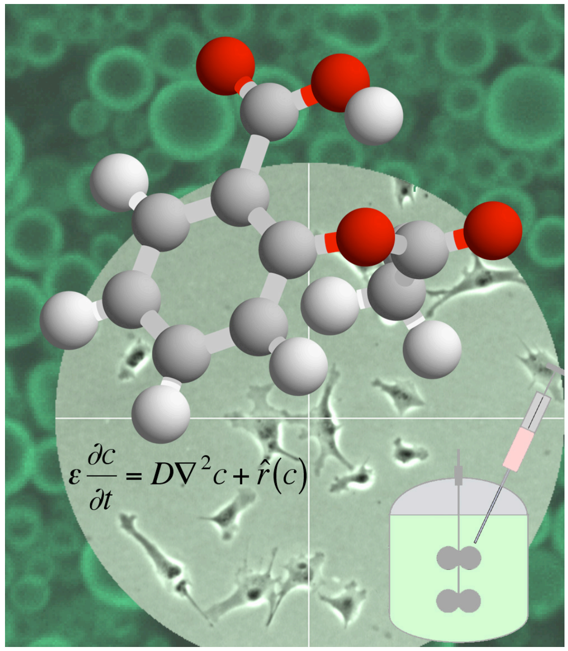


What do chemical engineers need to know?

ChE History

- Chemical Engineering has its roots in industrial chemistry.
- 1901: George E. Davis publishes the first textbook on chemical engineering. It concentrated on design of plant items for specific operations.

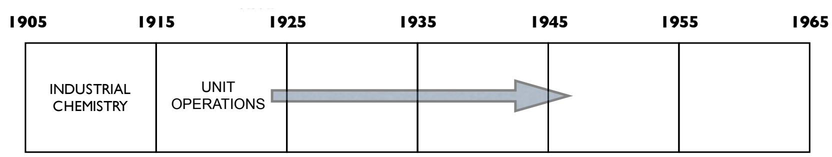
1905 1915 1925 1935 1945 1955 1965

INDUSTRIAL CHEMISTRY					

- Courses taught in 1900's: industrial chemistry, metallography, applied electrochemistry, steam and gas analysis, chemical manufacture.

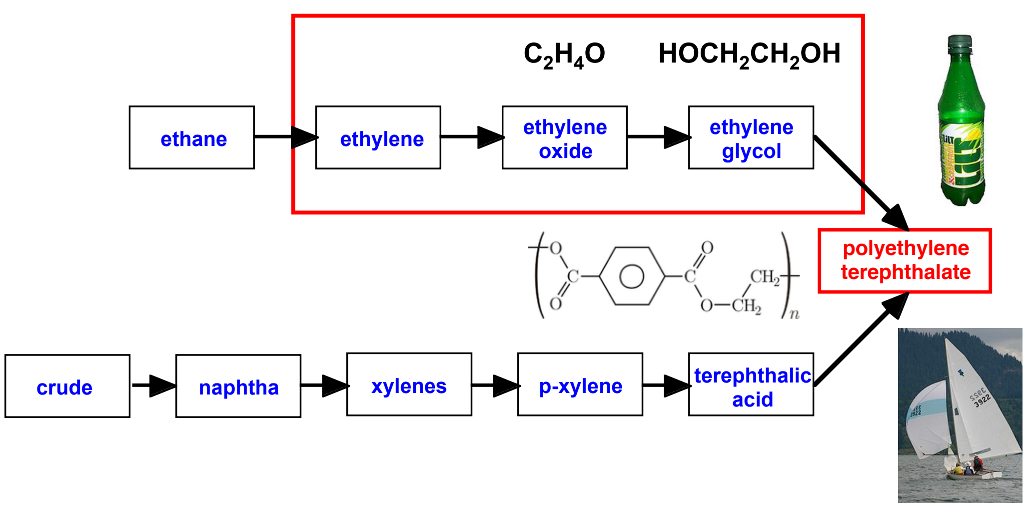
ChE History

- 1910: Arthur D. Little (chemical engineer from MIT) introduces the concept of unit operations
- Every chemical plant consists of a number of "*building blocks*," the unit operations.

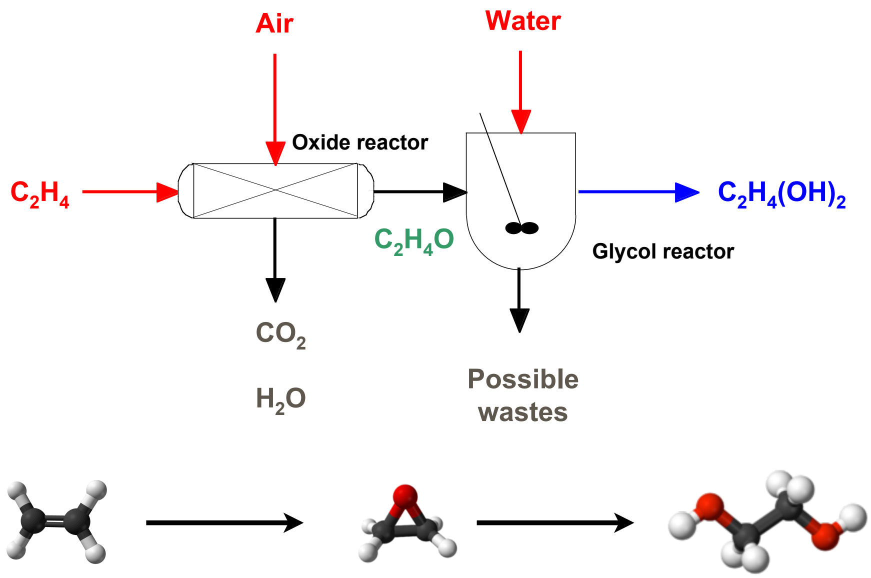


- The number of different "*building blocks*" in every plant is not very large.

