



WHY WAS VINYL CHLORIDE ON A TRAIN IN EAST PALESTINE, OHIO?

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WHAT I HOPE TO LEAVE YOU WITH

- Inorganic chemistry created the chemical industry and remains important, but not particularly valued
- Scale remains the major source of competitive advantage in commodity chemicals
- Sustainability is multifaceted and complex with hidden interactions.

EAST PALESTINE, OHIO



TRAIN DERAILMENT FACTS

- Norfolk Southern Railway train 32N derailed in East Palestine, Ohio on February 3, 2023
- a faulty wheel bearing caused the derailment
- fire ignited during the derailment and grew to involve 35 railcars
- derailed equipment included 11 tank cars carrying hazardous materials
 - 3 hazardous materials tank cars sustained mechanical and released flammable or combustible materials
 - 5 vinyl chloride (VCM) tank cars were not mechanically breached during the derailment
- VCM cars were explosively breached to initiate a vent and burn
- news outlets described the cargo as toxic, flammable and carcinogenic
- it was widely mentioned the burning created toxic materials

So why was VCM on the train?

Raymond, MN 30 March 2023



23 ethanol cars

BNSF Railway freight train L-TWI8801-291

TRAIN COMPARISON

- Vinyl chloride
 - flammable
 - toxic
 - carcinogenic
 - makes toxic materials when burned
 - HCl
 - CO₂
 - trace other stuff
 - fully-synthetic, unnatural
 - coproducts during production
- Ethanol
 - flammable
 - toxic
 - carcinogenic
 - makes toxic materials when burned
 - CO₂
 - trace other stuff
 - natural

VIEWS ON VINYL



“ PVC is single most environmentally damaging type of plastic.

PVC is one of the most toxic substances saturating our planet and its inhabitants. PVC contaminates humans and the environment throughout its lifecycle: during its production, use, and disposal.

Greenpeace

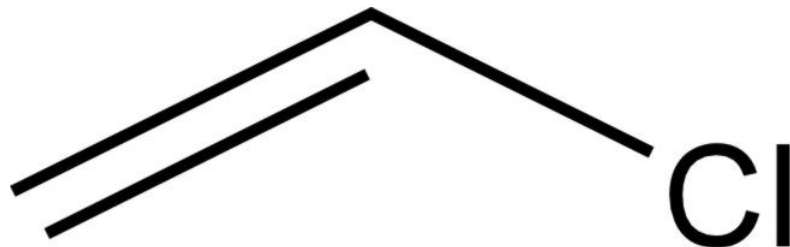
”

<https://www.greenpeace.org/usa/toxics/pvc-free/>

CARCINOGENIC



- carcinogens are substances that may increase your risk of cancer.
 - Cleveland Clinic
- a carcinogen is a substance, organism or agent capable of causing cancer.
 - National Human Genome Institute
- a substance, organism, or agent capable of causing cancer
 - International Agency for Research on Cancer
- substances, mixtures, or exposure circumstances that are known or reasonably anticipated to cause cancer in humans
 - National Toxicology Program (NTP)
- any substance that causes cancer.
 - National Cancer Institute



Vinyl Chloride Monomer(VCM)

Olin produced ~5 billion pounds/year

World demand is 49 billion pounds

Growth averages 4-5%

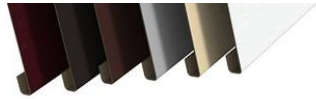
Source: Chemical Week product focus

USED TO MAKE POLYVINYL CHLORIDE (PVC)



- third largest polymer (by weight)
- infrastructure polymer
 - piping
 - siding
 - flooring
- main medical polymer

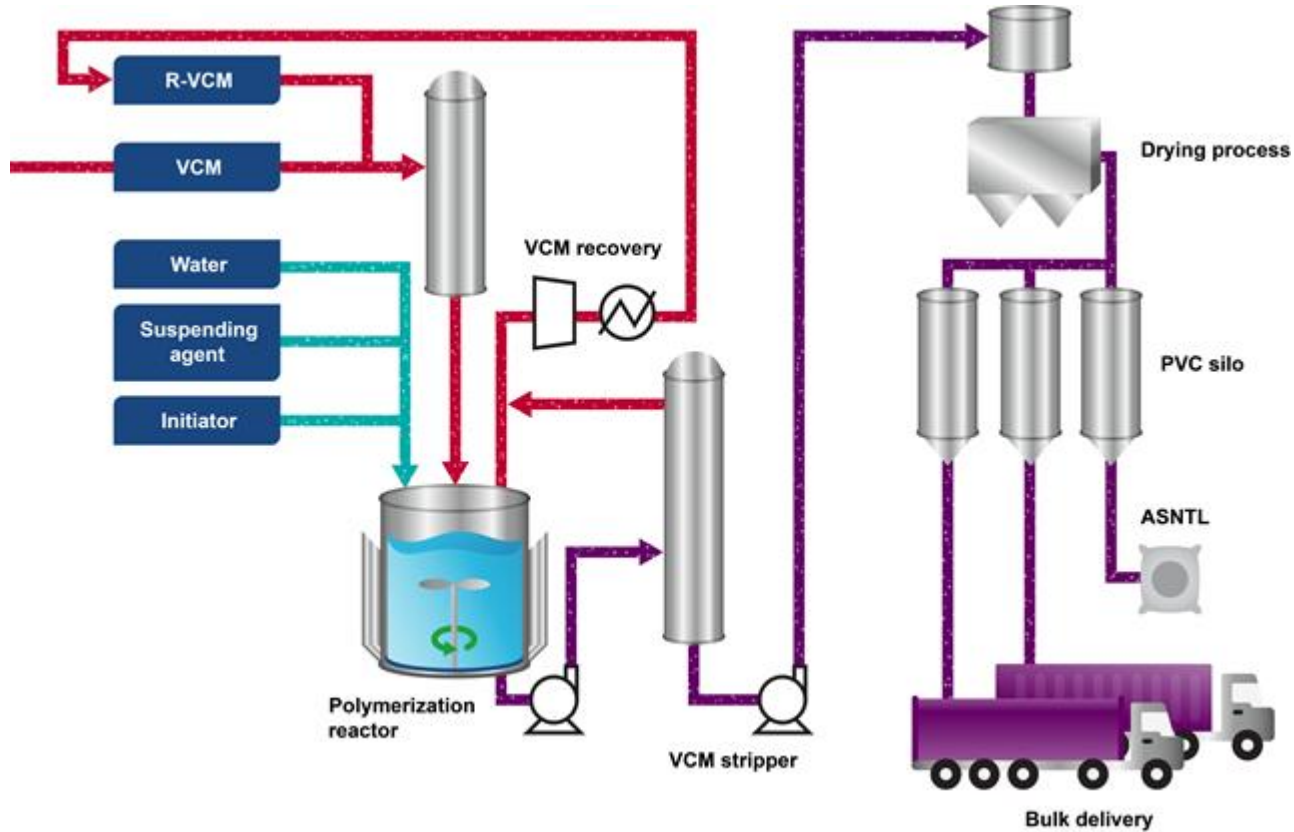
Vinyl chloride was on the train to make polyvinyl chloride.



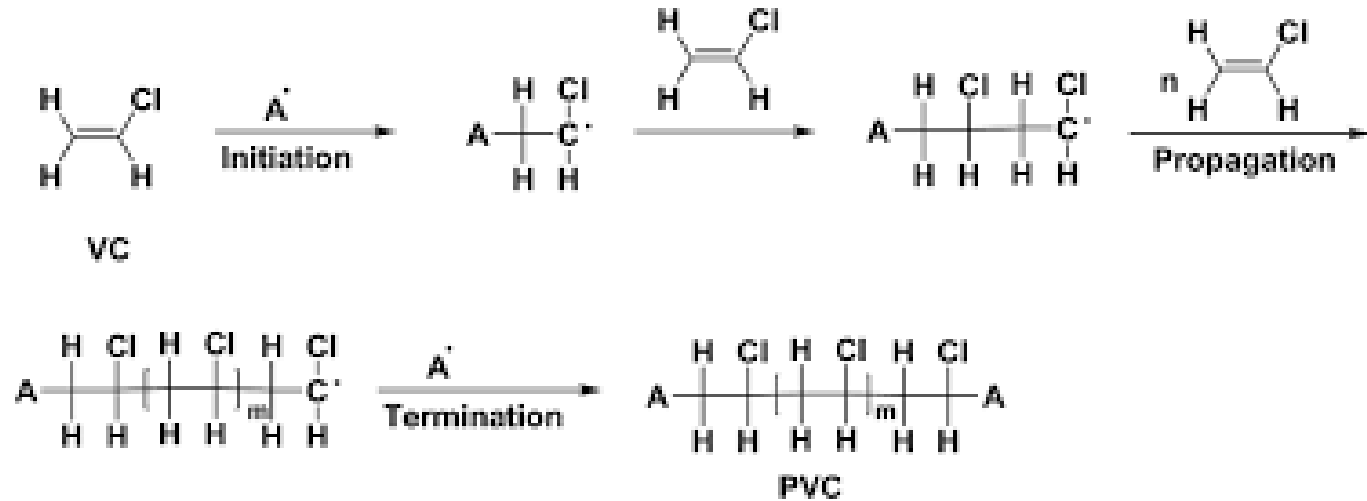
- really bad material properties
 - brittle
 - low melting point
 - poor solvent resistance
- saving graces
 - cheap
 - takes filler well
 - solvent weldable
 - great with plasticizers
 - naturally flame retardant



PVC PRODUCTION: SUSPENSION POLYMERIZATION



FREE RADICAL PROCESS



Going to Pedrickstown, NJ



OxyVinyls Rail Route

from La Porte and Ingleside, TX
to Pedrickstown, NJ



Vinyl chloride was on the train to provide feedstock for a polymer production facility far away from a monomer production facility.



887,400 pounds of VCM loaded at the Oxy Vinyls VCM plant in LaPorte, Texas

NOT THE FIRST TIME



- November 30, 2012 derailment on a moveable bridge in Paulsboro, New Jersey
- 3 VCM tank cars came to rest in Mantua Creek
- one was breached and released about 20,000 gallons of vinyl chloride

CHEMICAL INDUSTRY TECHNOLOGY WAVES

Inorganic

- mined materials
- electrochemical
- active reagents allow transformations

Functionalization

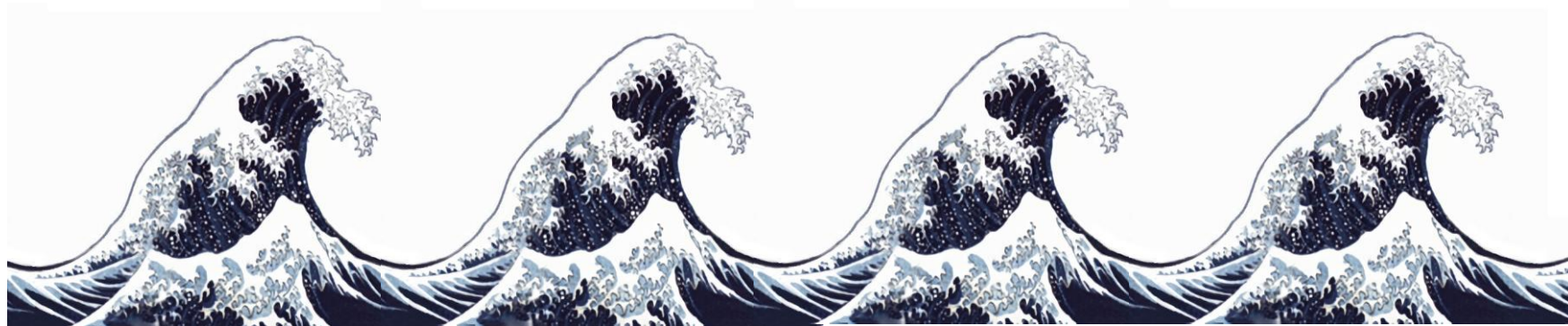
- use inorganics to transform organic substrates
- make dyes, solvents and drugs

Cellulosics

- use inorganics to transform natural materials
- partially synthetic polymers

Polymers

- took off with synthetic rubber
- continues today



1760-1910

rocks



1870-1930

coal
salt



1895-1935

biomass

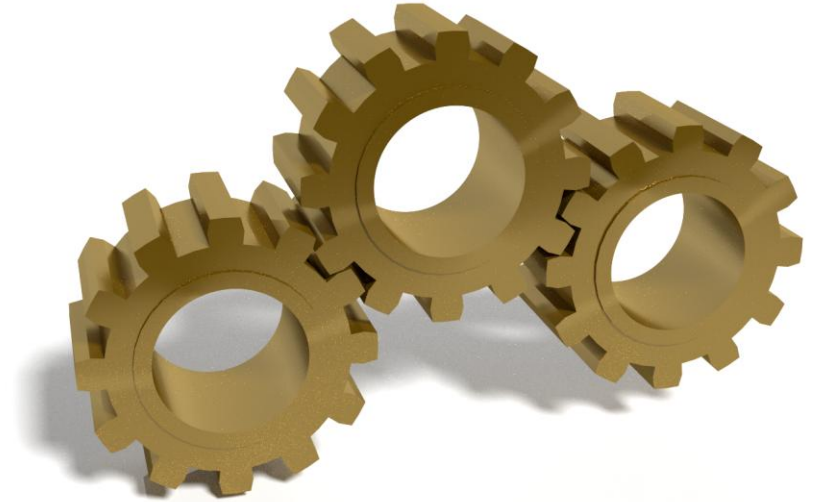


1925-present

petroleum
NGL

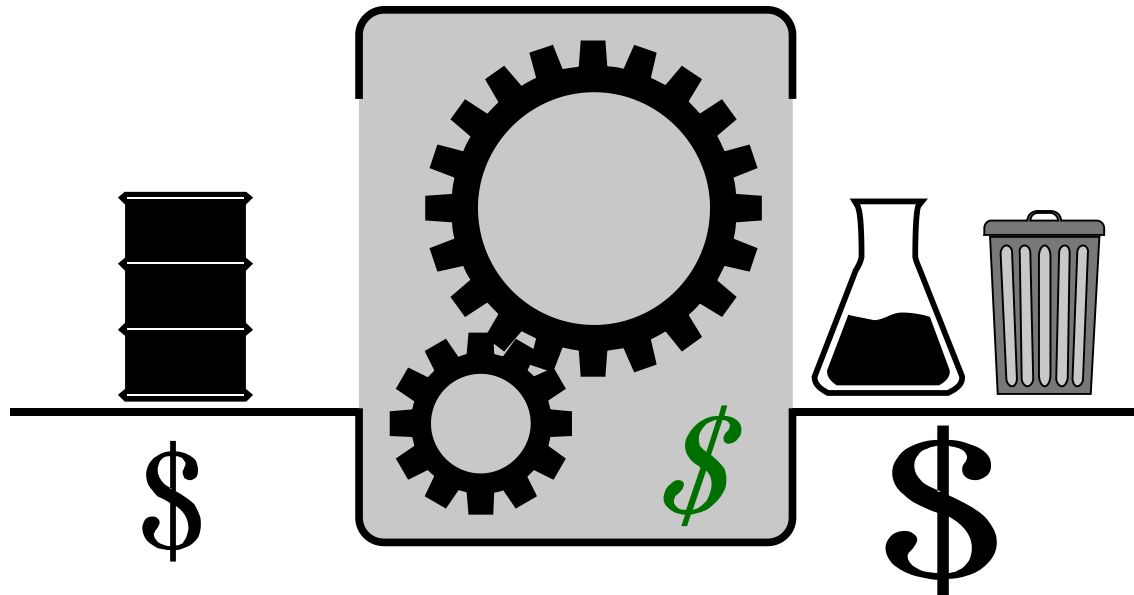
WHAT IS INTEGRATION?





