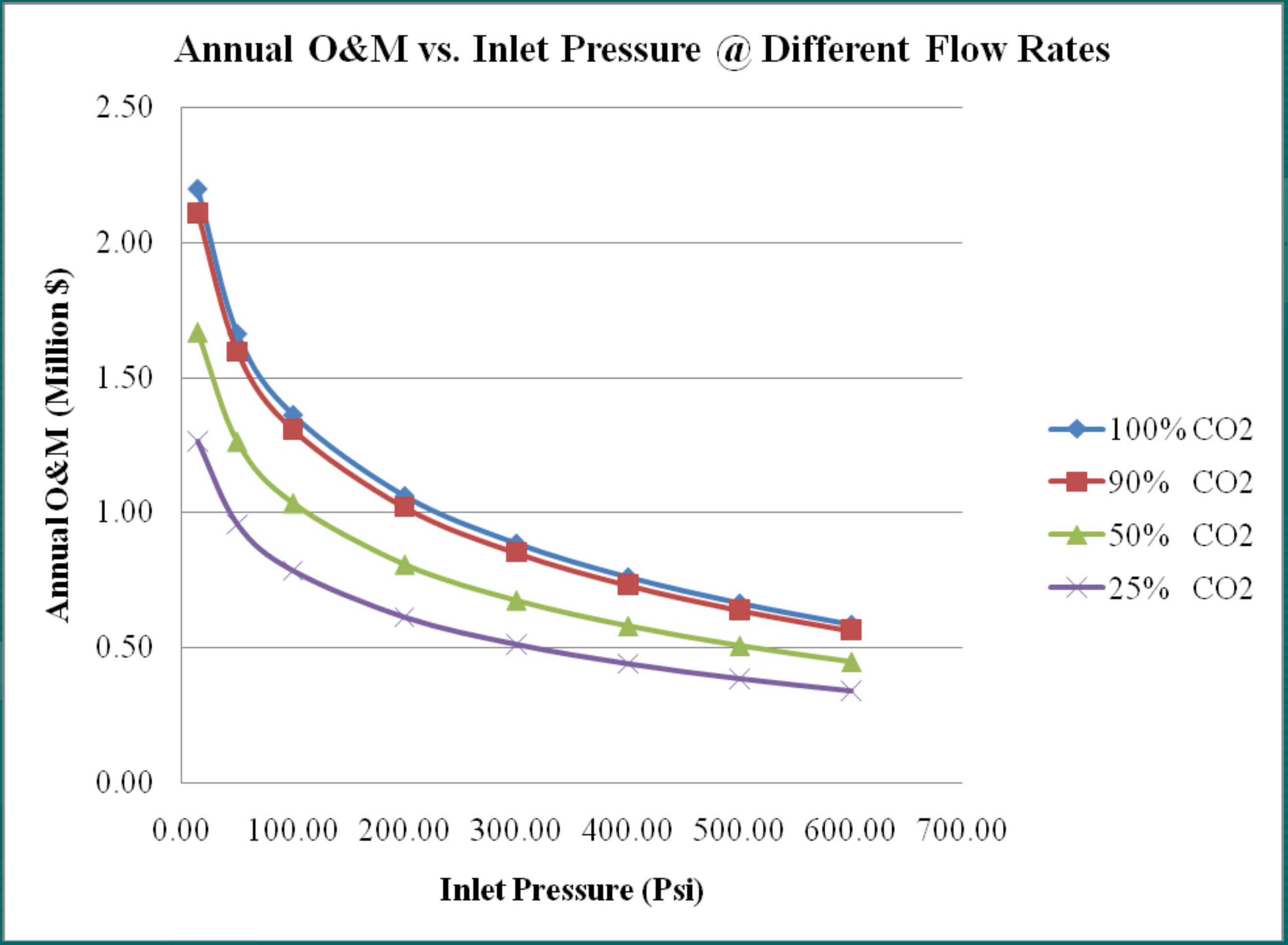
- **Specifications:**
- Model = Man Turbo
- Type = RG
- Stages = 2-8
- Max. Pressure Ratio = 225
- Inter-stage Coolers = 1-4
- Power = 4,500KW
- Flow Rate= 2000-500,000 m^3/hr

