A TEN-STEP PROCESS FOR ENERGY ANALYSIS

Understand the energy used to transform raw material into finished product to enhance energy efficiency

North Jersey Section AIChE

Spring Symposium – Part I

April 16, 2019

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  - EI Associates – A/E consulting
  - BOC Gases – industrial gases
  - Schering-Plough - pharmaceuticals
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ATTRIBUTIONS

Some information presented on these slides was obtained (with permission) from:

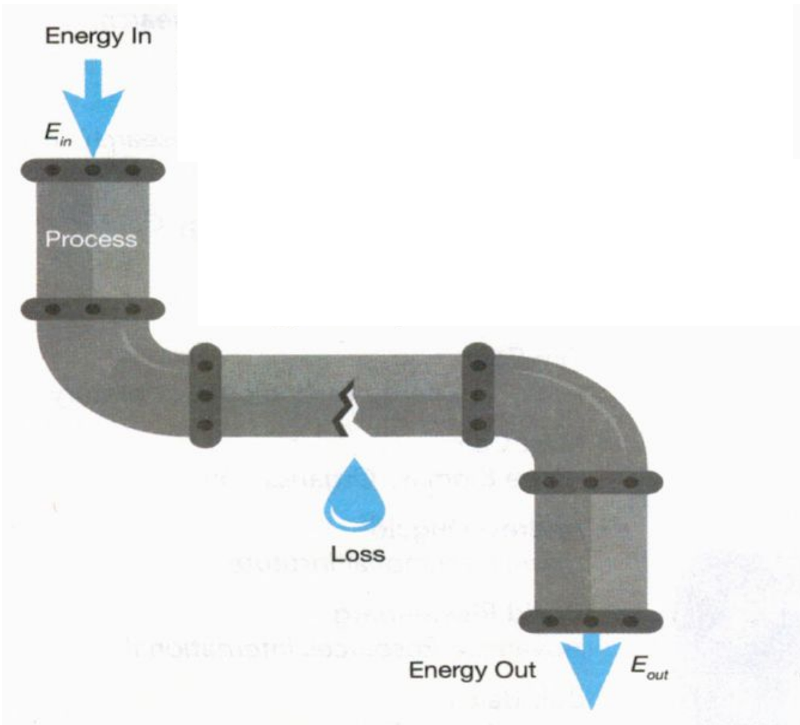
- **A Ten-step Process for Energy Analysis** – Michael L. Stowe, P.E., CEM, PEM, Senior Energy Engineer - Advanced Energy, Chemical Engineering Progress, November 2018

- *…as well as over 35 years of experience in the chemical process industry!*

Definitions:

- **ENERGY EFFICIENCY:**
  - The total energy into a system is E_{in} which is the amount that appears on your utility bill
  - The total energy out of the system is E_{out}, which represents the useful energy that adds value to the product during the process
  - The difference between E_{in} and E_{out} is the loss
    - » *Loss is wasted energy that is not useful to the process and degrades efficiency*
- **For energy efficiency to be sustainable, energy losses must be identified, documented, tracked, corrected, and prevented from recurring**
- **If the losses were zero, the system would be 100% efficient - but this does not occur in the real world.**

Energy Efficiency – Example 1



- A simple way to envision energy efficiency is to think about water flowing through a pipe - the water represents the energy and the pipe is the process
- $\boldsymbol{E_{in}}$ would be the water into the system in gallons per minute (gpm), and a loss could be a leak in the pipe that reduces the amount of water available to add value to the product
- Using the water pipe example, we can calculate energy efficiency
- If $\boldsymbol{E_{in}}$ is 100 gpm and the loss due to leaks is 10 gpm, $\boldsymbol{E_{out}}$ is 90 gpm, and the energy efficiency of the system is **90% ($\boldsymbol{E_{out} / E_{in}}$)**

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Energy Efficiency – Example 2

PROCESS HEATED BY NATURAL GAS:

- ***E_{in}*** is **1,000,000 Btu/hr** of natural gas
  - *the fuel combustion loss is 100,000 Btu/hr*
  - *stack loss is 250,000 Btu/hr*
  - *stored heat loss is 75,000 Btu/hr*
  - *furnace wall loss is 50,000 Btu/hr*
  - *opening loss is 25,000 Btu/hr*
  - *and conveyor loss is 20,000 Btu/hr*
  - *…………………..**for a total loss of 520,000 Btu/hr***
- ***E_{out}*** is the difference between *E_{in}* and the total loss, which is *1,000,000 – 520,000 = 480,000 Btu/hr*, making the energy efficiency of the system *(480,000 / 1,000,000 = 0.48 or **48%**)*
- Over half of the original natural gas energy input is lost and does not provide useful work in the process

Definitions:

- **ENERGY INTENSITY:**
  - The energy intensity of a manufacturing process is the amount of energy that is required to produce one unit of product:
    - » *kWh / ton metal melted at a foundry*
    - » *MMBtu / barrel of oil refined at refinery*
    - » *MMBtu / lb of polymer produced at a chemical plant).*
- **Energy intensity provides an order-of-magnitude estimate of the significance of energy in the production process, and it varies widely from industry to industry**

Energy Intensive Industries:

Figure 7-4. Energy-intensive industry shares of total OECD industrial sector energy consumption, 2012 and 2040 (percent of total)