Linkage of mass and energy flows that create a significant advantage.

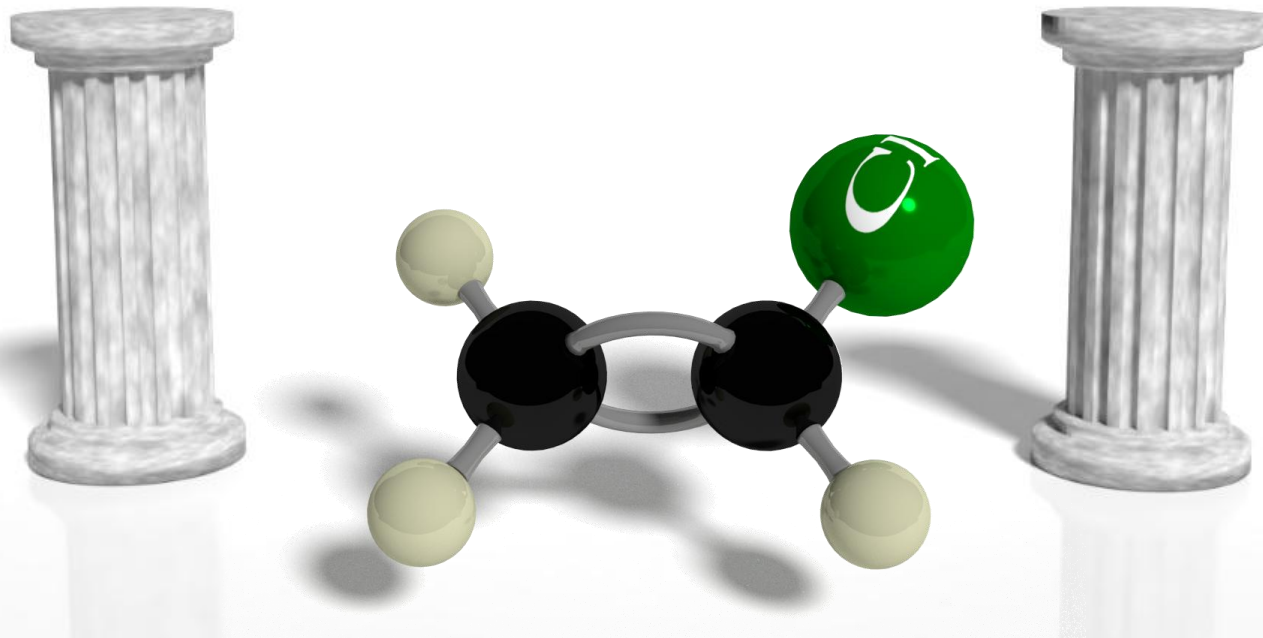
SIMPLIFIED CHEMICAL INDUSTRY



FOUNDATIONAL Pillars OF THE MODERN CHEMICAL INDUSTRY

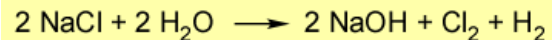
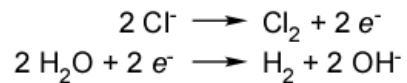
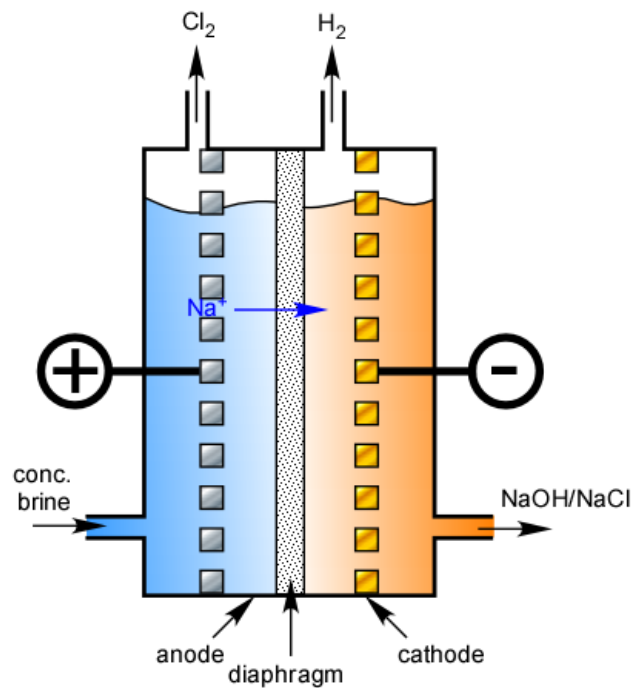
Electrochemical Chlor-Alkali

Steam Cracking





CHLOR-ALKALI

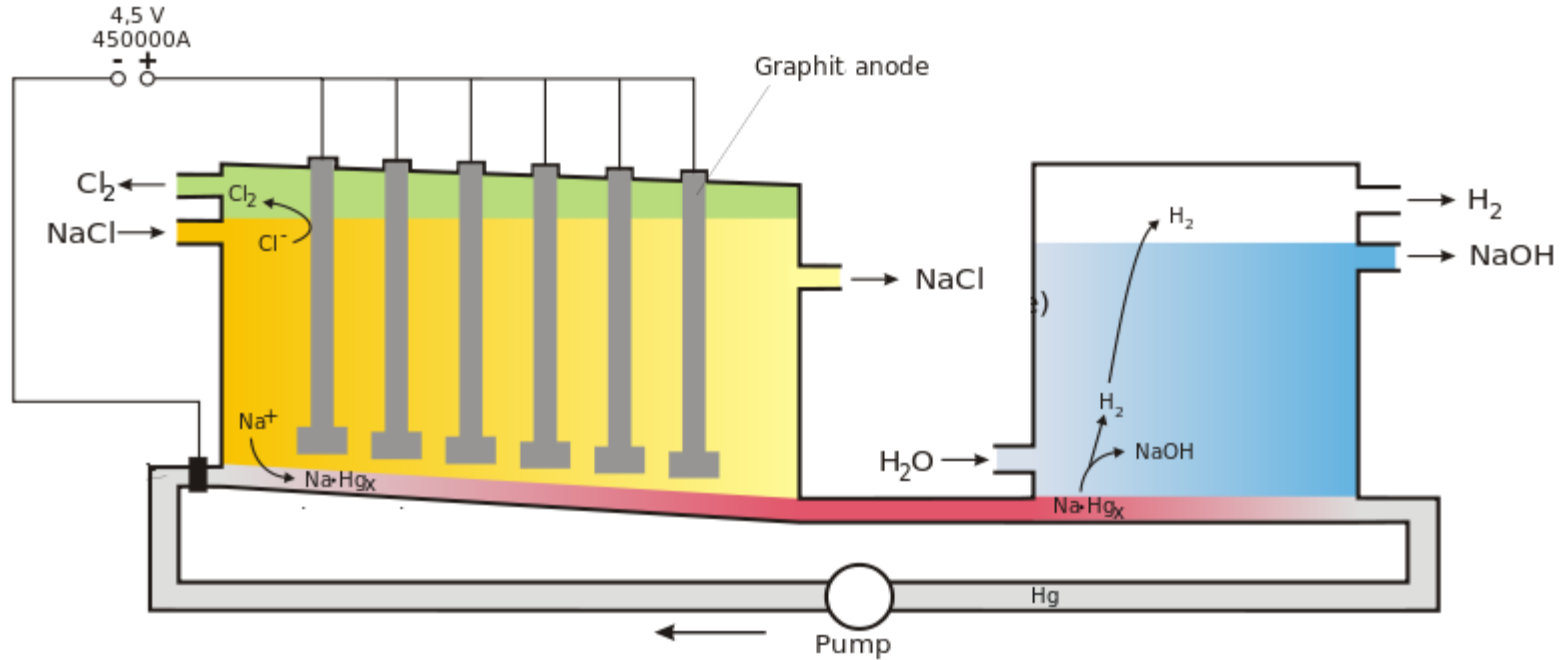


BLEACH WAS THE PRODUCT

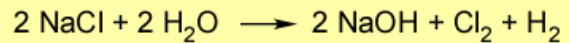
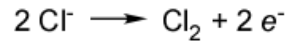
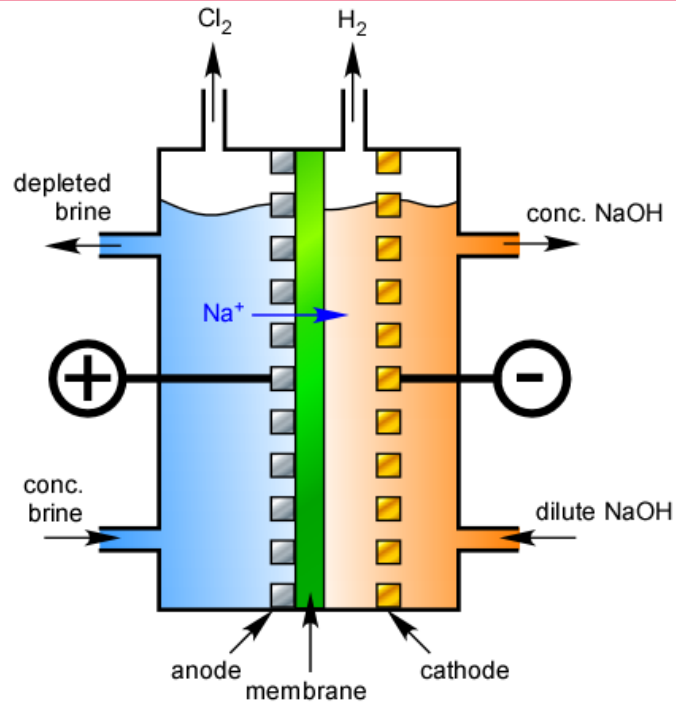


- The oxidizing power of chlorine was what was desired.
- *No net production of alkali*