Polyester Synthesis

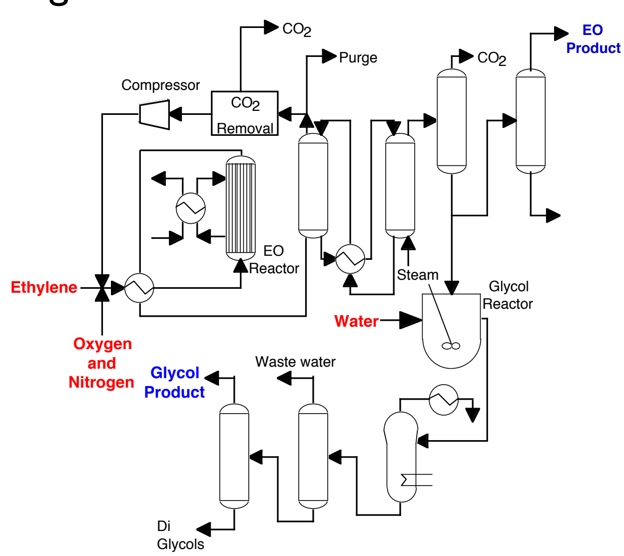


Conceptual Glycol Process



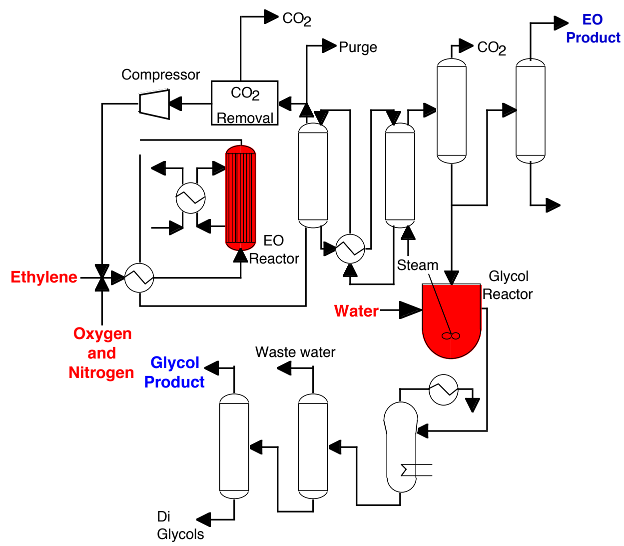
EO and Ethylene Glycol Plant

- Plant has many units that can be classified into a few categories.



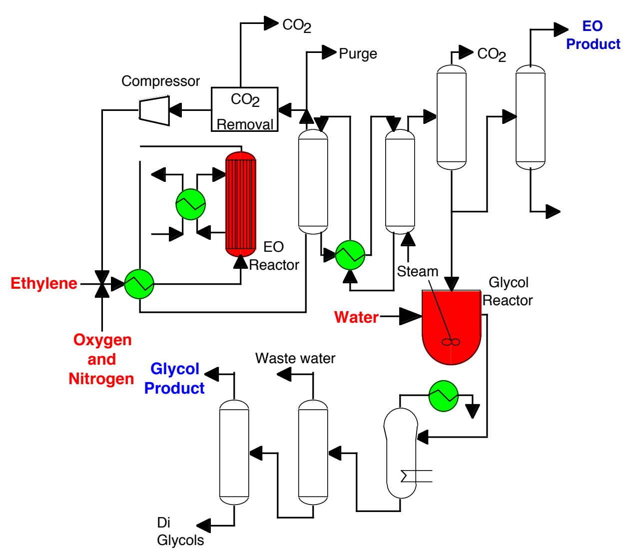
EO and Ethylene Glycol Plant

- Reactors...



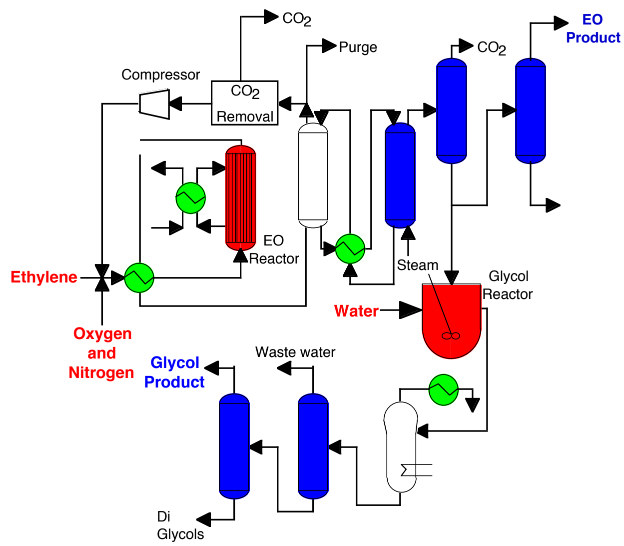
EO and Ethylene Glycol Plant

- Reactors... Heat Exchangers...



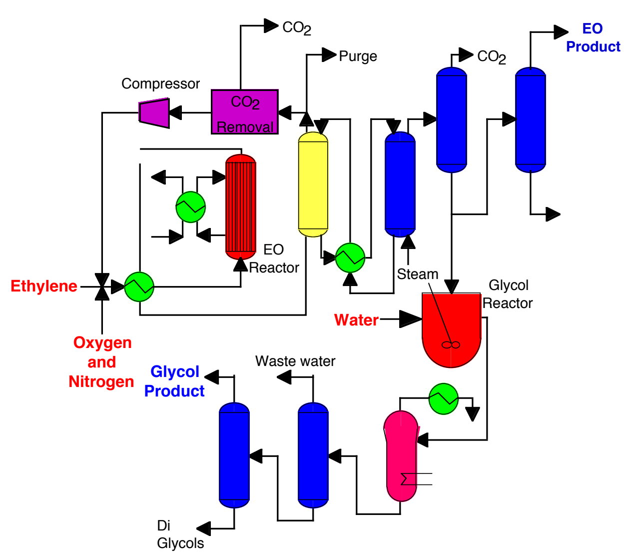
EO and Ethylene Glycol Plant

- Reactors... Heat Exchangers... Separation Columns...



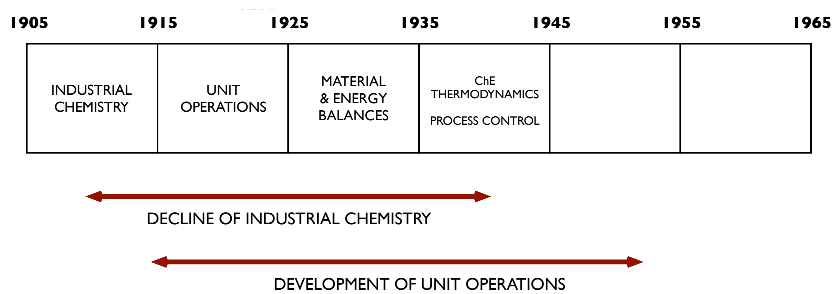
EO and Ethylene Glycol Plant

- Reactors... Heat Exchangers... Separation Columns... and Other Units...