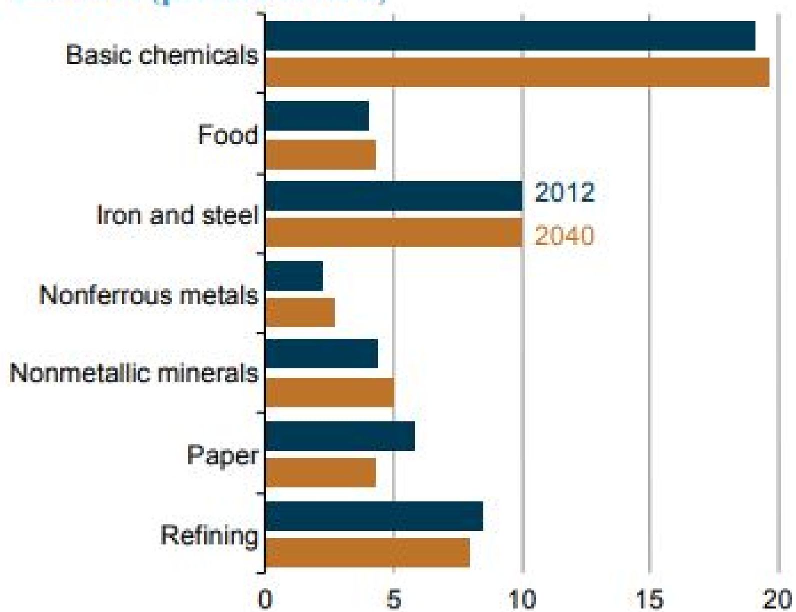
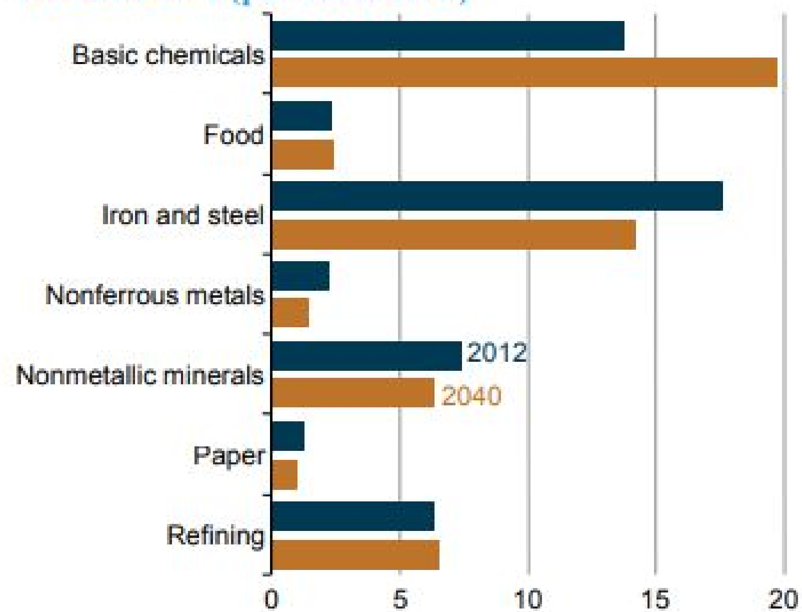


Figure 7-5. Energy-intensive industry shares of total non-OECD industrial sector energy consumption, 2012 and 2040 (percent of total)



U.S. Energy Information Administration | International Energy Outlook 2016 117

The **Organization for Economic Cooperation and Development (OECD)** was established in 1961 as a forum for governments to share experiences and seek solutions to common economic and social problems. Today, approximately 50 industrialized and emerging-economy countries have joined the OECD as members or adherents.

https://www.eia.gov/outlooks/ieo/pdf/industrial.pdf

Definitions:

- **TRANSFORMATION:**
  - *Each step of the transformation process should add value with minimal waste*
  - *Every step requires some type and amount of energy to carry out the transformation*
  - *Certain steps require a large amount of energy, while others require very little*
  - *Outlining each step and the required energy inputs is useful for planning and prioritizing energy projects.*
  -
- **To understand transformation, consider the process that produces a vase from a lump of clay, as outlined on the following slide…..**

Energy Transformation

▲ **Figure 2.** Modeling produces a useful shape from a lump of raw clay but requires energy inputs from human labor and an electric motor.

Table 1. Each step in the process to transform a lump of clay into a finished vase requires energy inputs.

Process Step	Energy Input	Value Added
Storing the clay	Storage warehouse utilities, *e.g.*, lights, heating/cooling, ventilation	None
Modeling the clay vase	Human labor Electric motor	Create a useful shape
Firing the clay vase in a kiln	Electric resistance heat	Strength Durability
Painting a glaze on the vase	Human labor	Aesthetics
Refiring the glazed vase in a kiln	Electic resistance heat	Aesthetics Protective coating
Storing the finished clay vase	Storage warehouse utilities, *e.g.*, lights, heating/cooling, ventilation	None

- **Table 1** presents the details of the transformation of a lump of clay into a piece of pottery.
- The steps that require a kiln are the obvious big energy users and would be logical candidates to evaluate for energy savings.
- The same approach of evaluating each transformation step can be applied to complex manufacturing systems using the ten steps outlined on the following slides…

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Step 1:

- **IDENTIFY THE RAW MATERIALS**
  - Some industrial processes have one main raw material, while others have dozens or even hundreds
  - Raw materials can come into the process at many places along the transformation journey
  - To determine the type and amount of energy required in the system, first consider these aspects of the raw materials:
    - *type of material, e.g., metal, chemical, mineral, textile, vegetable, finished goods*
    - *physical state, e.g., solid, liquid, gas, subassembly*
    - *delivery method, e.g., tanker ship, tanker truck, common carrier, railcar*
    - *storage methods, e.g., dry bulk, tank farm, warehouse, sacks, pallets, cardboard boxes*

Step 2:

- **CHARACTERIZE THE FINAL PRODUCT(S)**
  - The final product is the destination of the transformation journey
  - Manufacturing plants are in the business of making money, so raw materials are brought in, transformed into something useful, and then sold for a profit
  - The manufacturing plant adds value to the raw materials and produces a final product of a designated design and quality
  - Answer these questions to characterize the final product(s):
    - » *Is the final product a completed consumer good that is ready for sale?*
    - » *Is the final product an intermediate finished item that will become the raw material at another manufacturing site?*
    - » *How is the final product packaged?*
    - » *How is the final product shipped?*

Step 3:

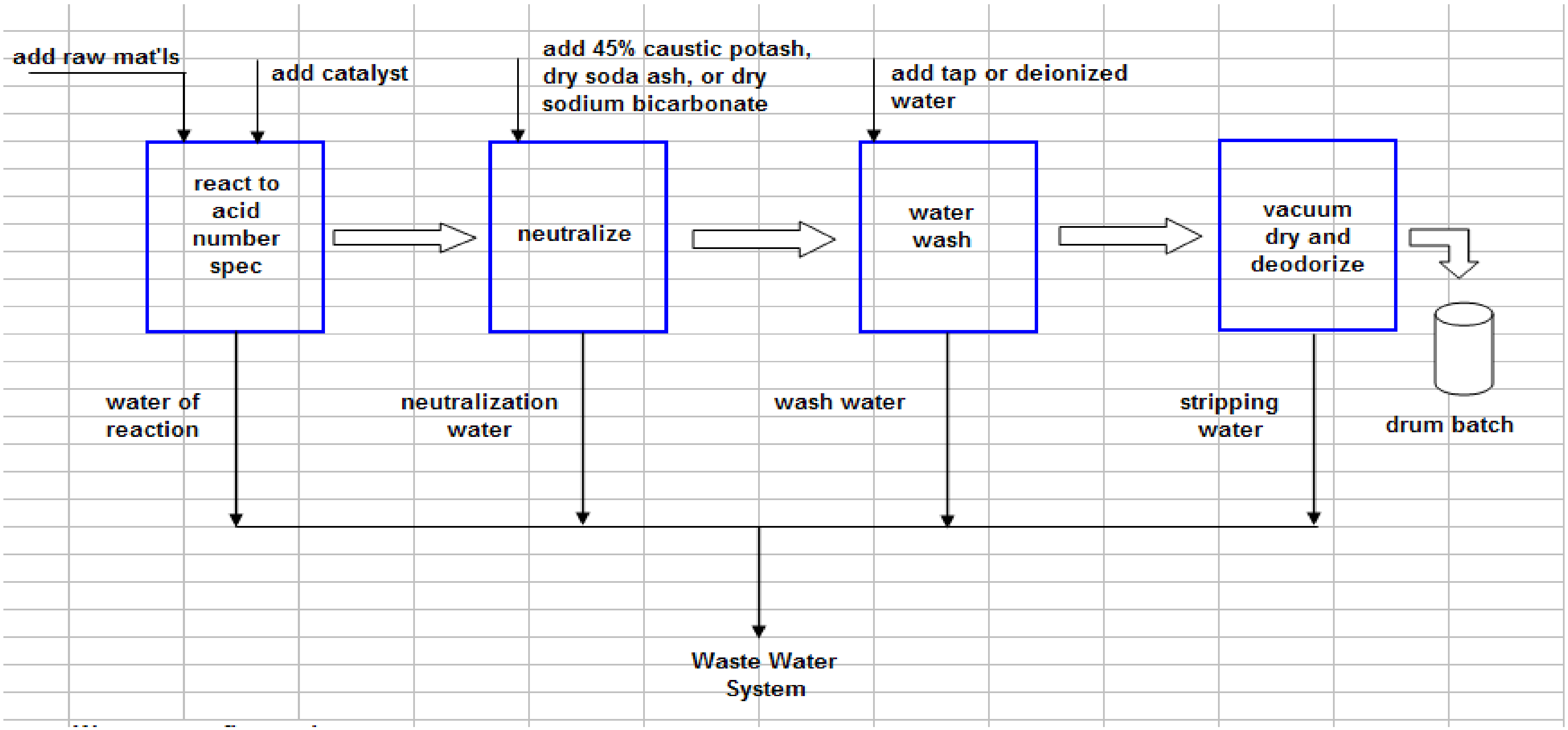
- **TOUR THE PLANT**
  - Touring the manufacturing site with process operators and maintenance personnel chronologically, from raw materials to finished products
  - Take notes paying particular attention to:
    - » *The major transformation steps*
    - » *Specific process parameters for each step (e.g., temperature, flowrate, pressure, material characteristics)*
    - » *Energy inputs into each step (e.g., electricity, natural gas, steam, chilled water, compressed air)*
    - » *Equipment used to complete the steps*
    - » *Facility equipment used to support the steps (e.g., air compressors, boilers, chillers, cooling towers)*
    - » *Waste streams (e.g., combustion stack gases, wastewater, metal shavings, sawdust).*

Step 4:

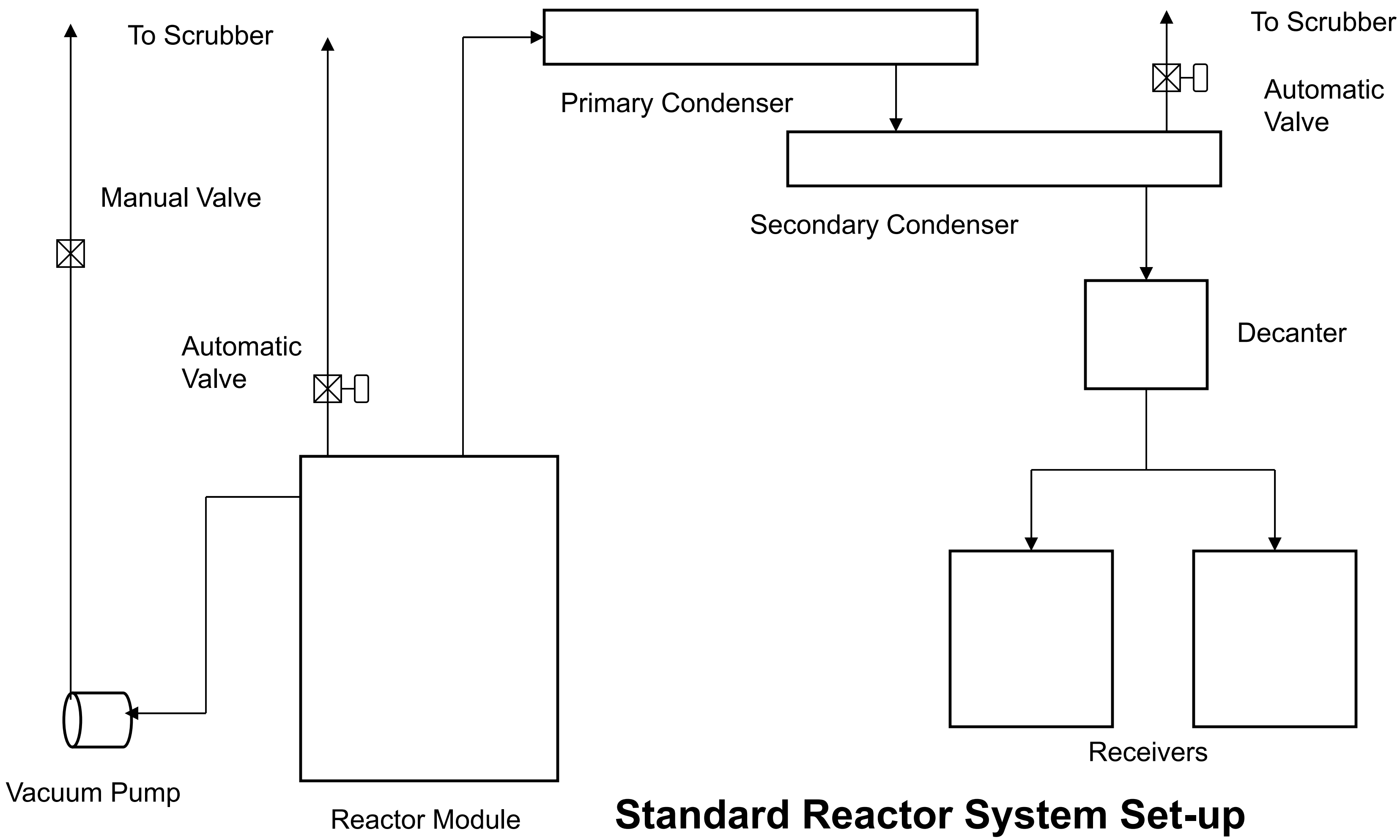
- **DEVELOP THE PROCESS BLOCK DIAGRAM**
  - Use your notes, conversations, utility data, and possibly some online research to document the transformation steps in the process
  - The product of your work should look something like the next slide, which shows the basic steps necessary to transform 2-Ethyl Hexanol and Isononanoic Acid into 2-Ethylhexyl Isononanoate
  - Evaluate each block to identify the energy components, including energy inputs, energy wastes, energy recovery possibilities, energy efficiency opportunities, and new technology opportunities (*Described in Steps 5*-9).