MERCURY CELLS



MEMBRANE CELLS



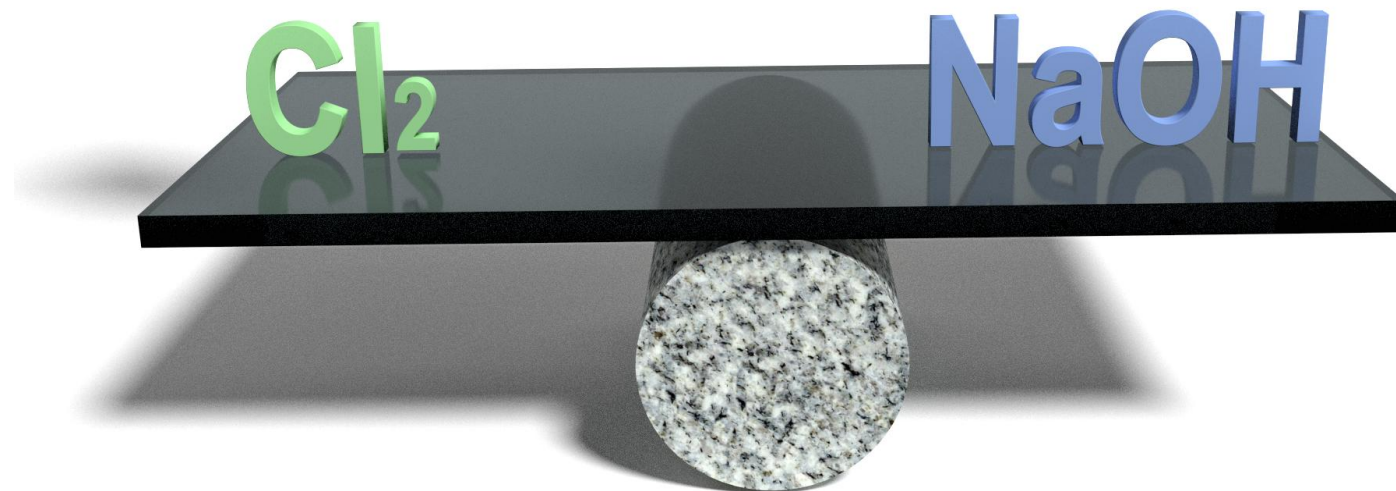
CO-PRODUCT PROCESSES



<https://www.youtube.com/watch?v=YYkj2yYaGtU>



BALANCING THE ECU

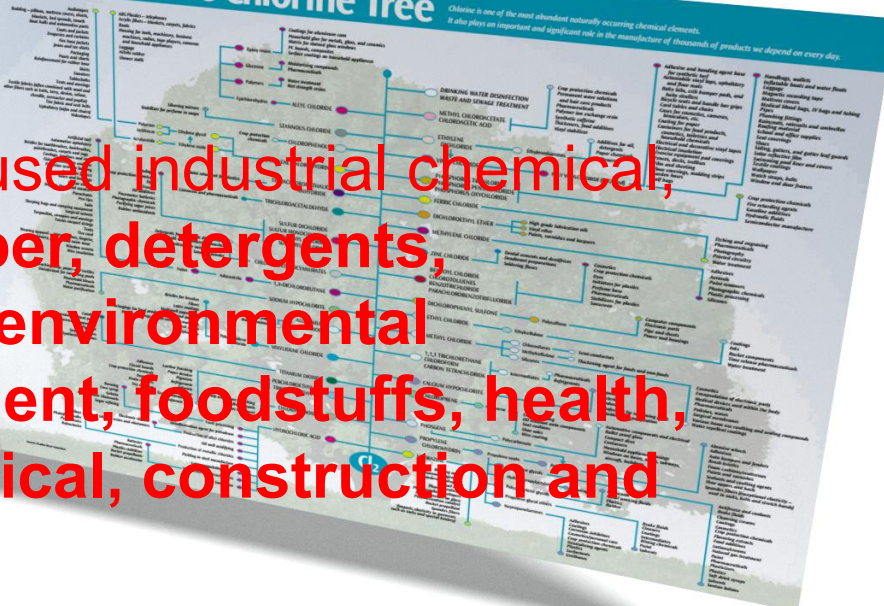


Caustic Soda Chemistry and End Product Uses



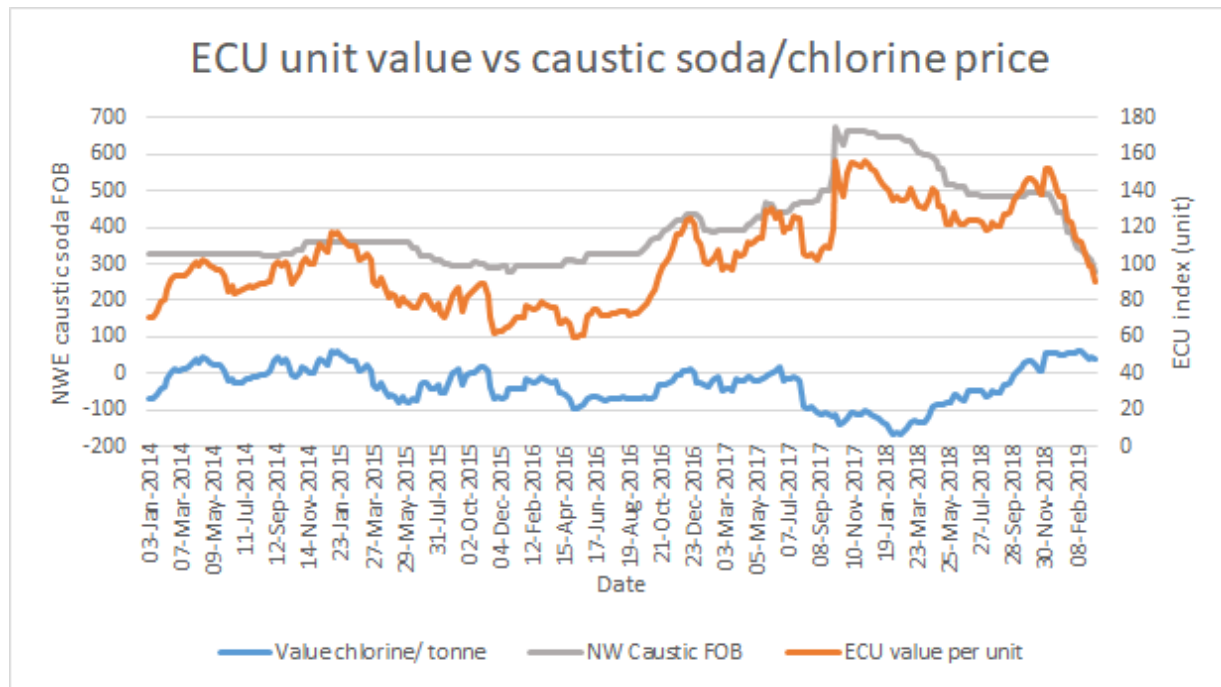
Products of the Chlorine Tree

Chlorine is one of the most abundant naturally occurring chemical elements. It also plays an important and significant role in the manufacture of thousands of products we depend on every day.



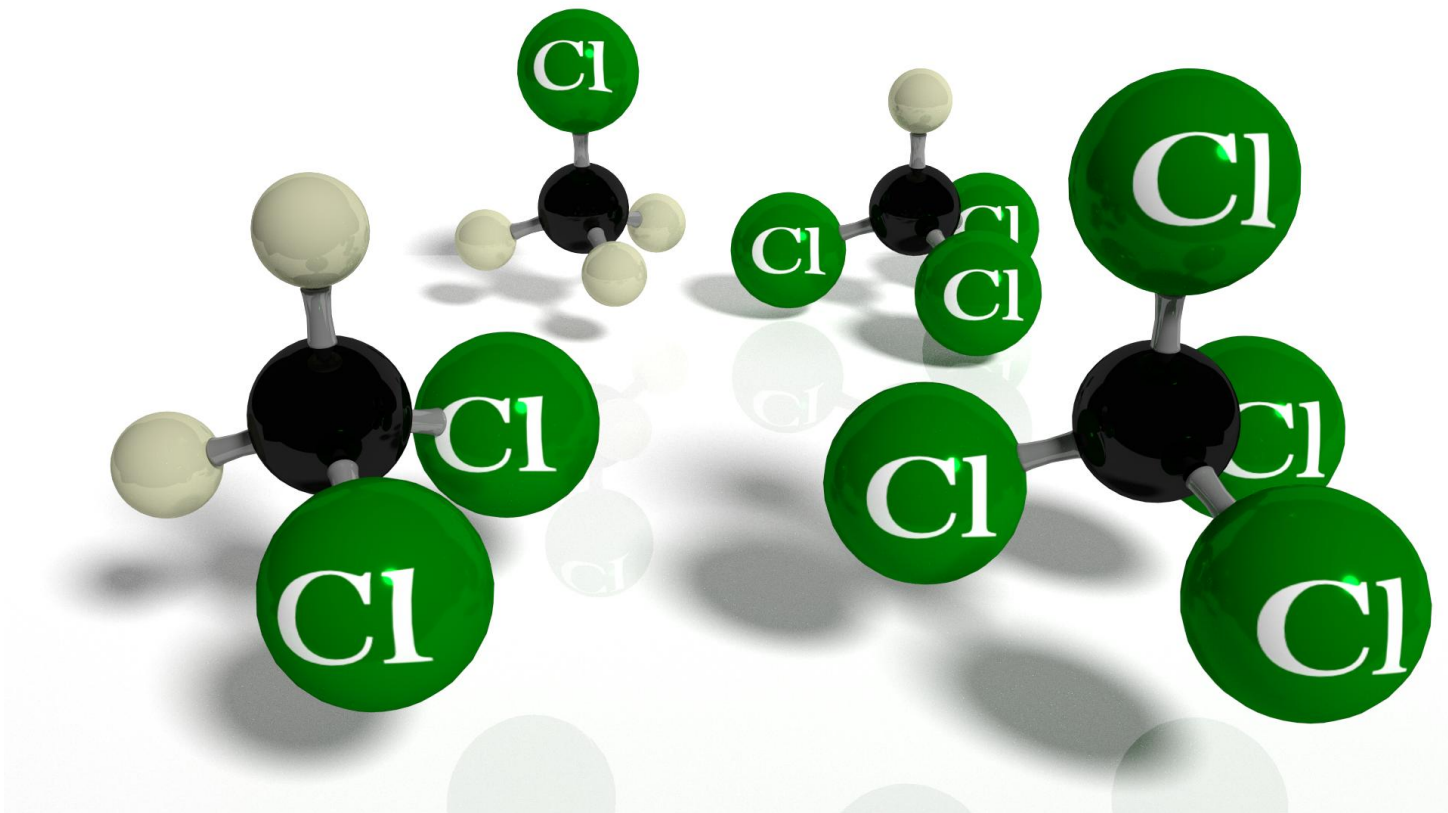
Caustic soda is a widely used industrial chemical, including in pulp and paper, detergents, packaging, agriculture, environmental protection, water treatment, foodstuffs, health, textiles and in the chemical, construction and car industries.

ECU PRICING



[ics.com/explore/resources/news/2019/03/21/10336962/insight-european-ecu-values-fall-to-the-lowest-level-since-2016/](https://www.ics.com/explore/resources/news/2019/03/21/10336962/insight-european-ecu-values-fall-to-the-lowest-level-since-2016/)

ORGANOCHLORIDES





SUPERSOLVENTS

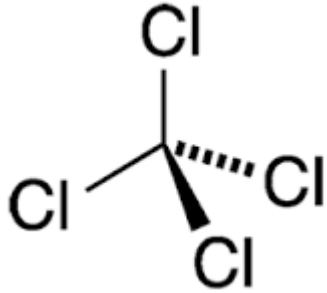
Ban

1970

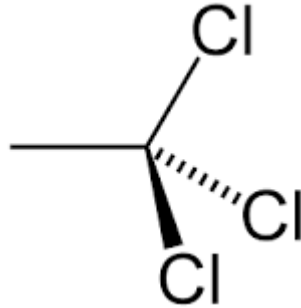
1996

2025

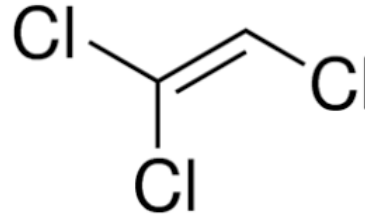
2025



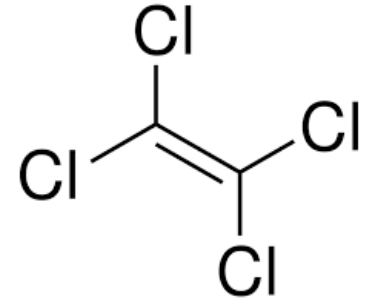
carbon tetrachloride
carbon tet
tet



1,1,1-trichloroethane
1,1,1
TCA

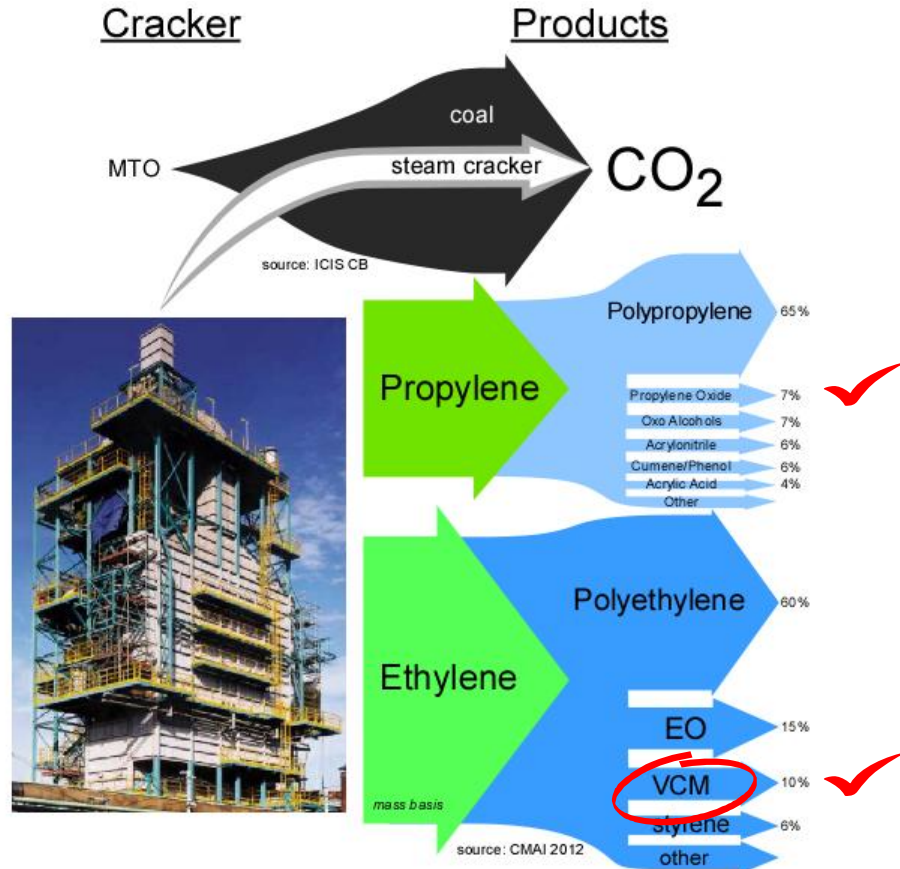
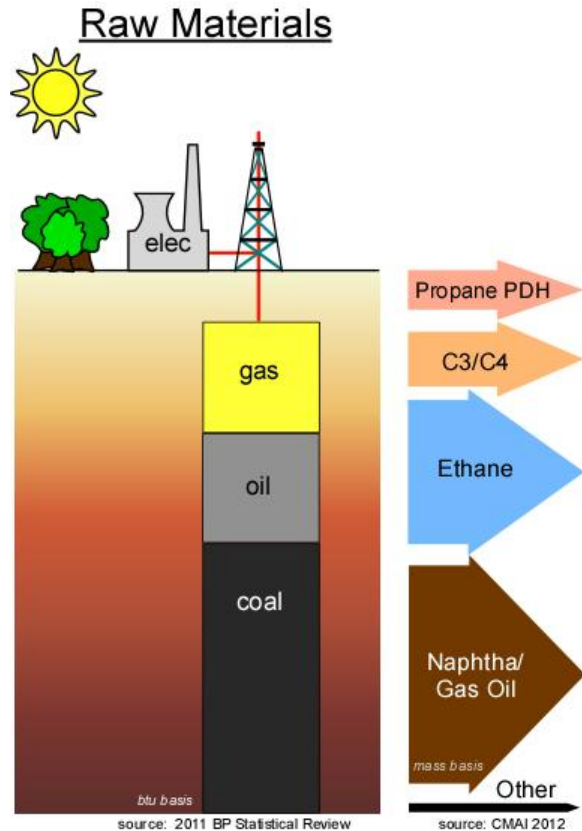