POWER VS. INLET PRESSURE



PRESSURE

Basis - $ 0.067/kW

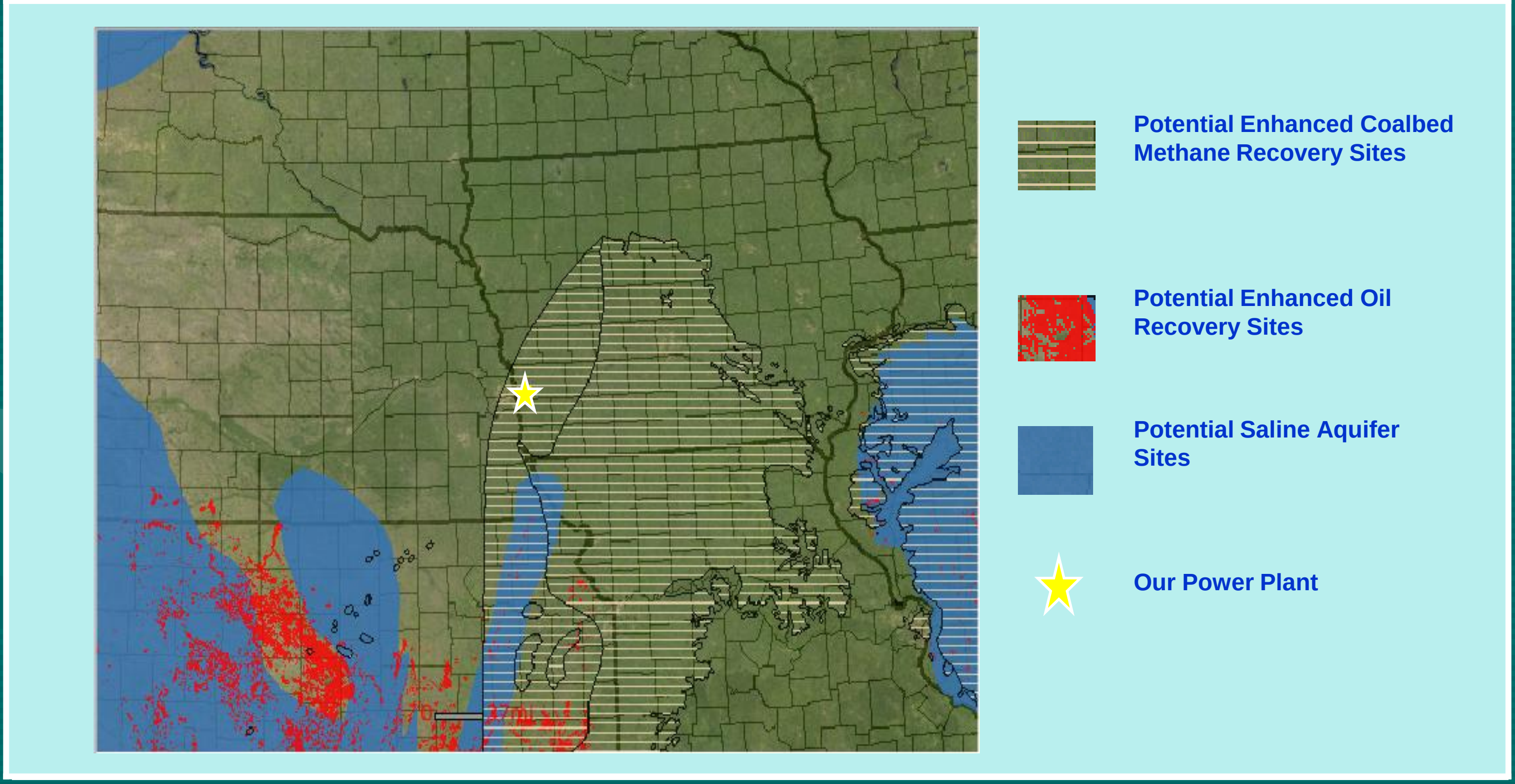


CO_2 Uses and Destinations

- Food Industry
- Enhanced-Oil Recovery
- Sequestration
  - Oceanic
  - Terrestrial
  - Geological