Unit Operations

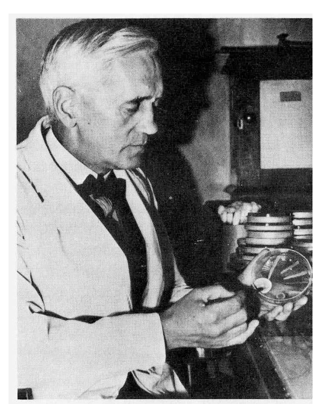
- This classification dominated the discipline for the following 40 years.



- Successes: Petrochemical Industry.. Polymers...

Penicillin

- 1928: Alexander Fleming observes for the first time the antibacterial action of the mold *Penicillium notatum* in a Petri dish, such as the one he holds here.
- 1939: Florey (Oxford University) produces enough penicillin to test it on mice. But, he cannot produce enough for human clinical trials.

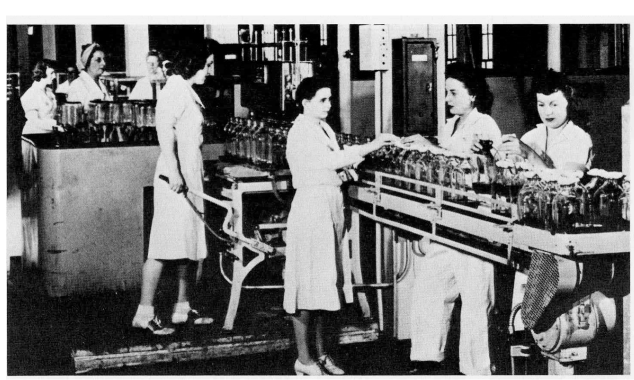


Penicillin

- 1941: Florey tours to the U.S. trying to persuade pharmaceutical companies and government officials to back the production of penicillin.
- 1941: A few days after the Japanese attack on Pearl Harbor, Merck commits to large-scale production of penicillin.
- 1942: Merck, Squibb & Sons and Charles Pfizer & Co. pool their R & D efforts to produce penicillin. By 1943, seventeen other companies had joined.

Penicillin

- Scaling up of penicillin production became a top-priority program of complexity and size rivaling that of the Manhattan Project.



Technical Problems

Pfizer's John L. Smith captured the complexity and uncertainty facing these companies during the scale-up process:

- "The mold is as temperamental as an opera singer, the yields are low, the isolation is difficult, the extraction is murder, the purification invites disaster, and the assay is unsatisfactory."

Technical Problems

- Manufacture of penicillin is similar to the brewing of beer.
- *Penicillium notatum* will ferment when provided with appropriate nutrients under proper conditions.
- Penicillin mold is aerobic and very sensitive to process conditions.

Scale Up of Penicillin Production

- **First breakthrough**: Growing the mold directly in the nutrient solution - submerged fermentation. Sterilized air was bubbled through the reactor to support the fermentation. This permitted the scale-up of production from flasks to "deep tanks."
- **Second breakthrough**: Introducing corn steep liquor (a byproduct of corn starch production) as a culture medium. This increased penicillin yields by an order of magnitude.

More Problems

- When corn steep liquor was used as the nutrient, the air bubbled through the reactor caused sever foaming.
- Solution: Antifoaming compounds were developed (glyceryl monoricinolate).
- Cooling systems were incorporated in the walls of the reactors, and special turbines were introduced to mix the penicillin mash.