trichloroethylene
tric
TCE



tetrachloroethylene
perchloroethylene
perc
PCE

CHEMICAL INDUSTRY SNAPSHOT

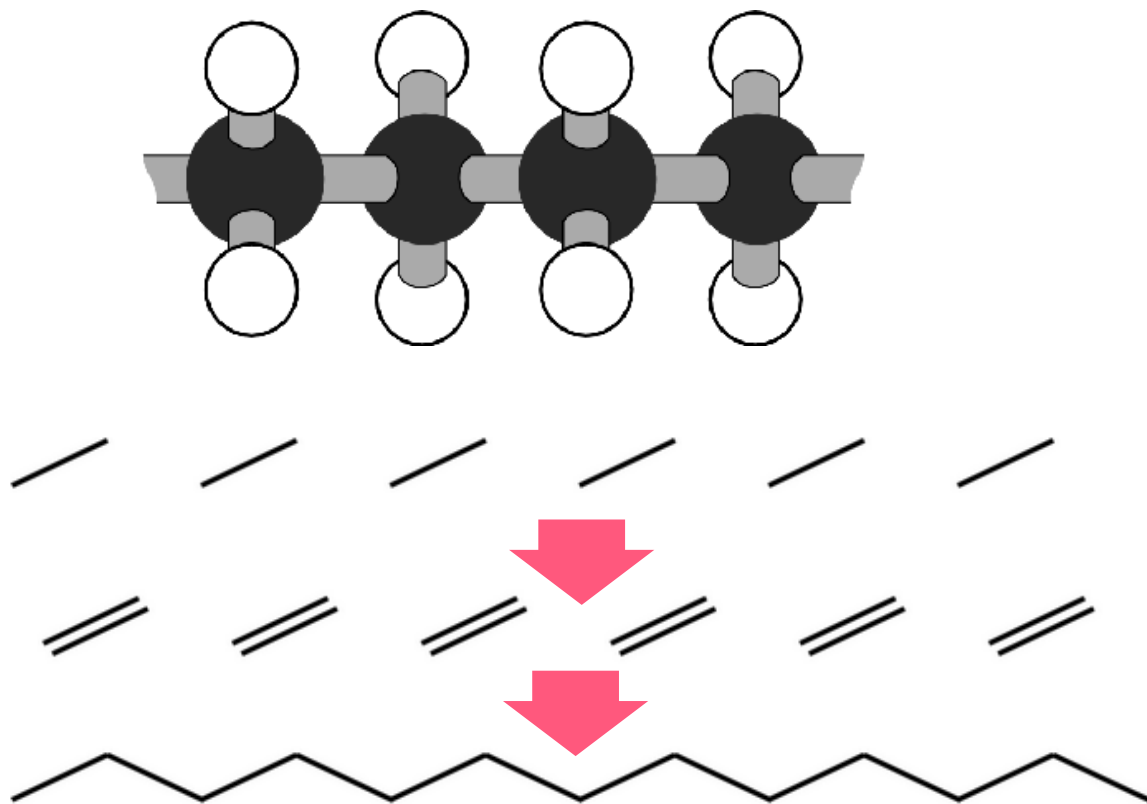


ROUGH INDUSTRY MASS BALANCE



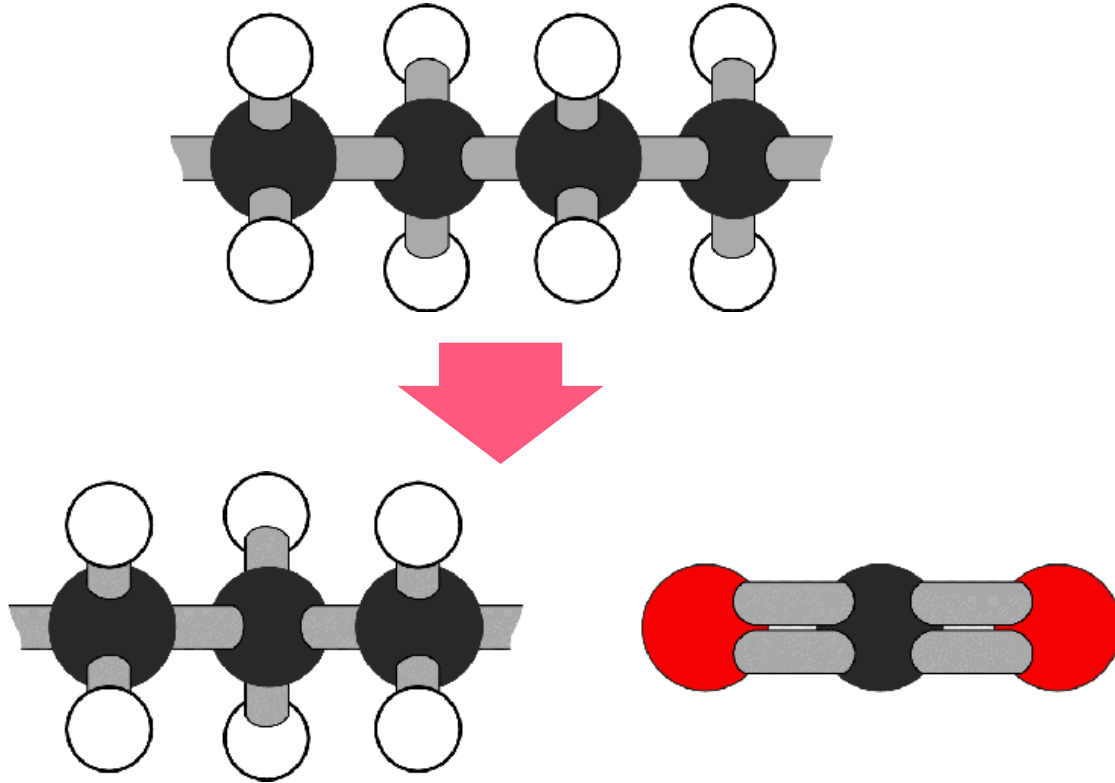
MJPhD

CHEMICAL TRANSFORMATION

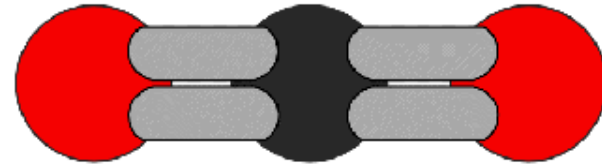
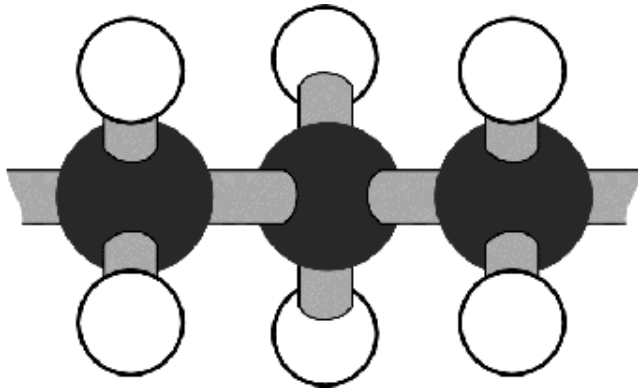


MJPhD

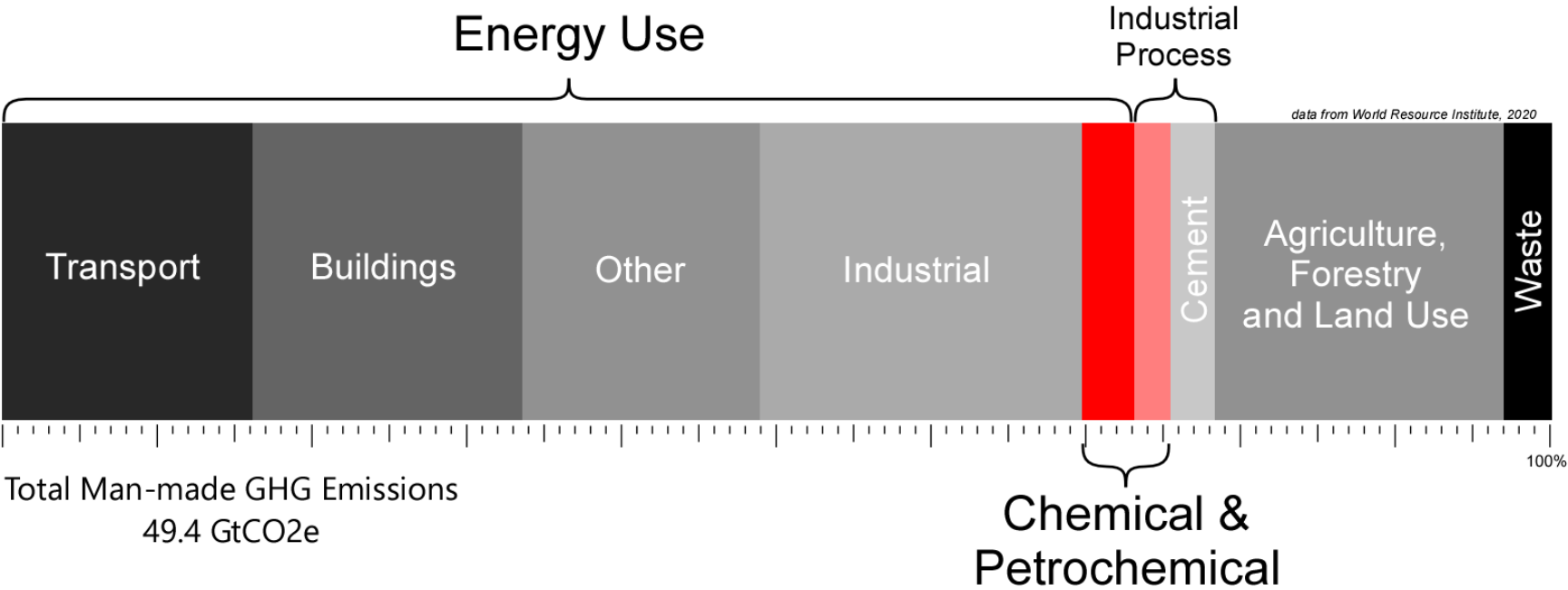
ROUGH MASS BALANCE



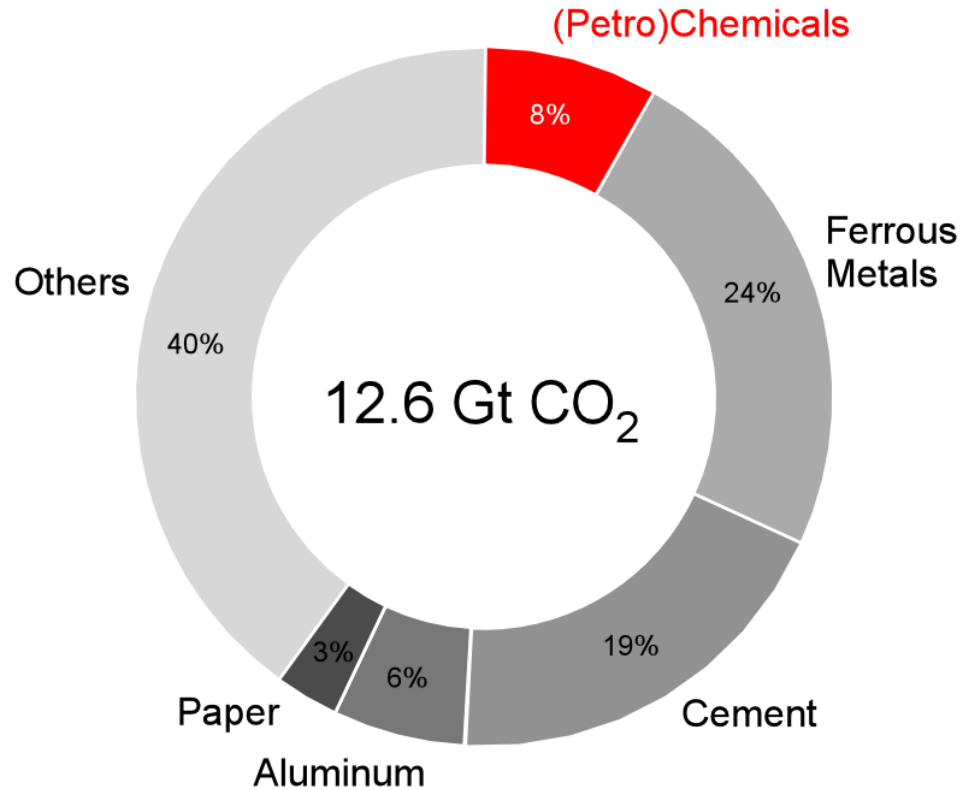
IMPLICATIONS



CARBON FOOTPRINT OF INDUSTRY

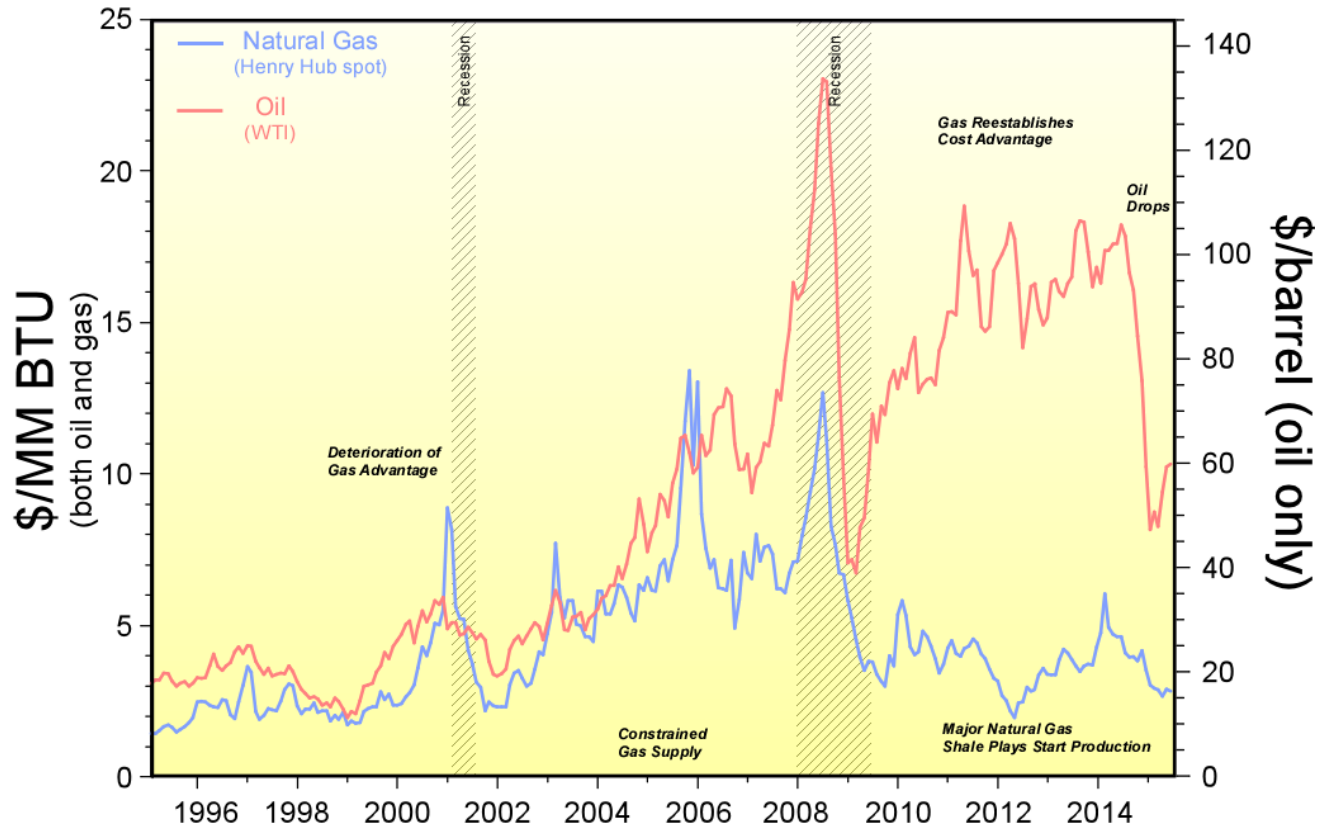


GLOBAL CO₂ EMISSIONS FROM INDUSTRY

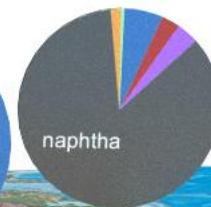
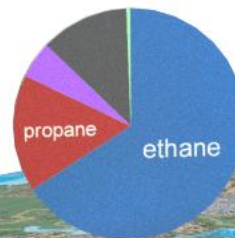
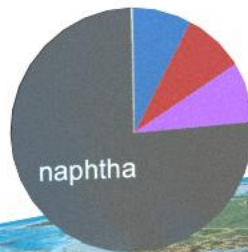
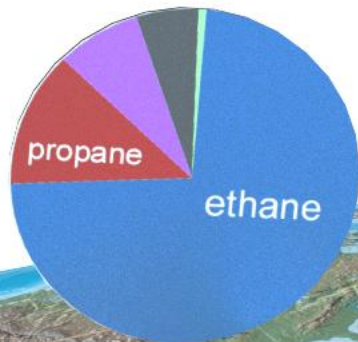