Standard Reaction Flow Diagram

We will look at the process for making 2-Ethylhexyl Isononanoate, a product of the esterification of 2-Ethyl Hexanol and Isononanoic Acid

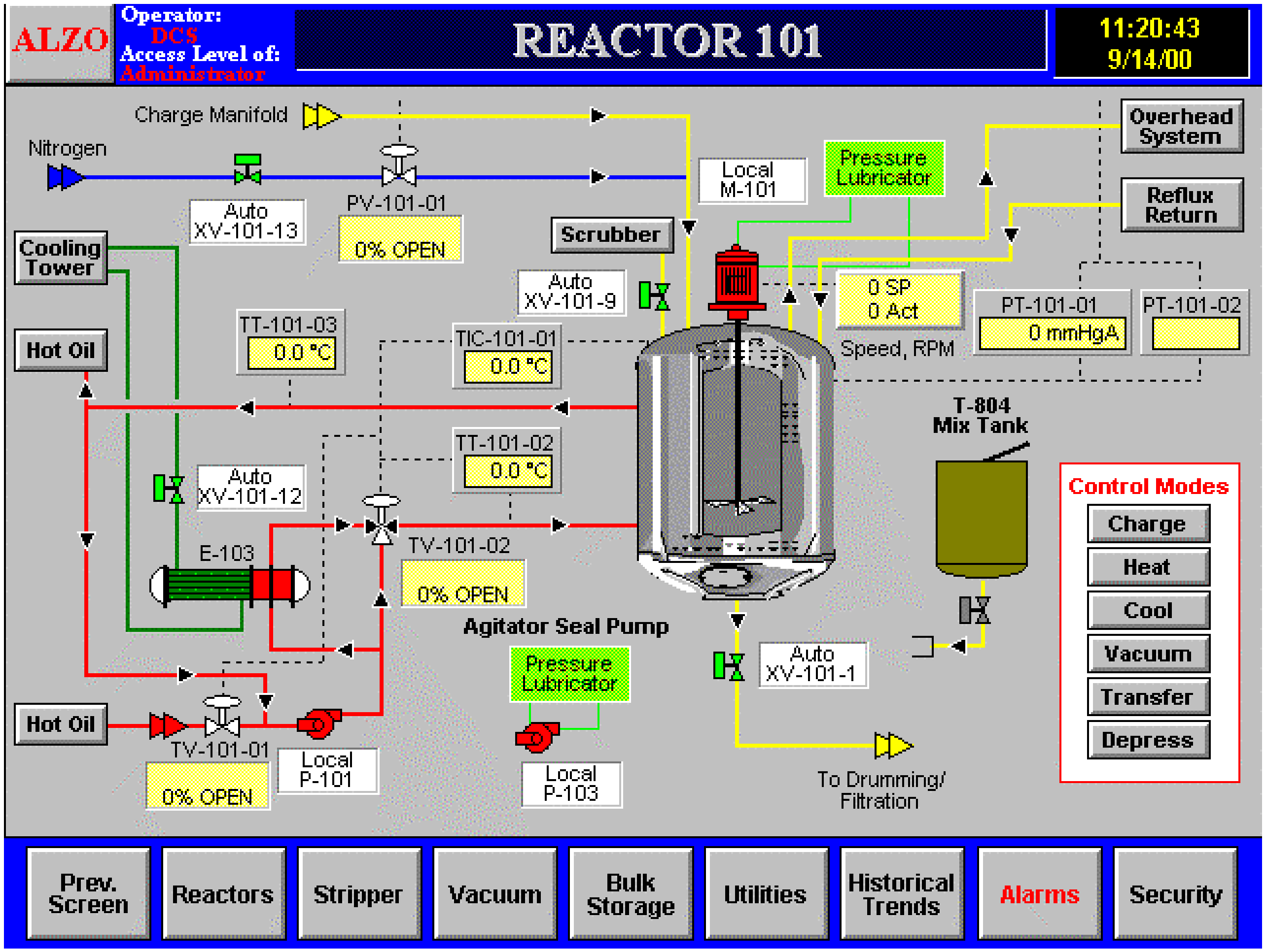


Standard Reactor System Block Diagram

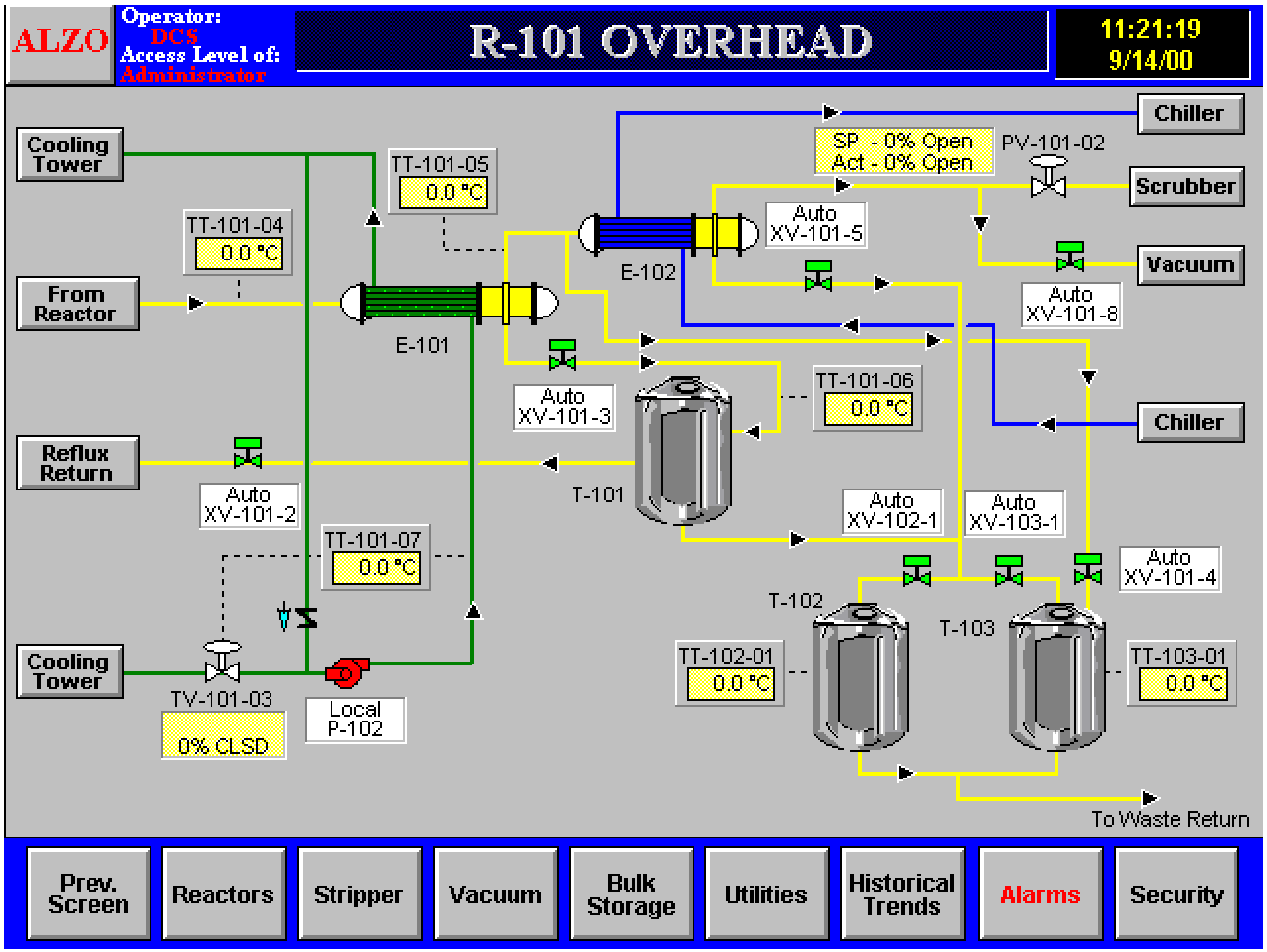


Standard Reactor System Set-up

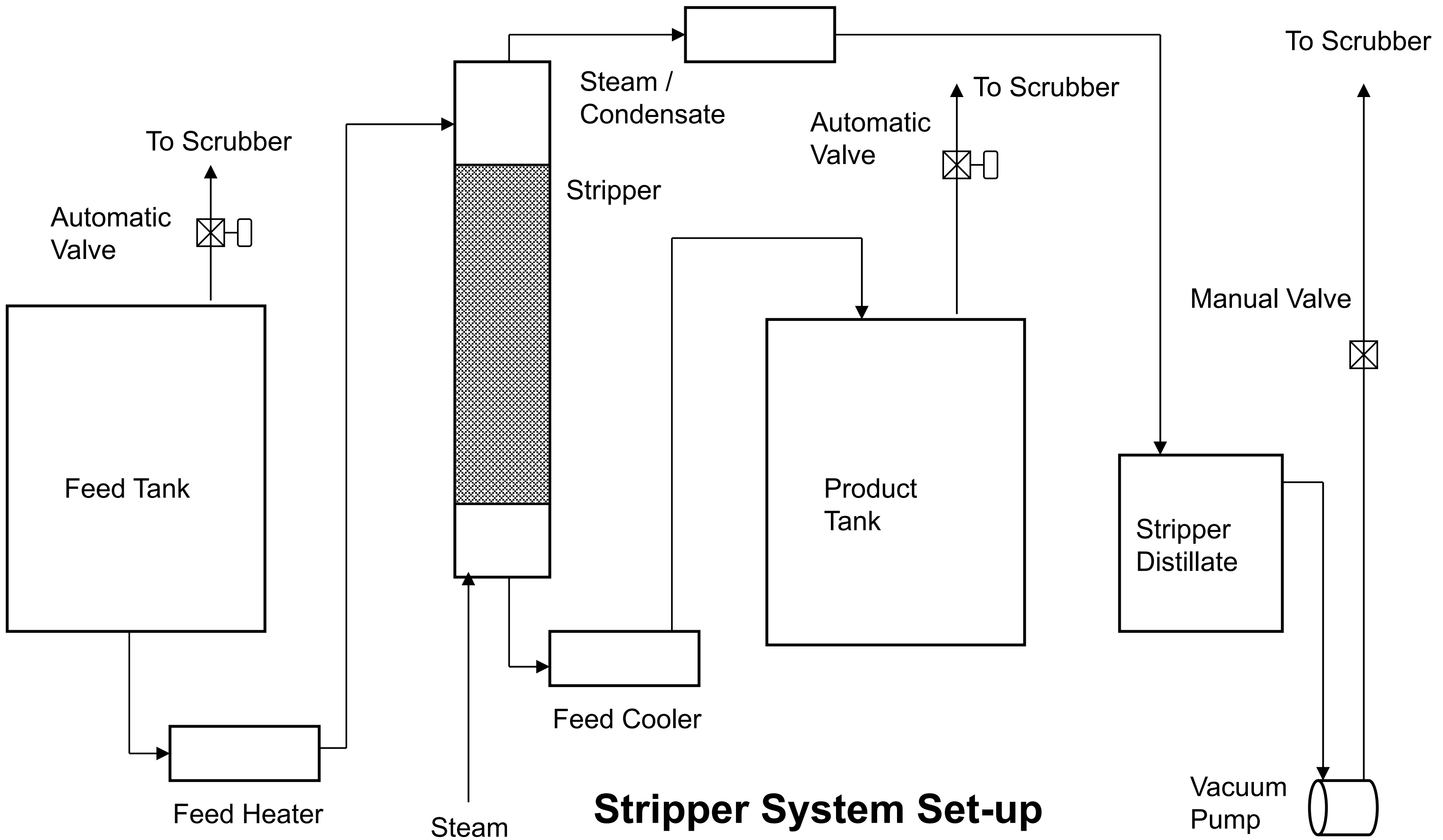
Esterification Reactor



Esterification Reactor Overheads

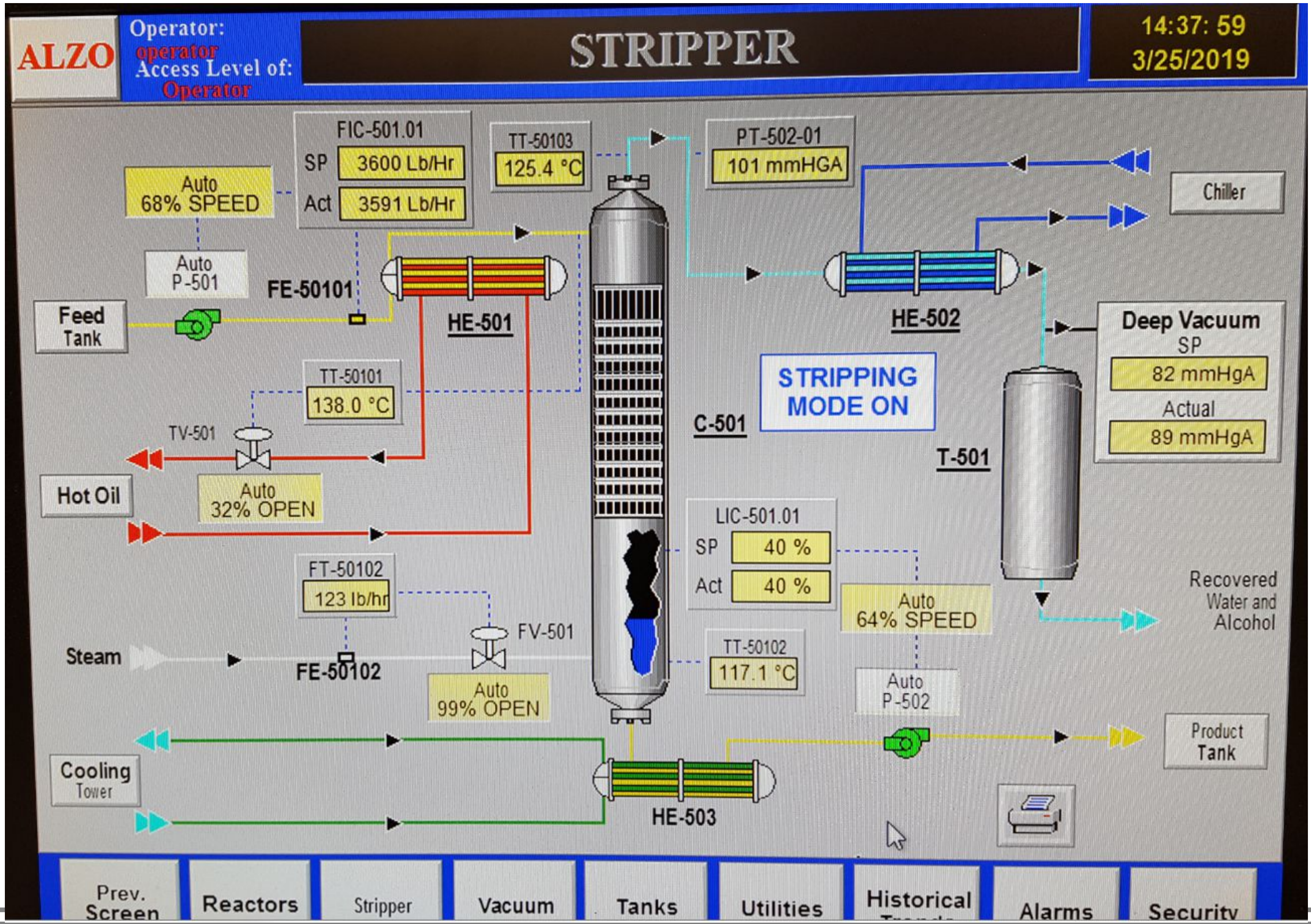


Stripper System Block Diagram

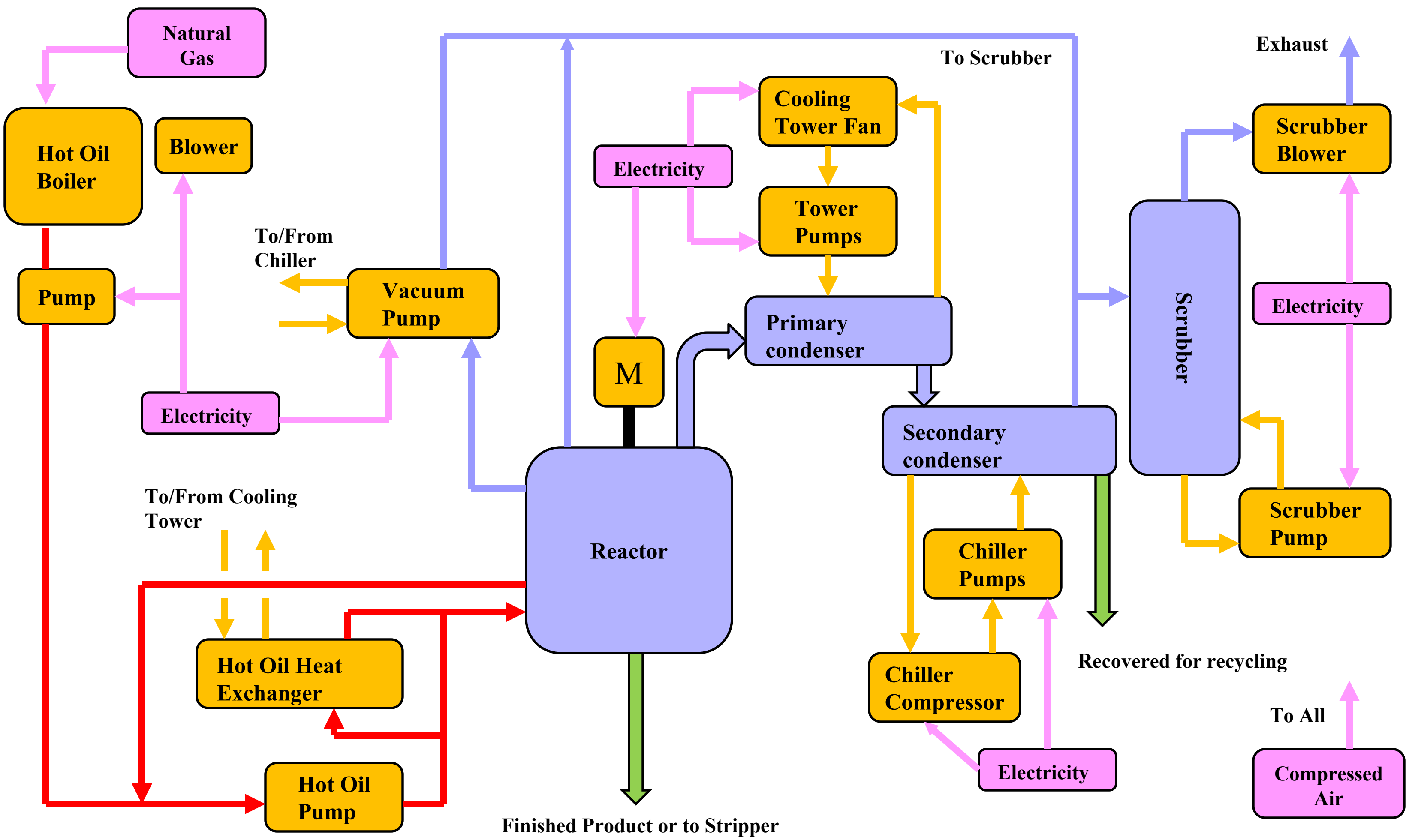


Stripper System Set-up

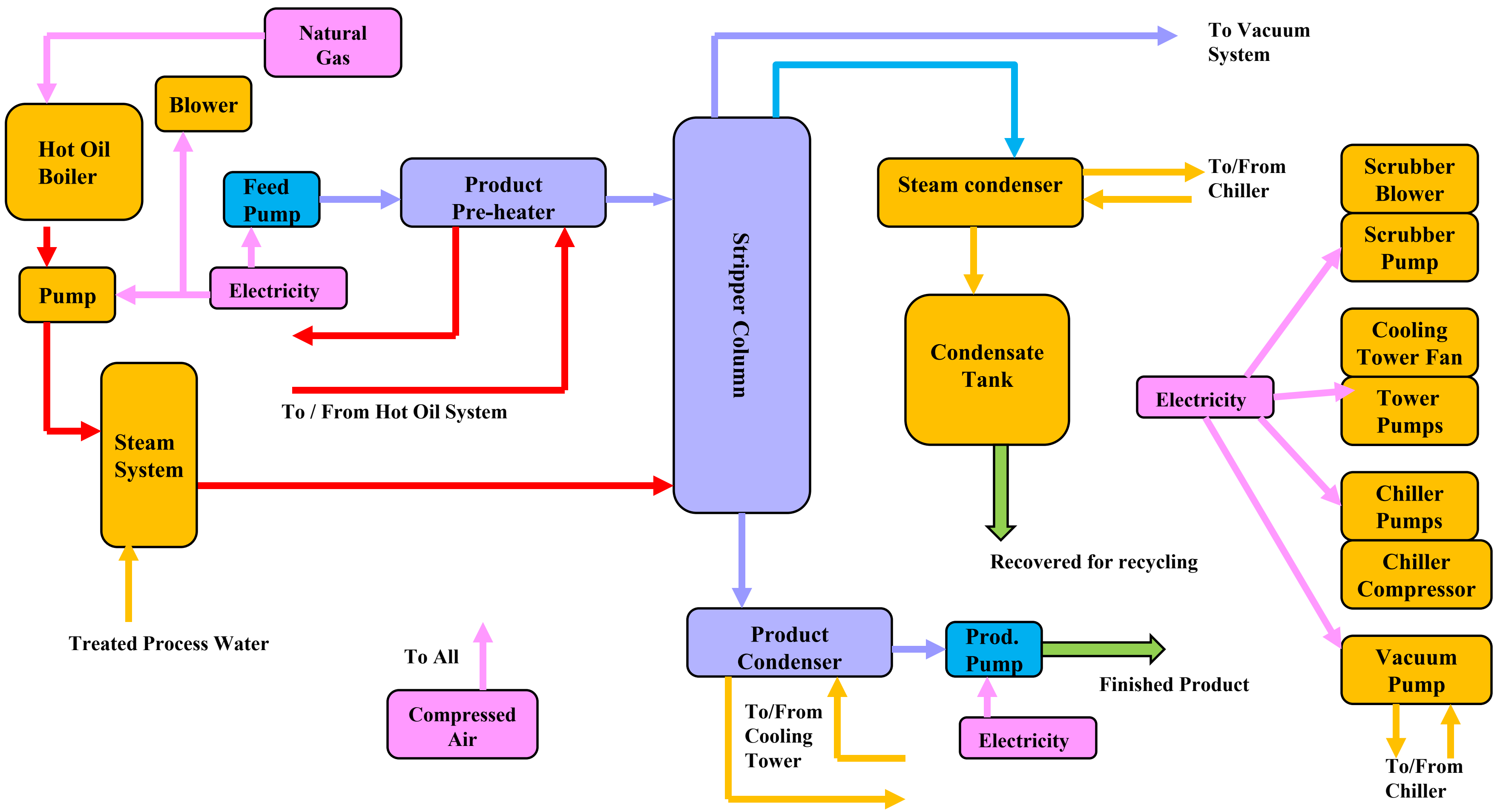
Stripper System Details



Reactor System Energy Use Diagram



Stripper System Energy Use Diagram



Step 5:

- **CATALOG ENERGY INPUTS**
  - Review each step of the process block diagram to identify the primary energy inputs required to perform the transformation
    - *Energy inputs may be direct energy, such as electricity, natural gas, propane, and fuel oil or,*