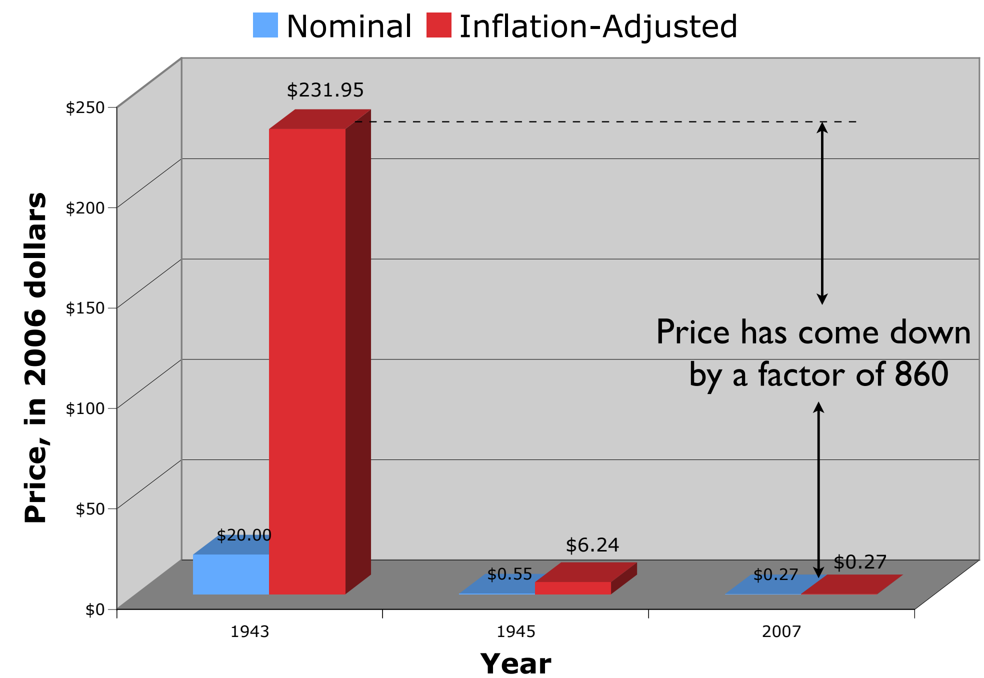
Scale Up of Penicillin Production

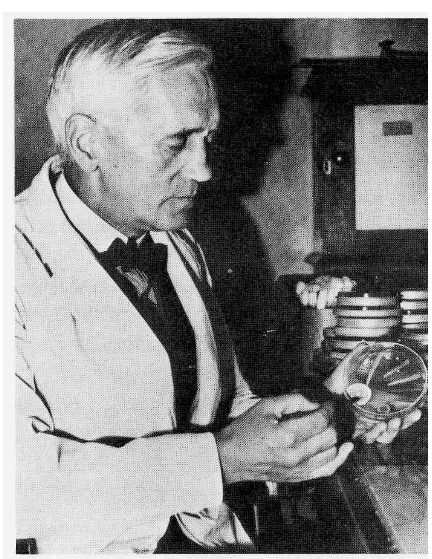
- Once the fermentation was complete, recovery was also difficult; as much as two-thirds of the penicillin present could be lost during purification because of its instability and heat sensitivity. Extraction was done at low temperatures: Pfizer, responding creatively to wartime shortages, adapted an old ice cream freezer!
- New separation techniques were introduced to extract the penicillin from the moldy brew.
- Finally, a new freeze-drying technique was scaled up to convert the penicillin into a stable and useful form.

Scale Up of Penicillin Production

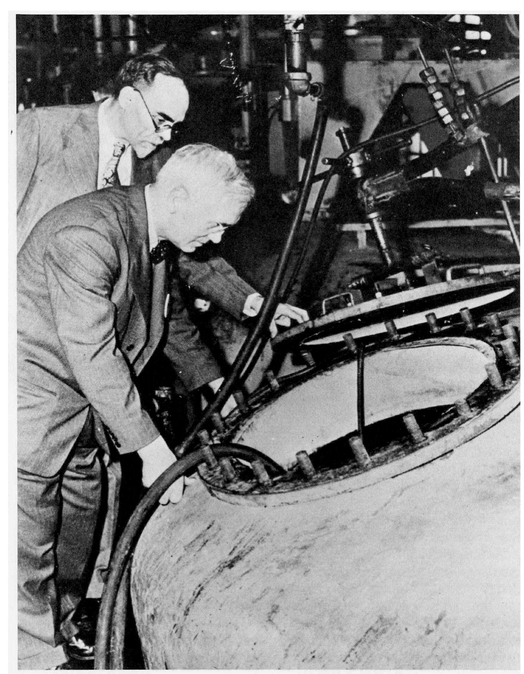
- The project was completed in a very short time (1943 - 45).
- On March 1, 1944, Pfizer opened the first commercial plant for large-scale production of penicillin by submerged culture in Brooklyn, New York.
- 1943: A dose of penicillin cost $20.
- 1946: A dose of penicillin cost 55 cents.
- Today: A 500 mg pill of penicillin costs ~25 cents.
- Submerged fermentation process is still the dominant production technique for penicillin.

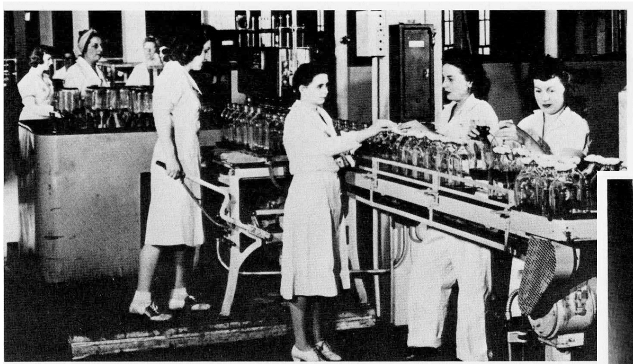
The price of penicillin

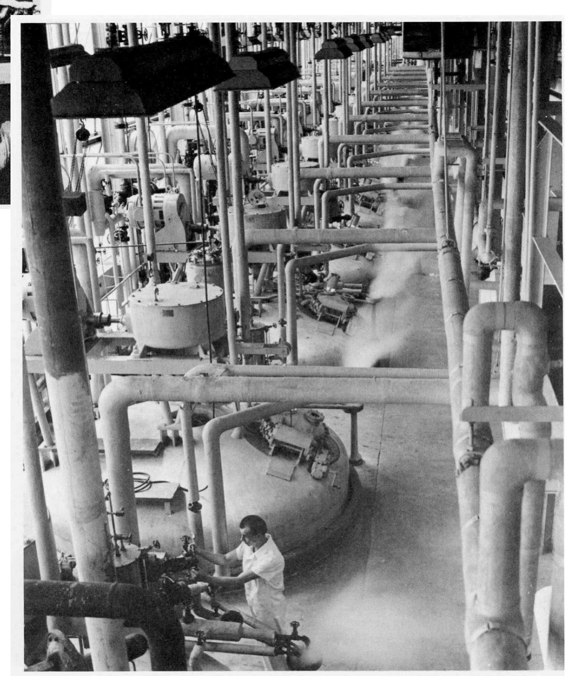




Sir Alexander Fleming holding a petri dish with *Penicillium notatum* culture (Top) and inspecting a 15,000 gallon “deep tank” used in penicillin production at a Squibb plant in New Brunswick, NJ, June 1945 (Right).







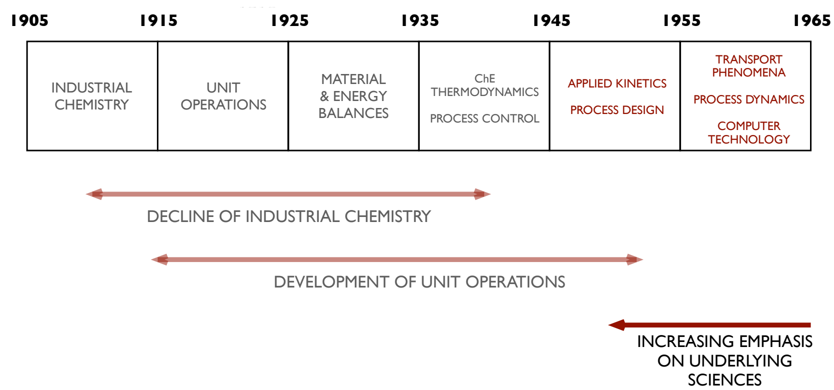
Top: Assembly line used in 1944 to prepare half-gallon milk bottles for penicillin production. Workers sterilized the bottles, added nutrients, sealed the bottle with cotton pledgets, laid the bottles on their sides in racks and inoculated them with penicillin spores.