Martin Brudemuller, BASF at the World Economic Forum, 21 Jan 2020

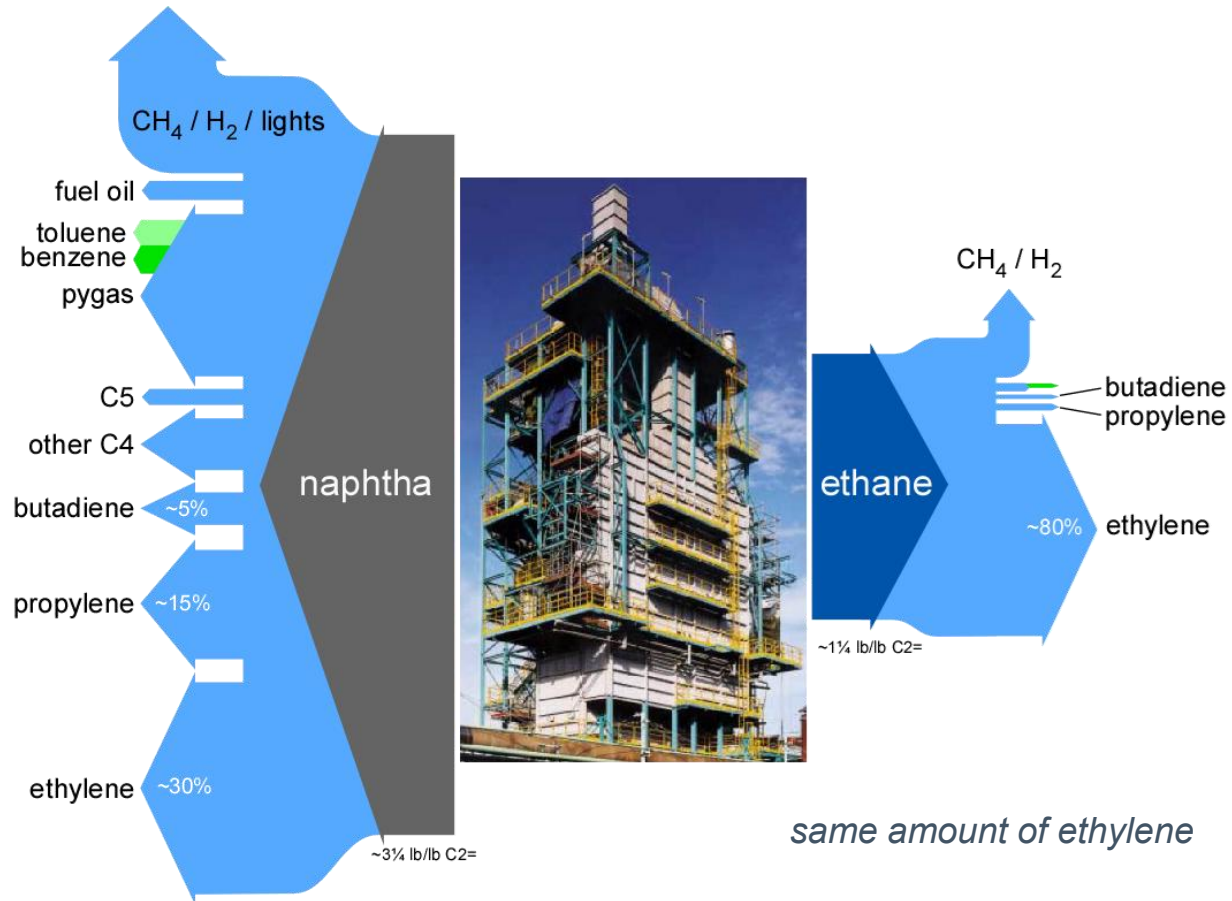
RECENT INDUSTRY HISTORY



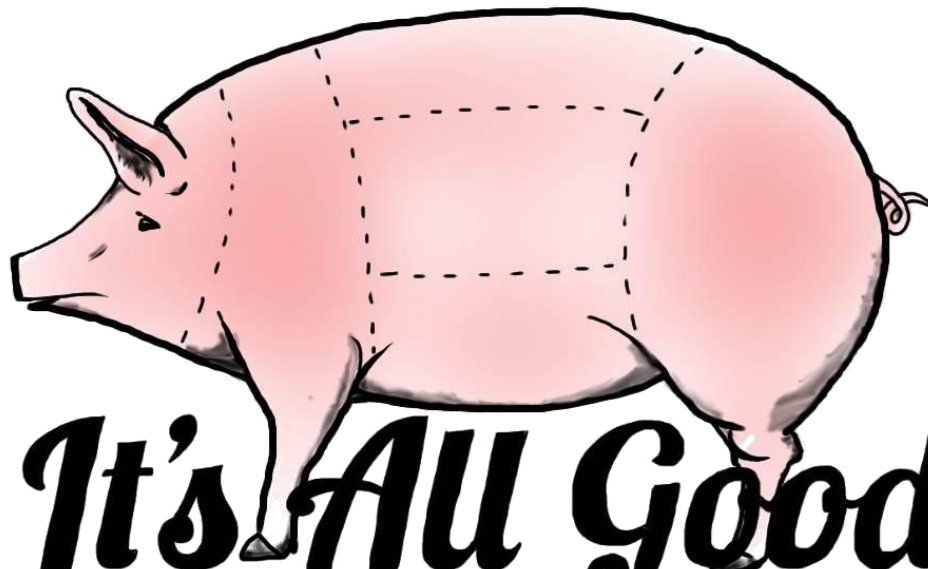
■ ethane ■ propane ■ butane ■ naphtha ■ MTO/CTO ■ other



CRACKING COMPARISON



ALL REACTION PRODUCTS FIND USES

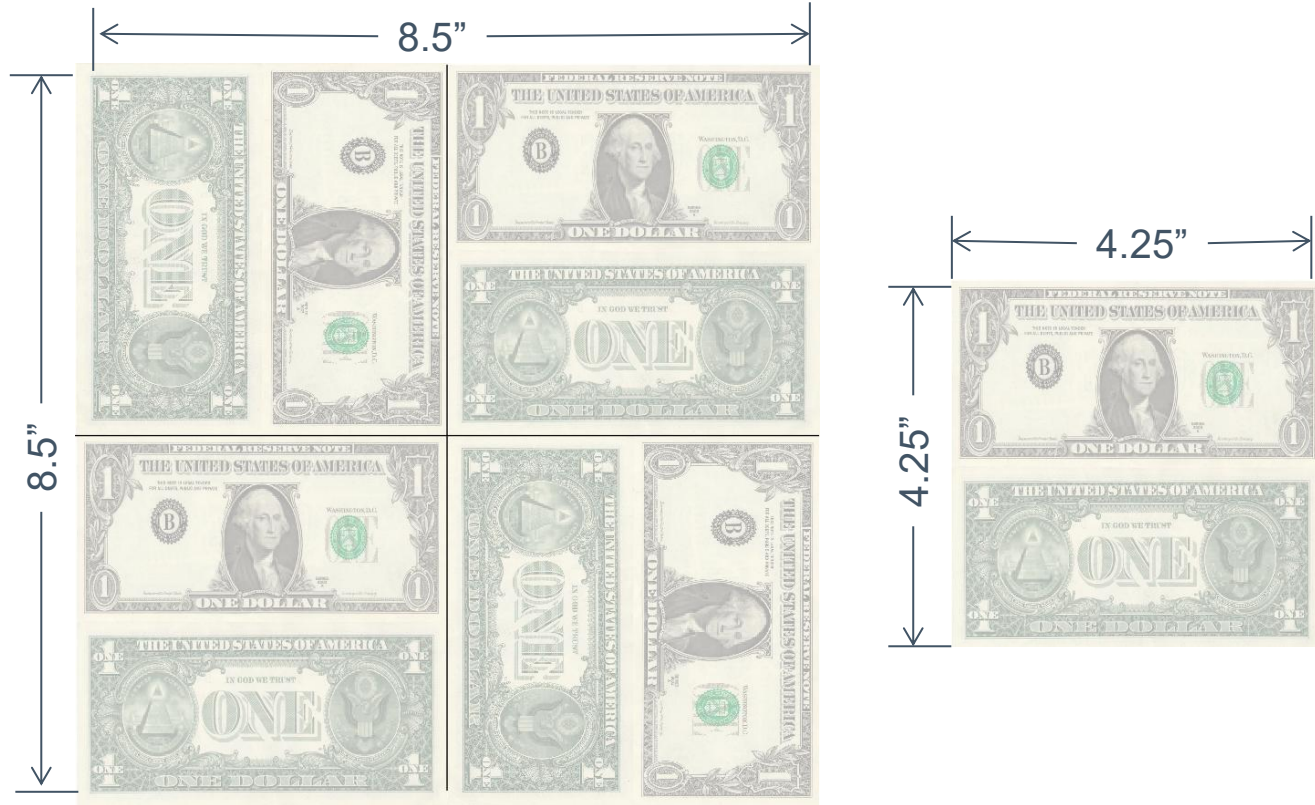


It's All Good!

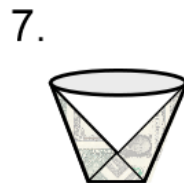
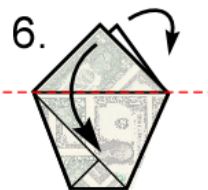
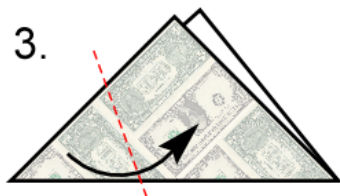
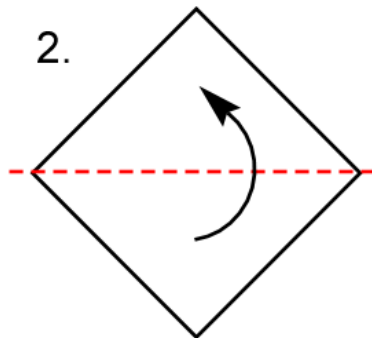
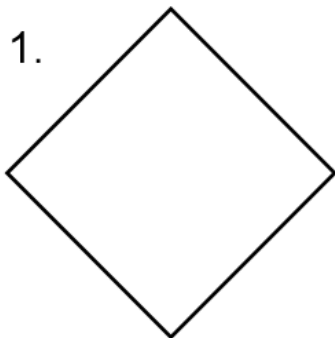
SCALE IS IMPORTANT



ORIGAMI DEMO



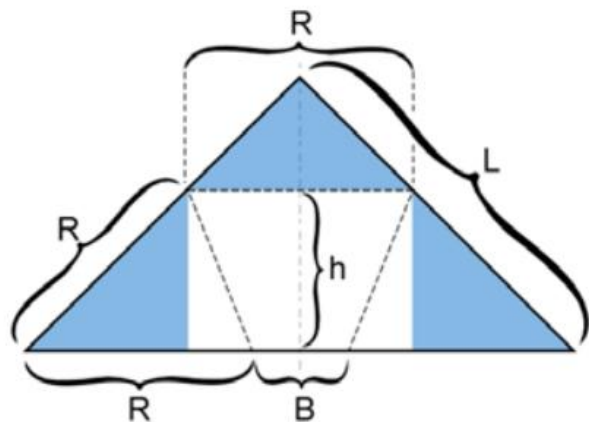
SCALE DEMO



Make a cup
with an $8\frac{1}{2}$ "
square and
another with a
 $4\frac{1}{4}$ " square