    - *derived energy, such as compressed air, steam, and chilled water*
  - Repeating this analysis for every step helps to produce an overall qualitative energy usage model
  - From our block diagram, we can observe that:
    - *electric-driven motors account for a large portion of the energy load used by the process (e.g. reactor agitators, pumps, hot oil system blower)*
    - *several heat exchangers are required for process heating & cooling, and use electrically driven fans / blowers, or chillers as the cooling source*
  - Information to help quantify the energy input, including motor horsepower, actual metered cubic feet of natural gas, electric process sub-metering, etc. would be valuable to this analysis

Step 6:

- **IDENTIFY ENERGY WASTES**
  - Energy is wasted to some degree in every step of the manufacturing process
  - Major wastes should be identified when analyzing the process block diagram
  - Identifying process waste streams is the first step to minimize them, recover valuable energy from them, and reduce their environmental impact.
  - Our process includes several waste streams:
    - » *wastewater from the scrubber, which requires additional energy input for downstream processing in a wastewater treatment plant*
    - » *wastewater from the reactor/equipment boil-outs, which requires additional energy input for downstream processing in a wastewater treatment plant*
    - » *Recovered Stripper material, which requires additional energy input to process into saleable product*

Step 7:

- **IDENTIFY ENERGY RECOVERY POSSIBILITIES**
  - The energy waste streams should be examined for their potential for energy recovery
  - Observations of the waste streams for our process might include:
    - » *Lost steam condensate from water from Stripper's condensate tank*
    - » *Lost steam condensate from malfunctioning steam-traps*
    - » *Hot oil boiler fluegas could be used to preheat the product entering the Stripper*
    - » *Lost energy from un-insulated or under-insulated piping*
    - » *Lost energy from inefficient pump or agitator motors*
    - » *Lost energy from air leaks throughout the system*

Step 8:

- **PINPOINT ENERGY EFFICIENCY OPPORTUNITIES**
  - Each block in the process block diagram should be evaluated for energy-efficiency opportunities
  - Depending on the energy input for the process operation, a variety of options may be available to reduce energy consumption, for example:
    - » ***Motors***
    - *Motors consume a significant amount of process energy*
    - *The biggest cost over the life of a motor, by far, is the electricity to turn it - typically accounting for 96% of a motor's total lifecycle costs*
    - *Maximizing the overall efficiency of the plant's motor population can be accomplished by implementing a motor management program, specifying National Electrical Manufacturers Association (NEMA) Premium efficient motors wherever possible, and implementing a motor repair and replacement policy*

Step 8 continued:

- **PINPOINT ENERGY EFFICIENCY OPPORTUNITIES, cont'd**
  - **Variable-frequency drives(VFDs)**
    - » *Where variable loads and good feedback parameters exist, VFDs help save energy*
    - » *Conduct a detailed analysis of VFD/motor combinations and implement where operationally and economically feasible*
    - » *Candidates for VFDs in our process in include blowers, chiller cooling tower fans, chilled water pumps, and air compressors*
  - **Compressed air**
    - » *Compressed air is a very expensive and inefficient energy source*
    - » *In our process, compressed air is used primarily for controls, valve operation, air-driven mixer motors, and air-driven diaphragm pumps The process contains numerous air solenoid valves, air piping and tubing, air valves, and air-actuated devices - all of which can develop costly leaks*

Step 8 continued:

- **PINPOINT ENERGY EFFICIENCY OPPORTUNITIES, cont'd**
  - **Energy-efficiency recommendations regarding compressed air might include:**
    - » *Establish and maintain a compressed air leak survey and repair program, which is inexpensive and has immediate payback*
    - » *Where feasible, replace air-driven mixers and diaphragm pumps with electric-driven mixers and pumps*
    - » *Use zero-loss condensate drains on the compressed air system throughout the plant*
    - » *Use energy-efficient air dryers for instrument air*

Step 8 continued:

- **PINPOINT ENERGY EFFICIENCY OPPORTUNITIES, cont'd**
  - **Chilled water supply**
    - » *Several steps in our process require cooling / chilled water*
    - » *Ensure that cooling towers are clean and properly maintained, and that chilled water equipment and piping are properly insulated*
  - **Energy-efficiency opportunities for chilled water supply include:**
    - » *reset the condenser water temperature as weather and load varies*
    - » *clean heat exchangers used for process cooling loads*
    - » *regularly clean the condenser and evaporator tubing on the chiller*
    - » *operate at the highest chilled water temperature that will still maintain process parameters (to help avoid overcooling)*
    - » *install a side-stream precipitator on the cooling tower to capture and remove suspended solids which can cause tube fouling*
    - » *Adjust tower blow-down to improve water quality an minimize fouling*

Step 8 continued:

- **PINPOINT ENERGY EFFICIENCY OPPORTUNITIES, cont'd**
  - **Boilers, steam, and combustion**
  - *The reactor in our process is heated by a Fulton hot oil system using Therminol 55 heat-transfer fluid*
  - *Steam for the deodorization step in our process is produced by our hot-oil system via a separate, hot-oil heated "steam pack"*
  - *The building is heated in the winter via a low-pressure, hot water boiler which heats thru-the-wall mounted heaters*

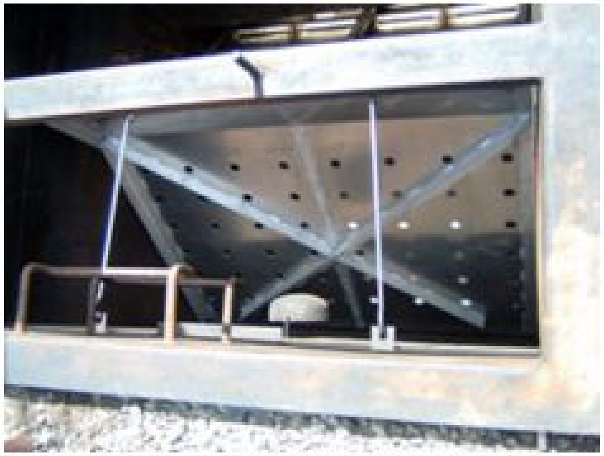
Step 8 continued:

- **PINPOINT ENERGY EFFICIENCY OPPORTUNITIES, cont'd**
  - **Opportunities for energy-efficiency improvements on these systems may include:**
  - Ensure combustion equipment and steam piping are properly insulated
    - *Assuming a cost for natural gas of $6 per dekatherm (1 Dth = 1 million Btu), exposed un-insulated steam piping can cost $200 per foot per year in lost heat*
  - Monitor the oxygen content of the flue-gas to ensure the most efficient combustion and reduce NO_x and SO_x releases, which will also reduce the amount of natural gas consumed, thereby lowering the amount of carbon released
  - Conduct a proper steam trap survey using a thermographic camera or ultrasonic leak detector, and perform maintenance to save energy on steam systems

Step 9:

- **IDENTIFY NEW TECHNOLOGY OPPORTUNITIES**
  - Implementing new or existing process technologies can provide energy savings in addition to those identified in Step 8. The goal is to reduce energy intensity, and a different technology may even lower the energy required to transform one logical unit of product, for example:
    - » *In our process, the wastewater could be processed more efficiently since it contains measureable and collectible amounts of product from boil-outs and washings*
    - » *The system was modified by installing chevron-style separator in the "separator tank", to promote organic / aqueous media separation, and enables the recovery of enough organic material to actually create a new revenue stream, (as well as reduce the organic loading on the waste-water system)*

Step 9:



Mercer's Custom Inlet Distribution Baffle System

Retrofitting an Existing CPI unit--Photo 1

Retrofitting an Existing CPI unit--Photo 2

http://www.oil-water-separators.com/oil-water-separators/Retrofitted-oil-water-separators/existing

Step 9 continued:

- ***Two examples of taking advantage of a new technology opportunity for energy improvements, related to product coatings:***
  - ***Example 1****. A water-based product coating is dried in a natural gas convection oven. A possible new technology opportunity would be to switch to a coating cured by ultraviolet (UV) light. Making the change from natural gas convection to UV curing has many potential advantages, including instant curing, high coating quality, fast line speed, low exhaust emissions, lower energy intensity, shorter oven residence time, and smaller floor space requirements.*
  - ***Example 2****. A volatile organic compound (VOC)-based product coating is cured in a natural gas convection oven. A possible new technology opportunity would be to switch to a powder-based coating system cured with infrared (IR) heating. A powder coating and IR curing system could be advantageous because it offers efficient heat transfer, rapid heat-up, low emissions, fast line speeds, lower energy intensity, shorter oven residence time, and smaller floor space requirements.*

Step 10:

- **IMPLEMENT SOLUTIONS**
  - After you perform the process energy analysis and develop the process block diagram, the next and most important step is to implement some of the energy-saving solutions you have identified. Savings will not be realized until the results are actually applied.
  - Your analysis should produce a detailed set of opportunities for energy improvements. Compile the results in a table or spreadsheet so they can be evaluated, prioritized, budgeted, and tracked for implementation. Then, repeat the approach periodically for continuous improvement

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In Summary

- Pursuing energy improvements often produces benefits in other areas as well. These non-energy benefits may include greater plant productivity, higher product quality, fewer process bottlenecks, better worker safety, more available floor space, and lower emissions and waste stream volumes.
- When exploring new technologies, a combination may produce the best energy-saving results and, depending on the process, there may be numerous technology opportunities available. Any idea should be subjected to rigorous energy and financial analyses to prove its feasibility prior to implementation.


The End

"There is no expedient to which a man will not resort to avoid the real labor of thinking."

Sir Joshua Reynolds

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