Right: A battery of "deep tanks" used in penicillin production.

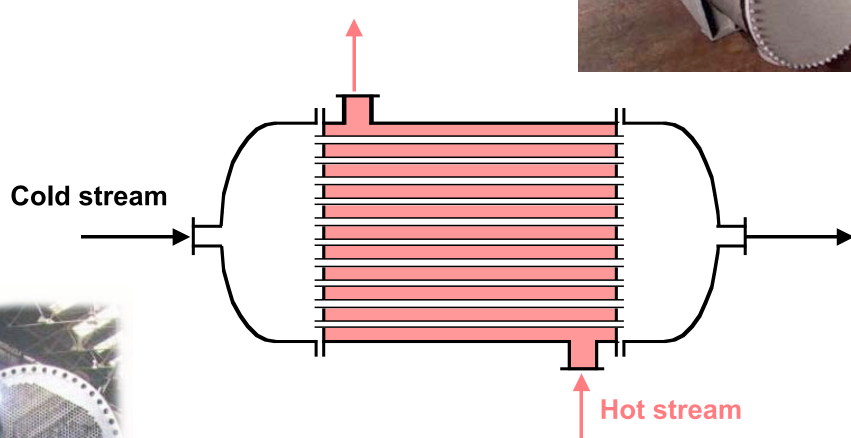
Change...

- Unit operations approach suffered from a restricted outlook based on existing practice.
- From empirical discipline to engineering science...

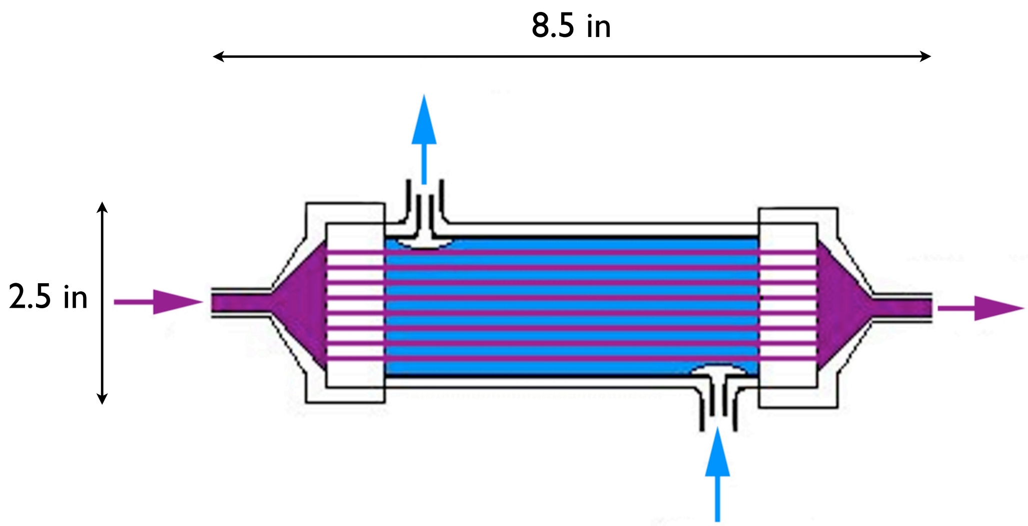
Engineering Science



Tube and Shell Heat Exchanger

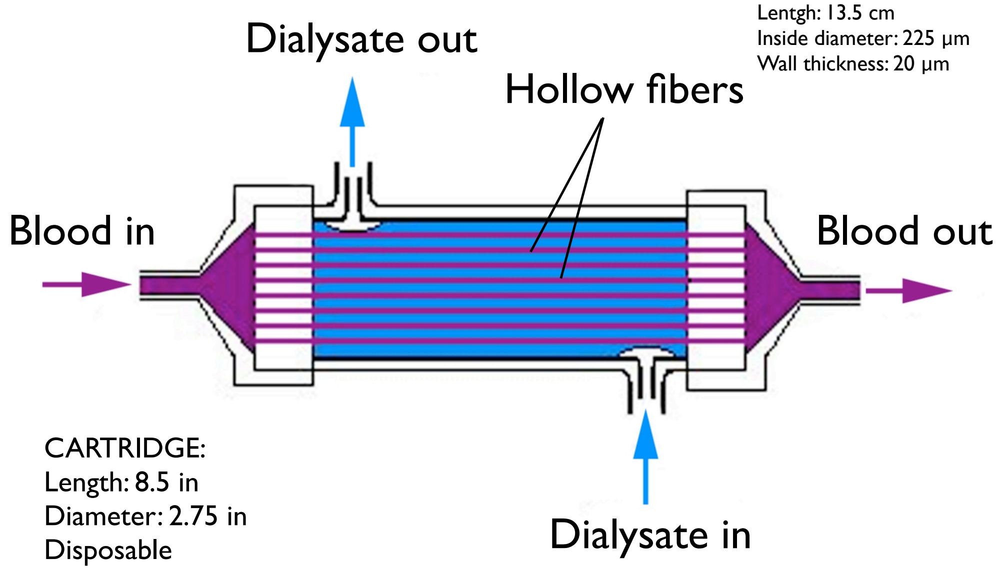


Another Unit?



Artificial Kidney

11,000 fibers
Material: Cellulose
Lentgh: 13.5 cm
Inside diameter: 225 µm
Wall thickness: 20 µm