Origami Demo of Scale





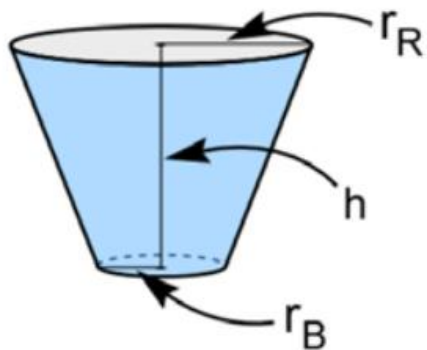
$$A = L^2$$

$$h = \frac{L}{1+\sqrt{2}}$$

$$R = \frac{\sqrt{2} L}{1+\sqrt{2}}$$

$$B = \frac{L(2-\sqrt{2})}{1+\sqrt{2}}$$

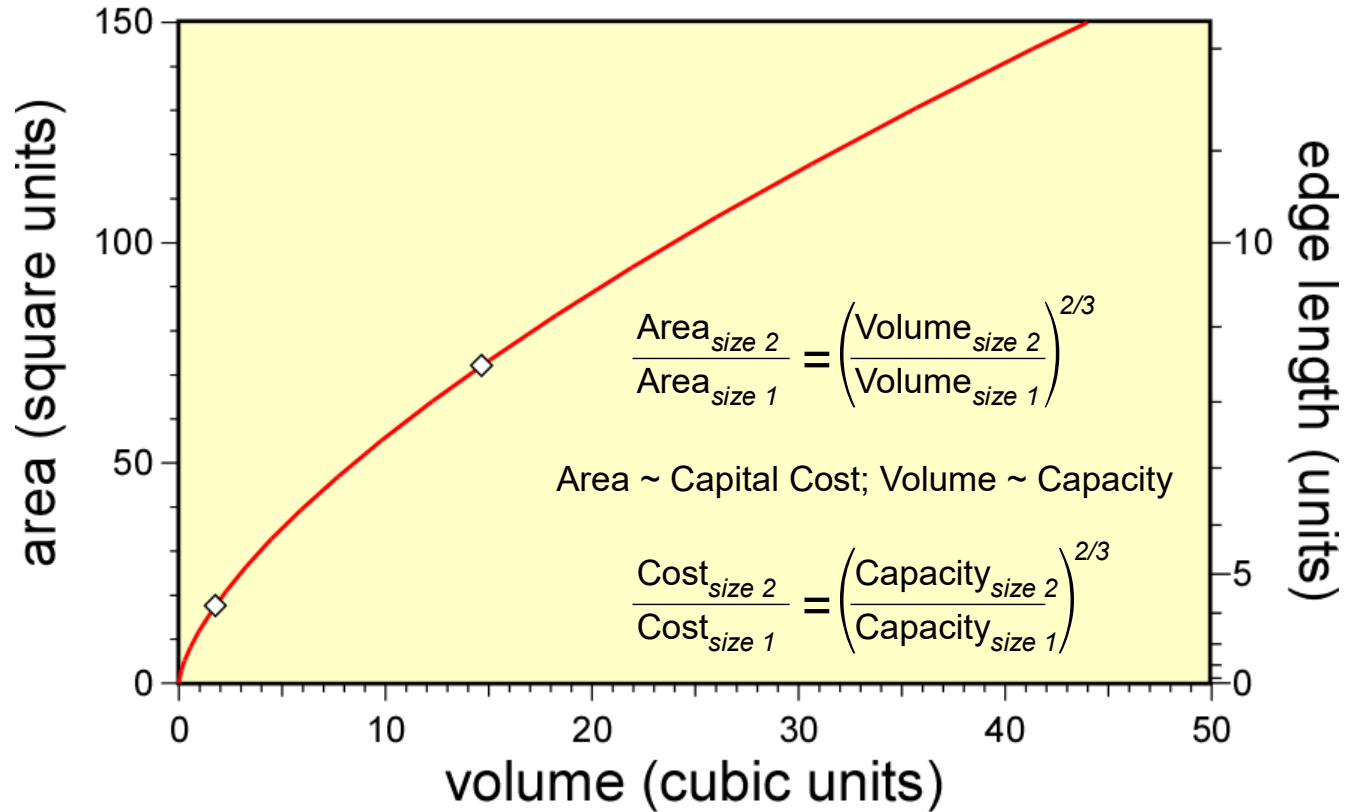
$$\frac{V_L}{V_{L/2}} = 8$$



$$r_B = \frac{B}{\pi} = \frac{L(2-\sqrt{2})}{\pi(1+\sqrt{2})}$$

$$r_R = \frac{R}{\pi} = \frac{\sqrt{2} L}{\pi(1+\sqrt{2})}$$

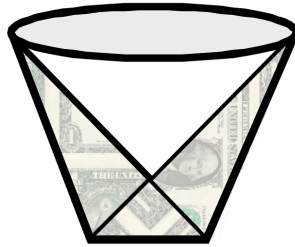
POWER LAW



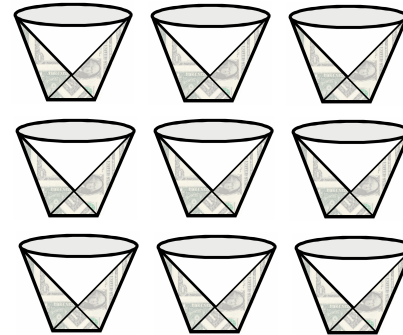
IMPACT OF SCALE TO CONTAIN SAME VOLUME



>2X material
~9X labor to construct



=

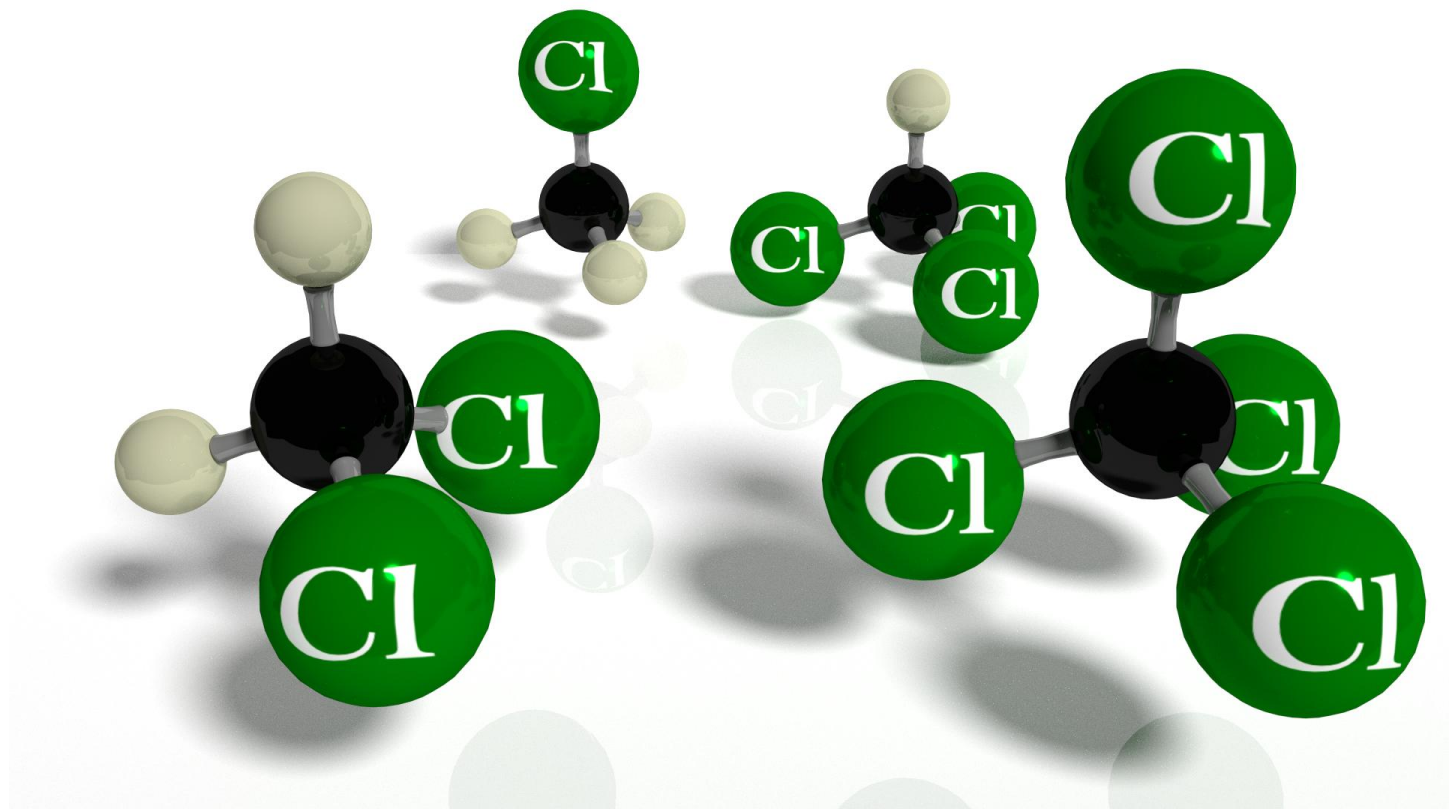


SCALE ALWAYS WINS

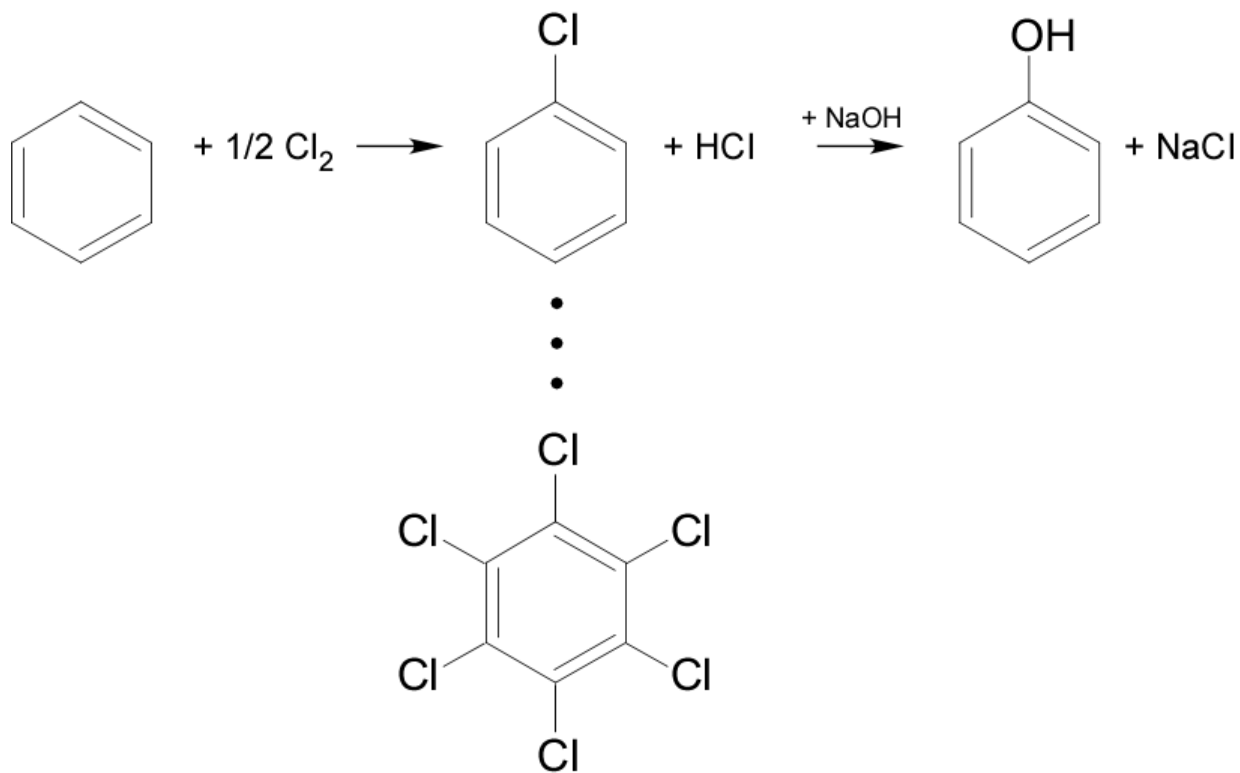


If you are moving mass around, scale reduces cost faster than experience.