Iowa Options

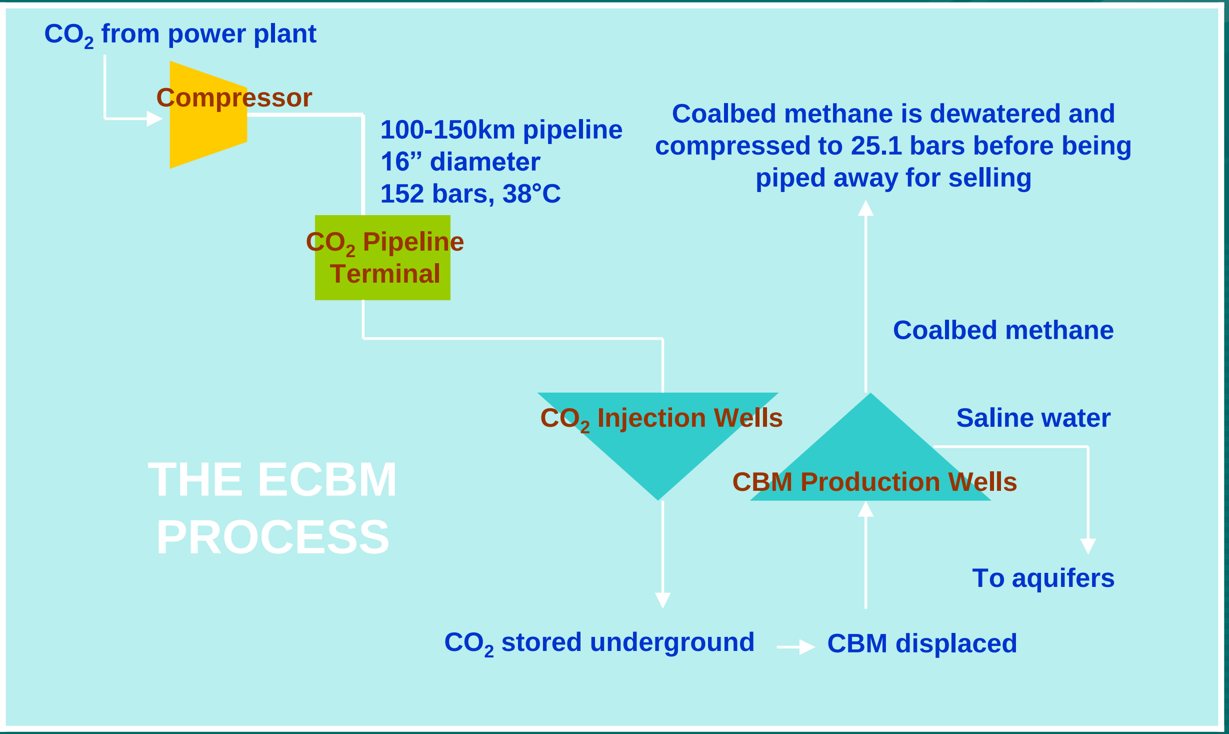
- Saline Aquifer Storage
- Enhanced Oil Recovery
- Coal-Bed Methane Recovery



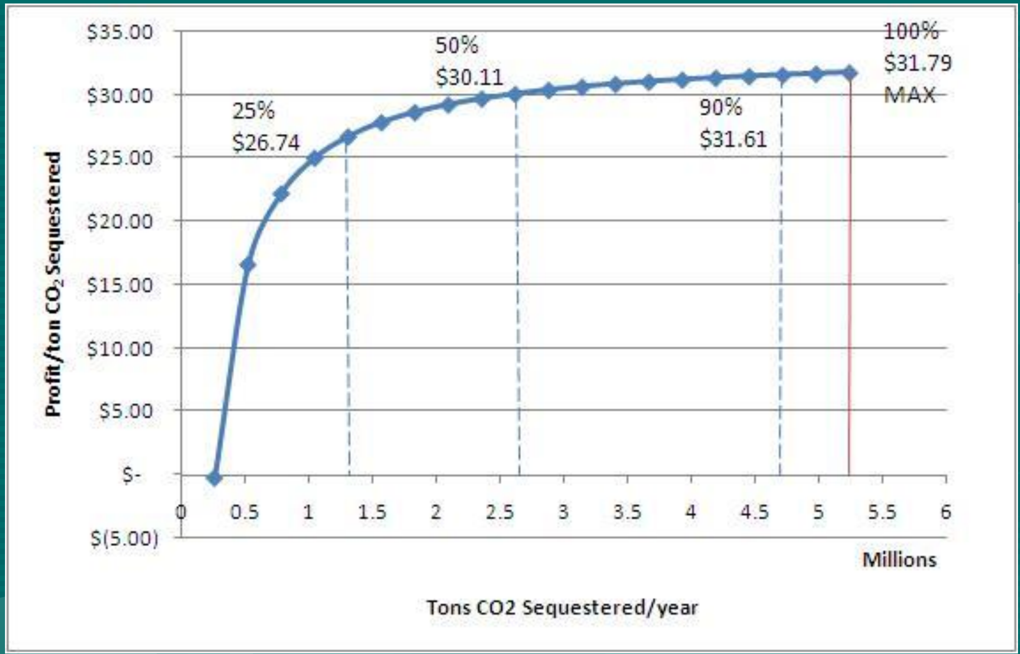
Recommendation

Coal-Bed Methane (CBM) Recovery!

- Relatively close proximity to power plant
- Offers value-added benefit of fuel extraction



Economics



- CBM benefits from sale of CO_2

Ethical Challenges

- Degeneration and loss of ammonia (~3500kg/yr)
- Ensuring reliable CO_2 storage
- Software Licensing (Law)
- Proprietary Information (Professional Codes)

Overall Conclusions

– 30MW Average Energy Penalty from Steam Cycle
– Only CO_2 capture with 25% feasible
– 158 bar compression to liquid CO_2 follows
– Coal-Bed Methane Recovery/Sequestration

Thank You

Special Thanks: Charles Guilfoyle
Lily Popadopoulos

Questions

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