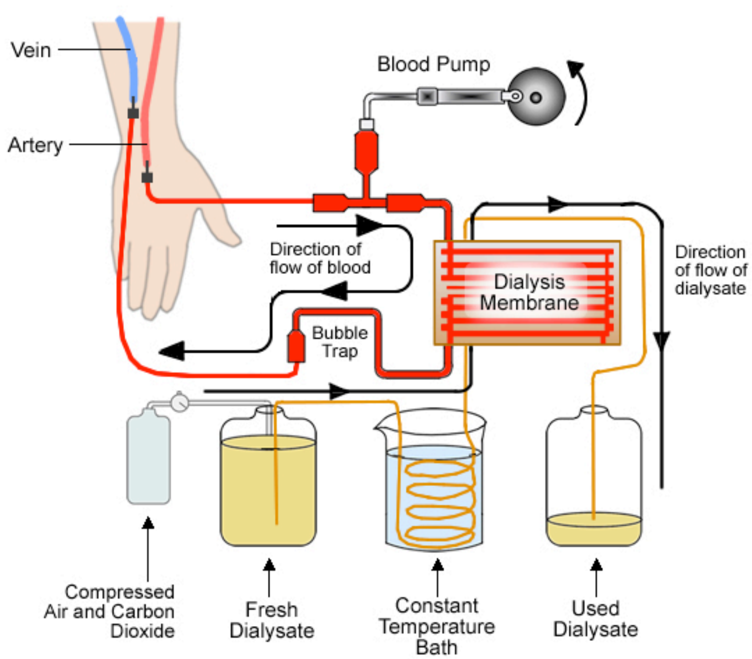


CARTRIDGE:
Length: 8.5 in
Diameter: 2.75 in
Disposable

Engineering Science

- Operation of processing units can be analyzed using mathematical equations derived from first principles:
  - mass balances
  - energy balances, and
  - momentum balances
- Same approach can be followed for many applications outside the traditional chemical industry.

Artificial Kidney - Hemodialysis



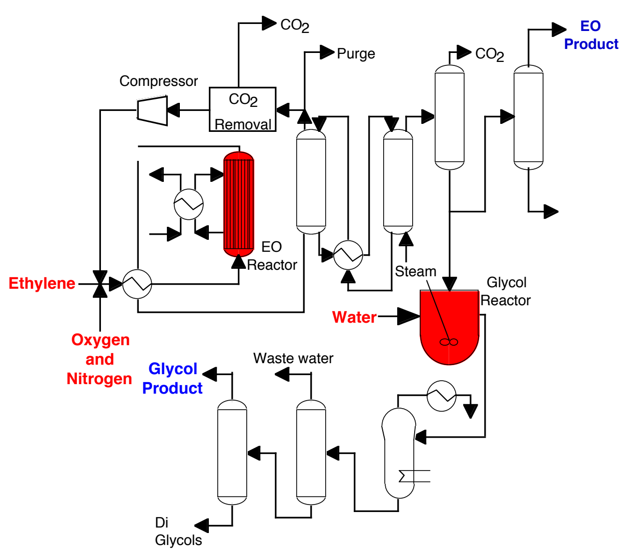
Artificial Kidney

Metabolite Concentrations in the Blood

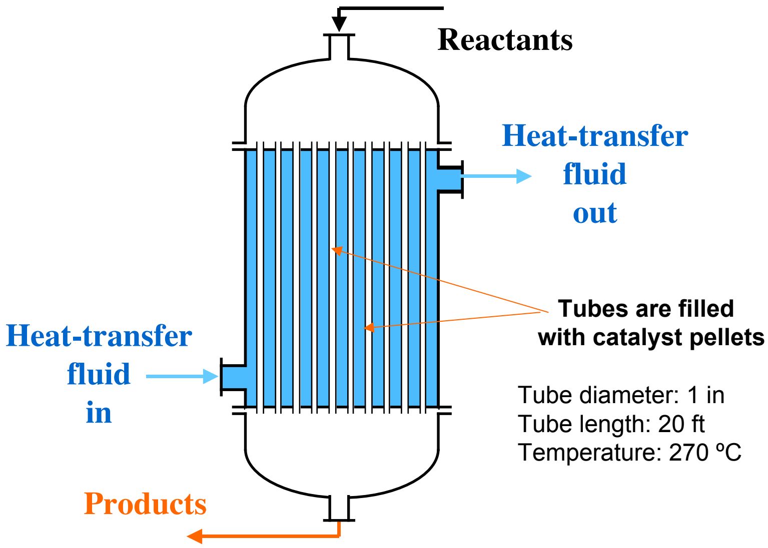
(mg/cm^3)

	Pre-Dialysis	Post-Dialysis	Normal
Urea	90	30	15
Uric Acid	10	4	1.5
Creatinine	15	7	3

Ethylene Oxide Reactor

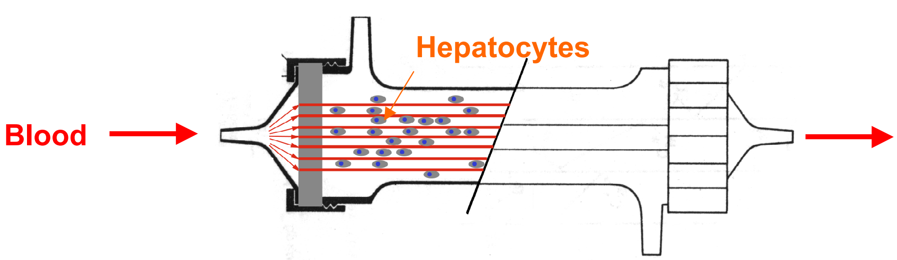


Multitubular reactor



A variation...

- Extracorporeal Liver Assist Device (ELAD)



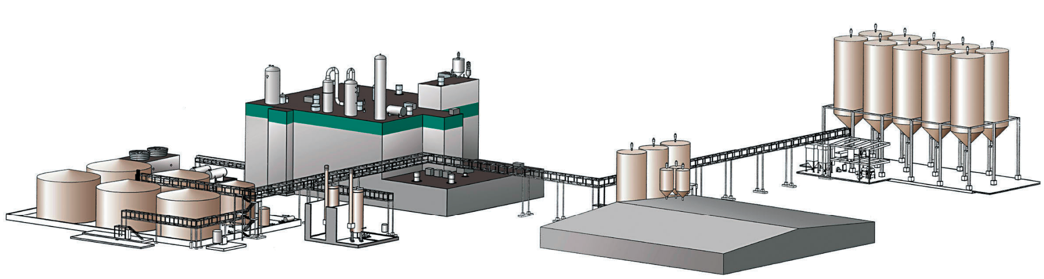
- Used either as a bridge-type therapy to support patients until a liver-donor can be found, or
- As a way to help the native liver regenerate.

The future?