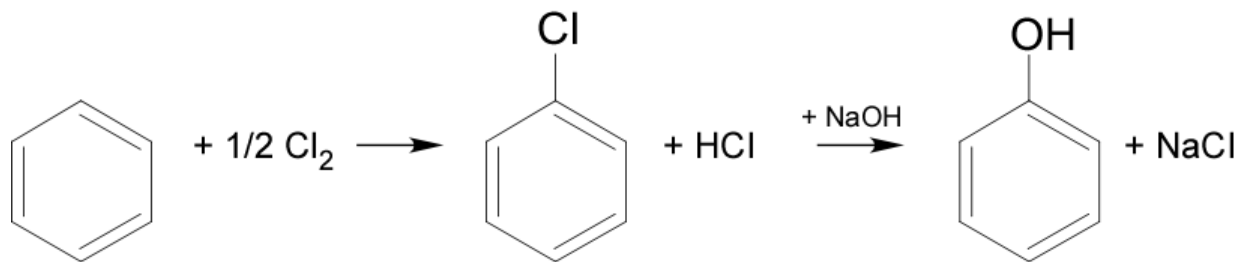
ORGANOCHLORIDES



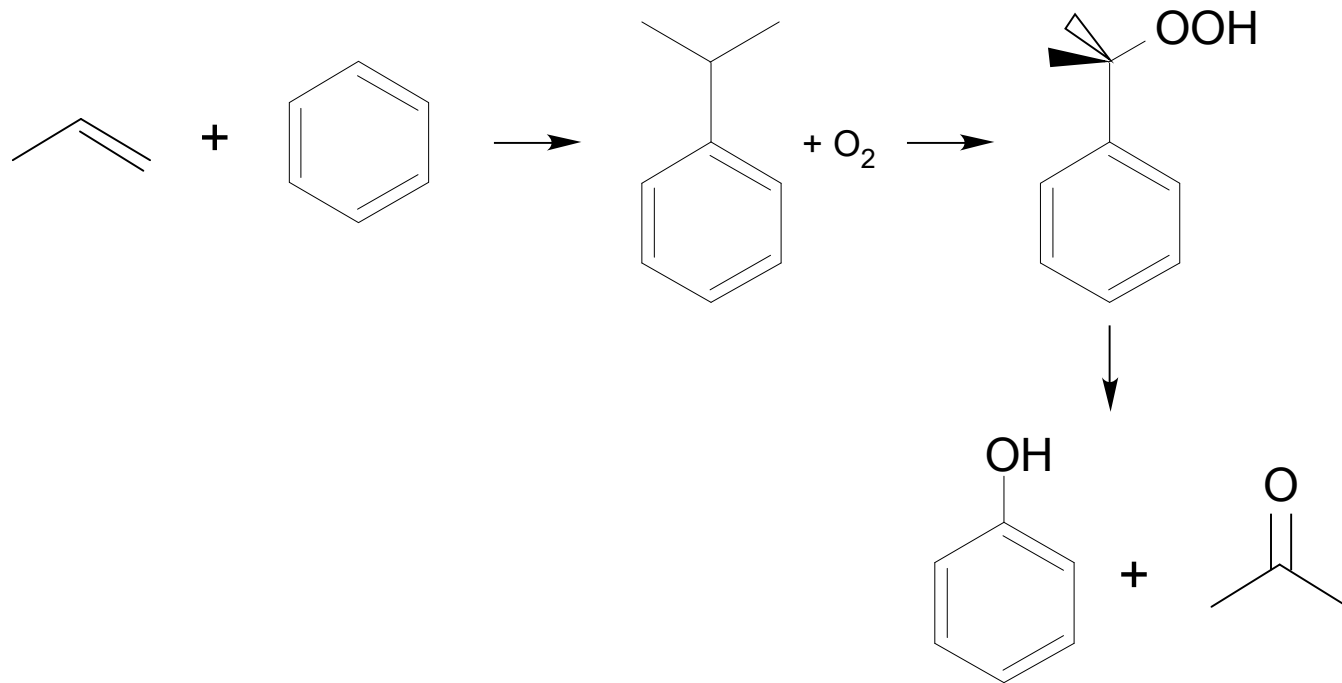
CHLORINE AS AN OXIDANT



CHLORINE AS AN OXIDANT

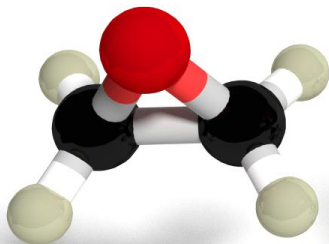


PHENOL TODAY

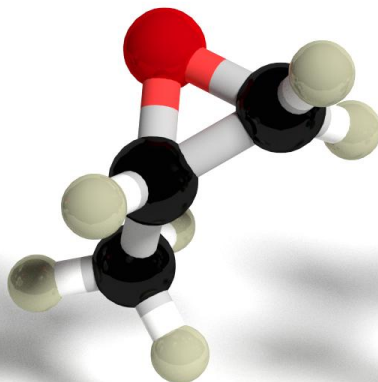


EPOXIDES

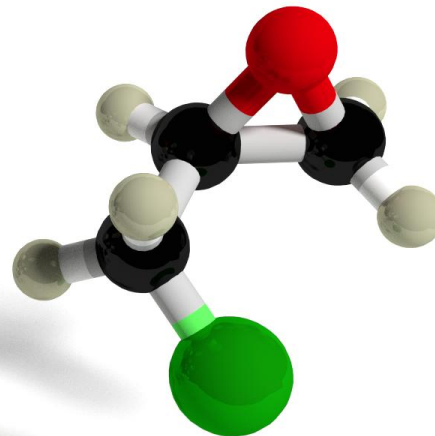
EO
ethylene oxide



PO
propylene oxide

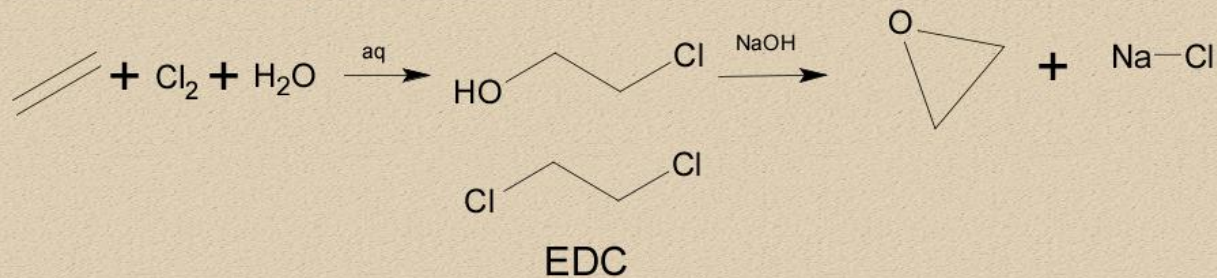


EPI
epichlorohydrin



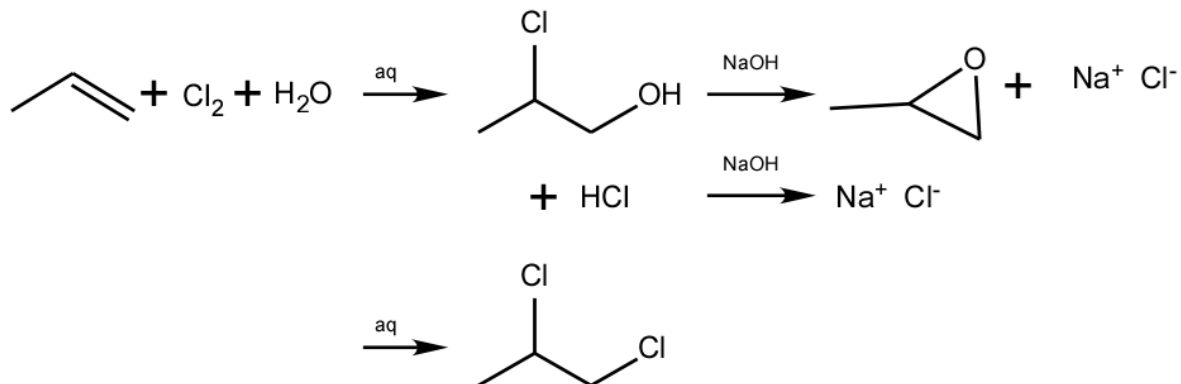
CHLOROHYDRIN CHEMISTRY

Chlorohydrin Ethylene Oxide



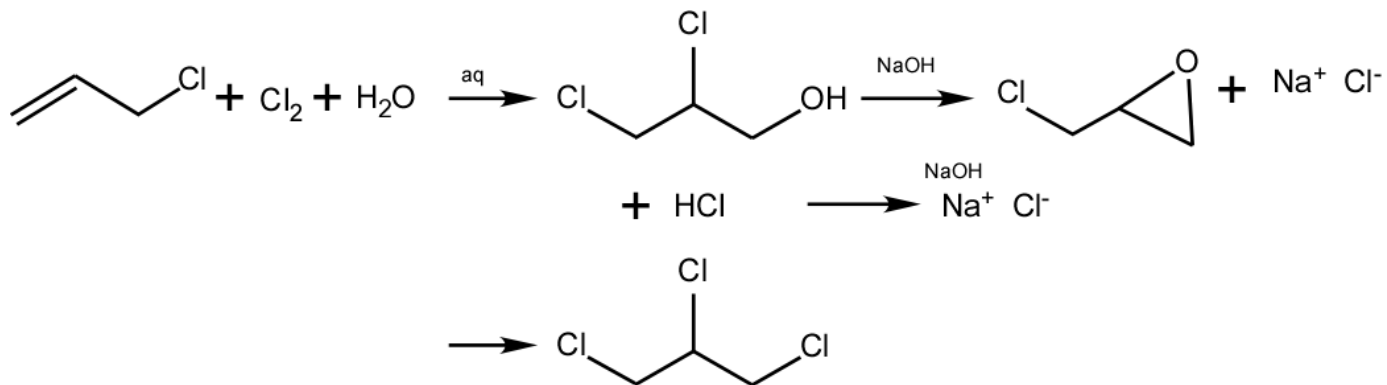
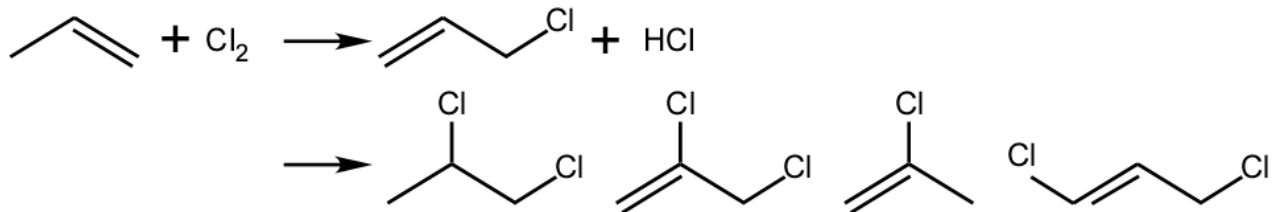
1915-1975

Chlorohydrin Propylene Oxide

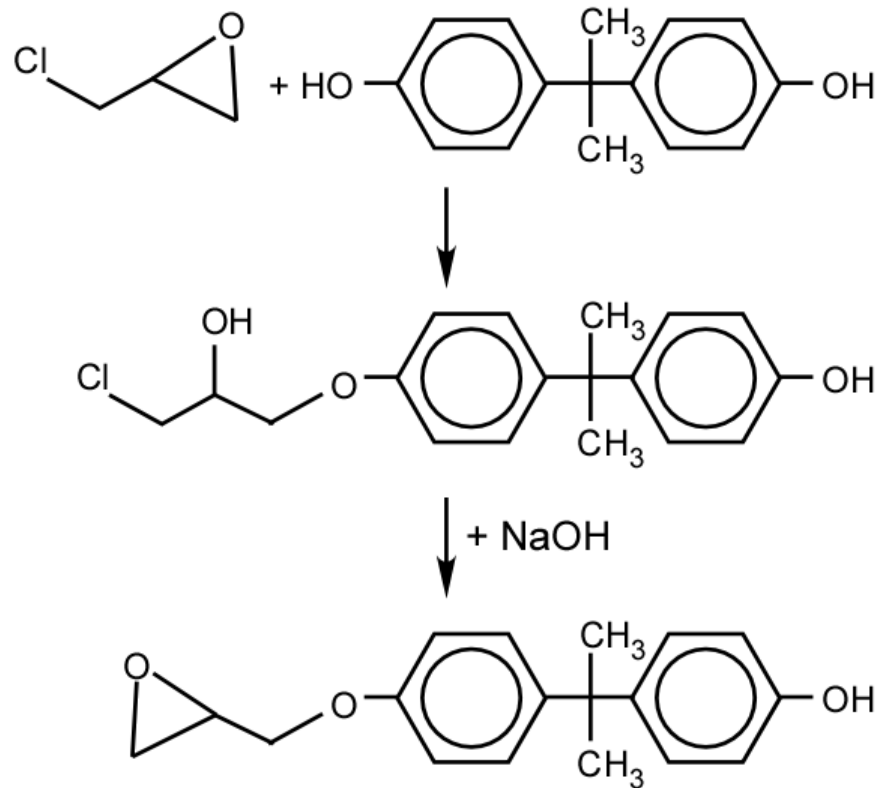


MORE CHLOROHYDRIN CHEMISTRY

Chlorohydrin Epichlorohydrin

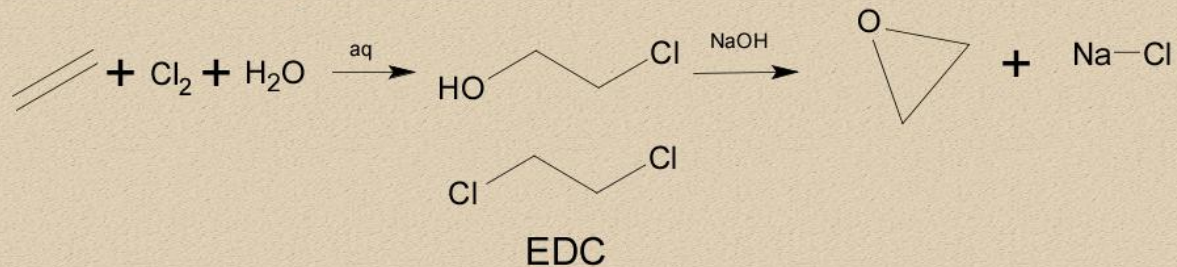


EPOXY RESINS

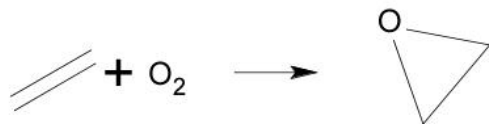


DIRECT OXIDATION

Clorohydrin Ethylene Oxide

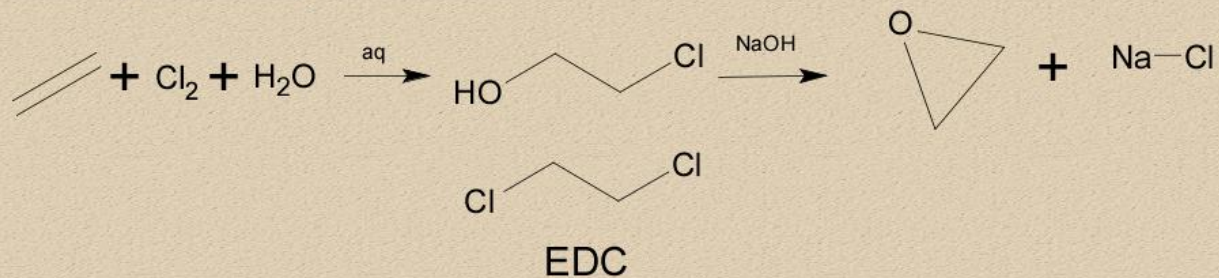


Direct Oxidation Ethylene Oxide

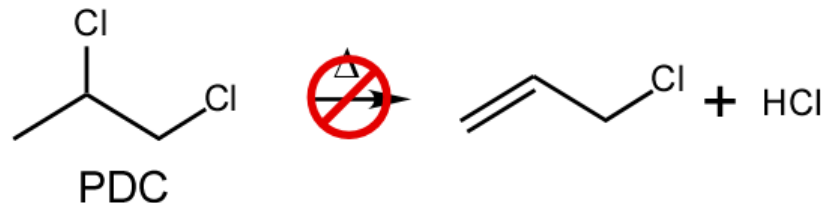
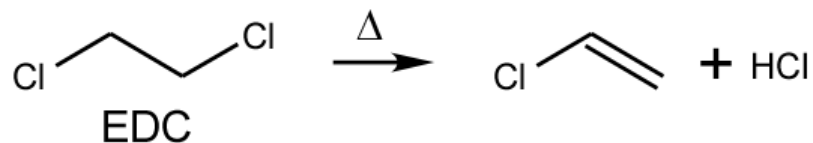


CHLOROHYDRIN CHEMISTRY

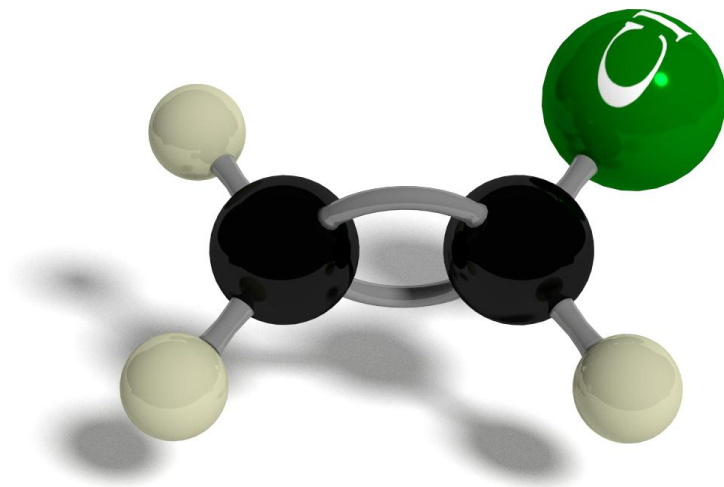
Chlorohydrin Ethylene Oxide



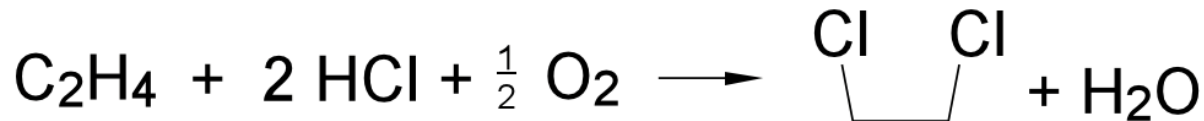
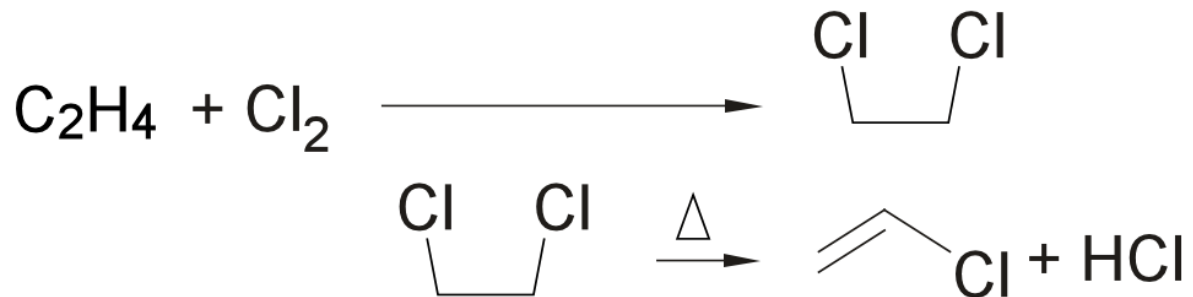
1915-1975