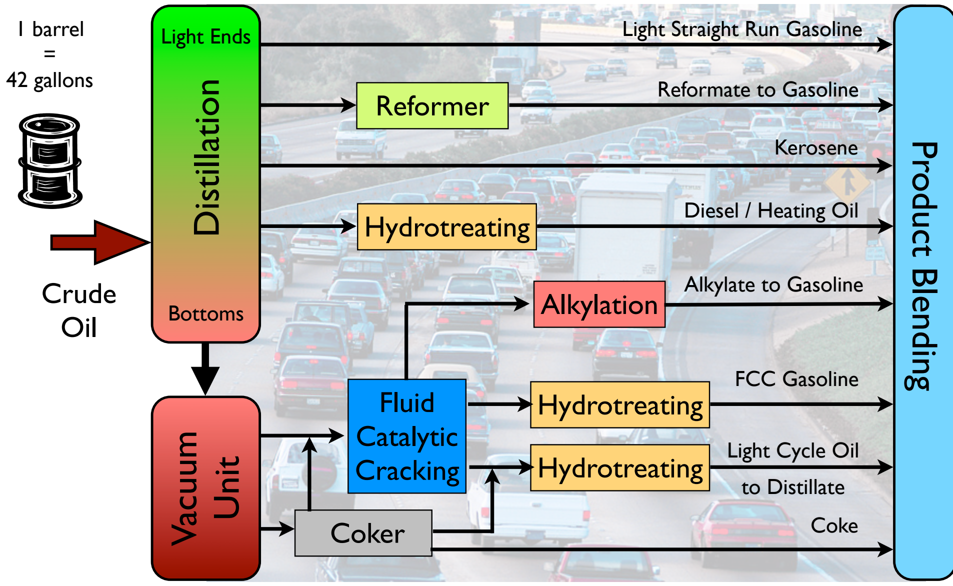
- 2005-2015: Increased emphasis in biology, integration (systems approach) and energy.
- New areas:
  - Biological systems
  - Nanotechnology
  - Sustainability (energy systems)

Characteristics: Systems and multi-scale analysis

The Changing Industrial Landscape

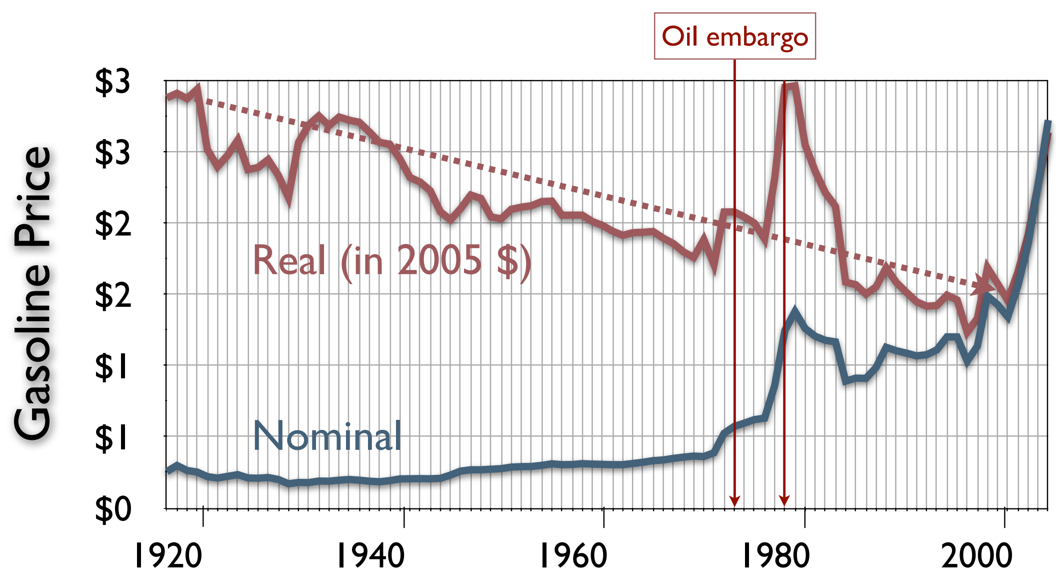


From Oil Refineries to...



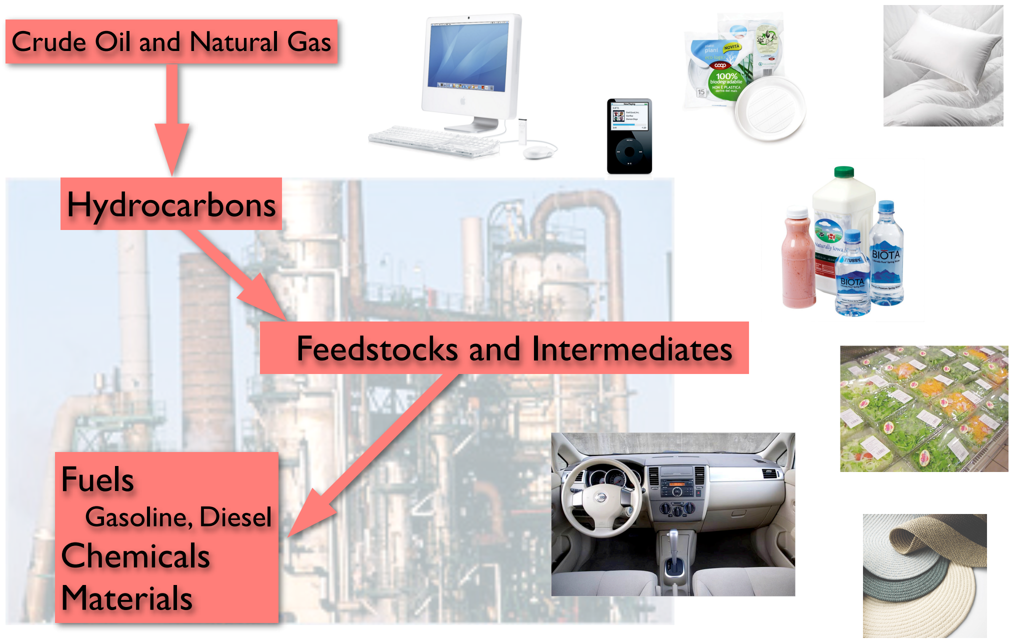
	Gallons
Gasoline	19.6
Diesel Fuel	7.8
Heating Oil	2.7
Jet Fuel	4.1
Heavy Fuel	1.7
LPG	1.5
Other	7.4
TOTAL	44.8

Price of Gasoline

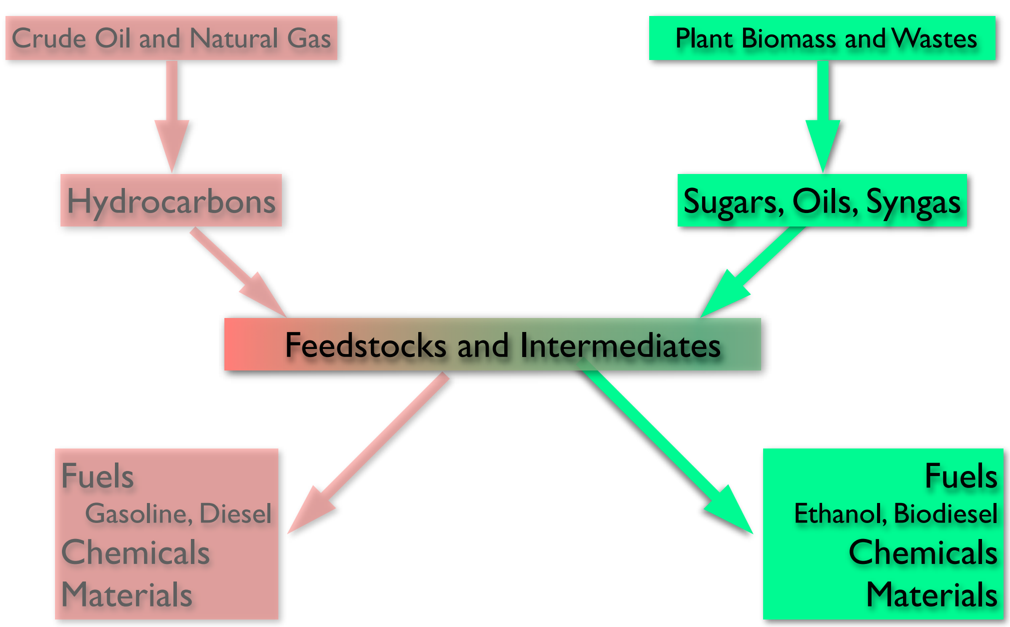


Source: Energy Information Administration (EIA), 2006

Oil Provides More Than Fuels!

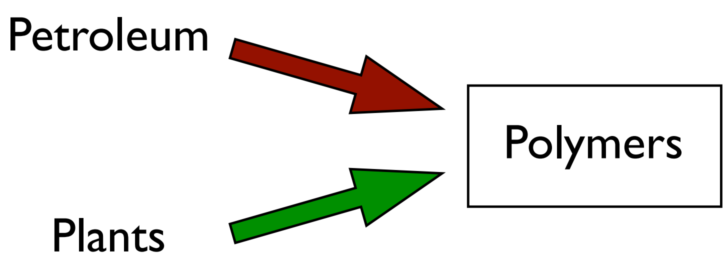


...to Biorefineries



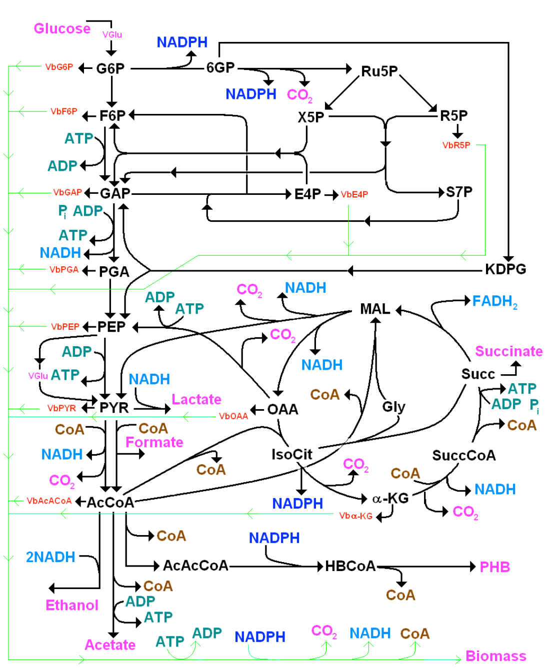
Biocatalysts

- How can we produce commodity chemicals from renewable raw materials with "greener" processes?



More environmentally-friendly processes;
products and intermediates are non-toxic
and do not persist in environment; lower T and P; aqueous.

Bacteria as Chemical Plants



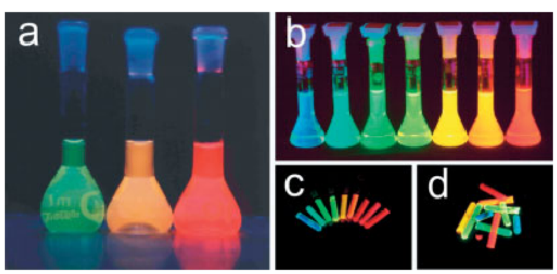
Metabolic pathways for *E. coli*

Biocatalysis

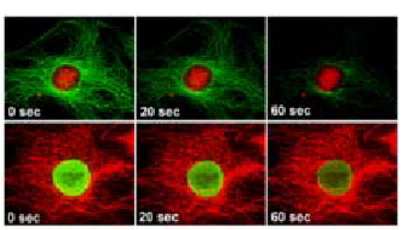
Pros and Cons Compared to Chemical Synthesis

Advantages	Disadvantages
- Unique and varied chemistry - Mild reaction conditions (P, T, aqueous) - Highly stereo-,regio-, and chemoselectivity - Environmentally friendly	- Poor operational stability - Unwanted reactions with impure preparations - Low volumetric productivity - High cost

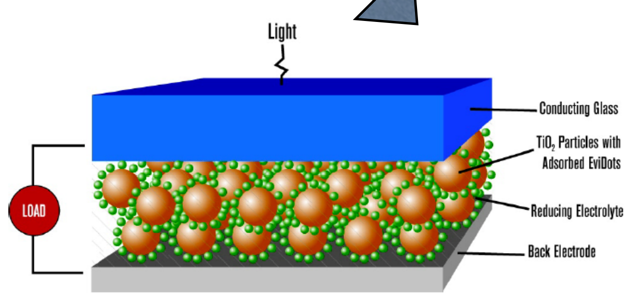
Nanocrystals



CdTe and CdSe/ZnS nanocrystals



Biological labels



Solar cells