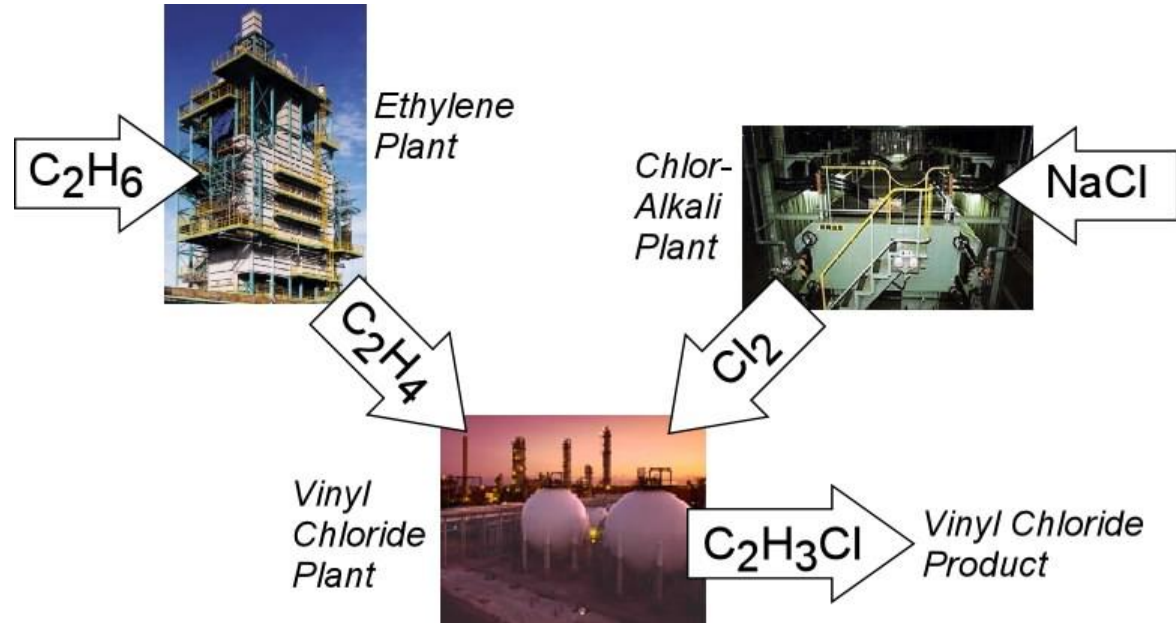
VINYL CHLORIDE

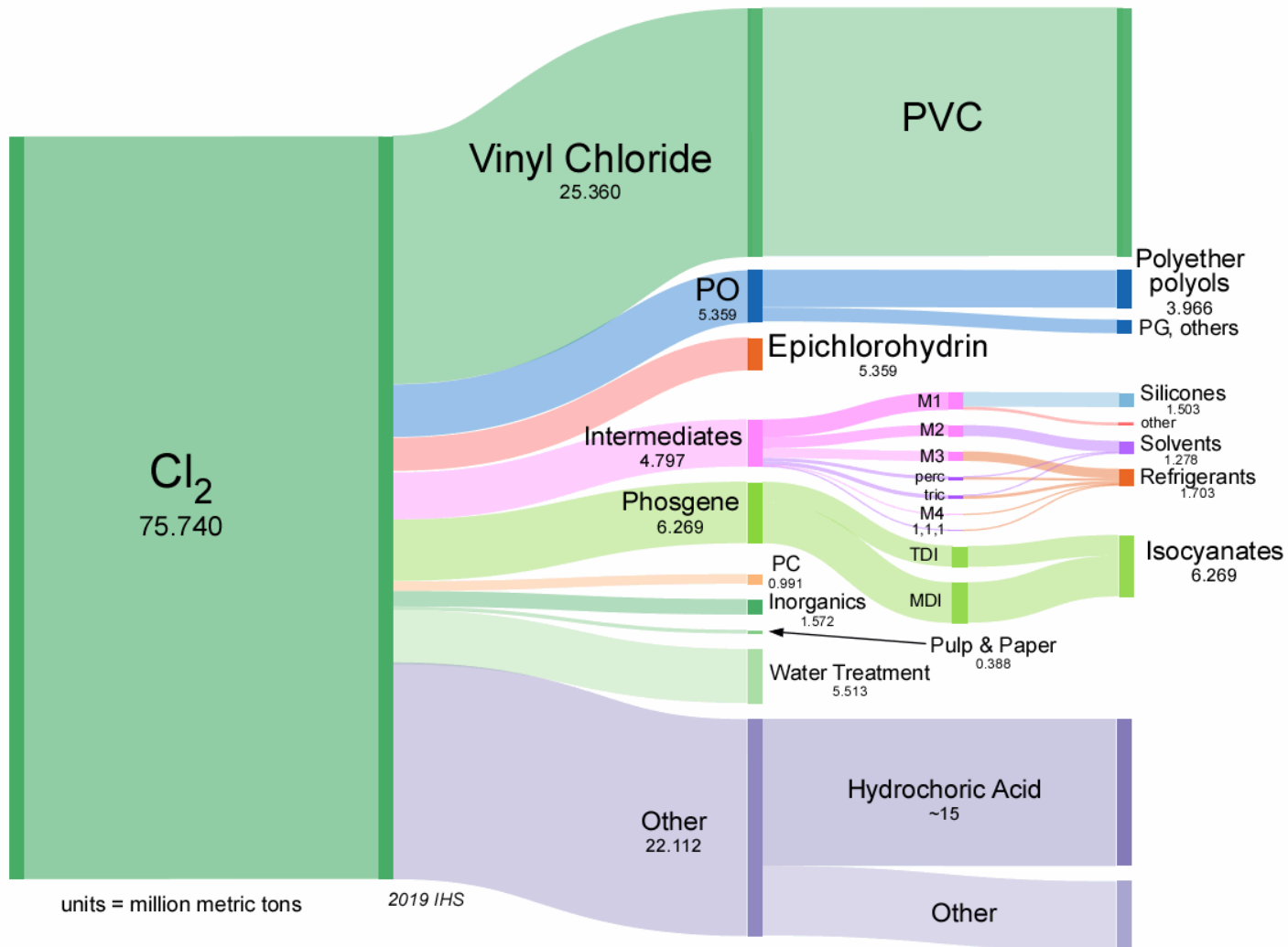


CONVENTIONAL PRODUCTION



CONVENTIONAL VCM

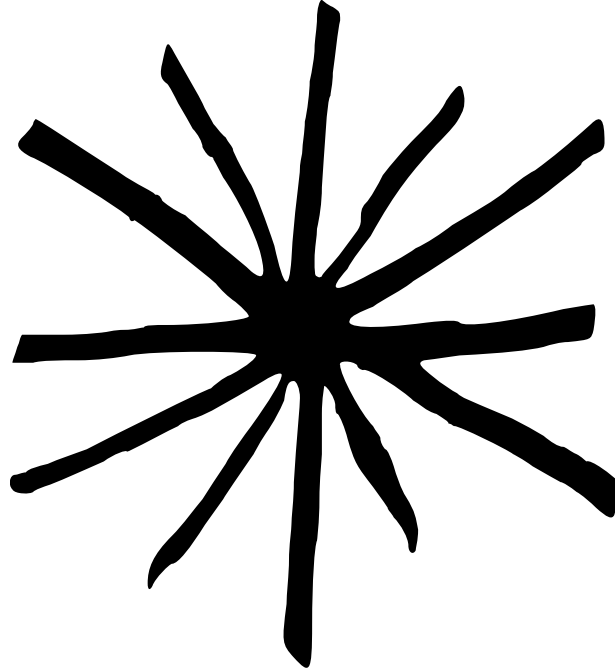




units = million metric tons

2019 IHS

BREAKFAST OF CHAMPIONS



see Vonnegut's *Breakfast of Champions*
or
Pete Davidson's *The King of Staten Island*

EAST PALESTINE, OHIO



Vinyl chloride was on the train because PVC production is the sink for chlorine that allows production of caustic soda.

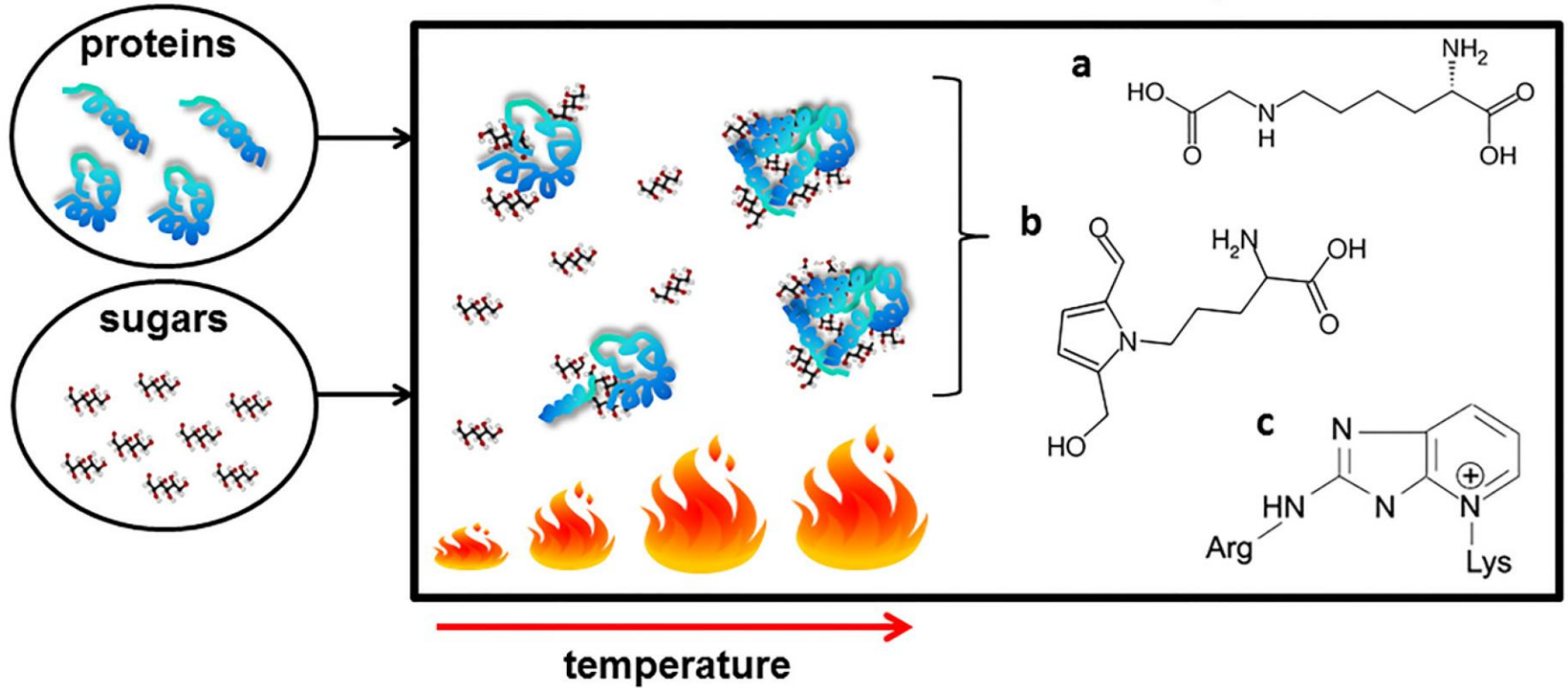


CO-PRODUCT PROCESSES



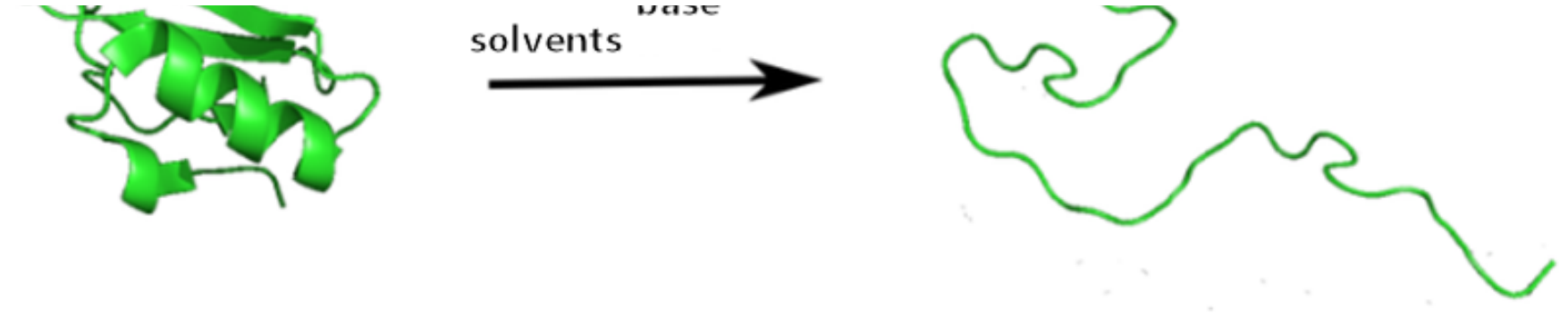


Formation of Maillard reaction products



Denaturing Proteins

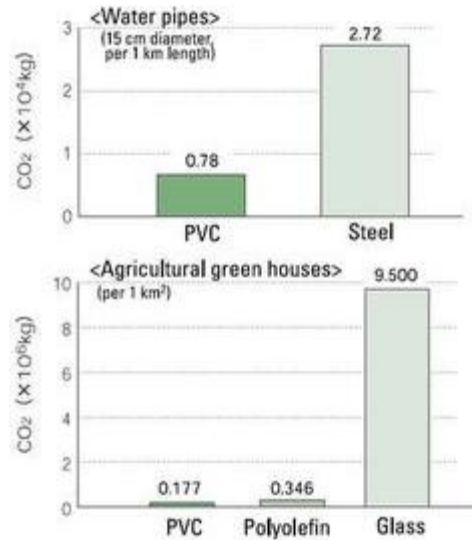
Vinyl chloride was on the train because of pretzels (and all the other uses of caustic necessary for modern life).



<https://montessorimuddle.org/2013/11/17/proteins-via-food-science/>

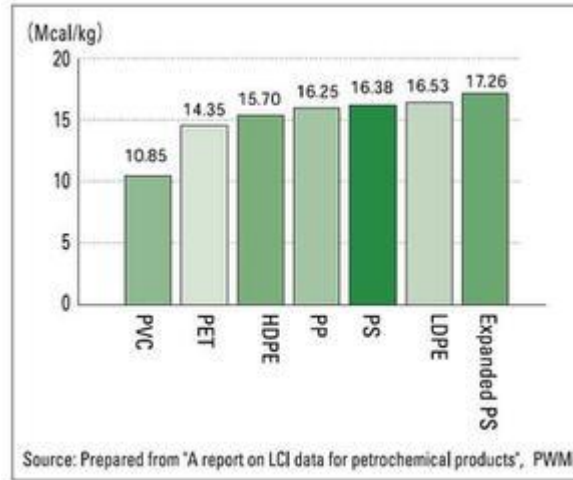
VINYL SUSTAINABILITY

Lower Carbon Footprint



Source: Prepared from the survey report by Chem Systems

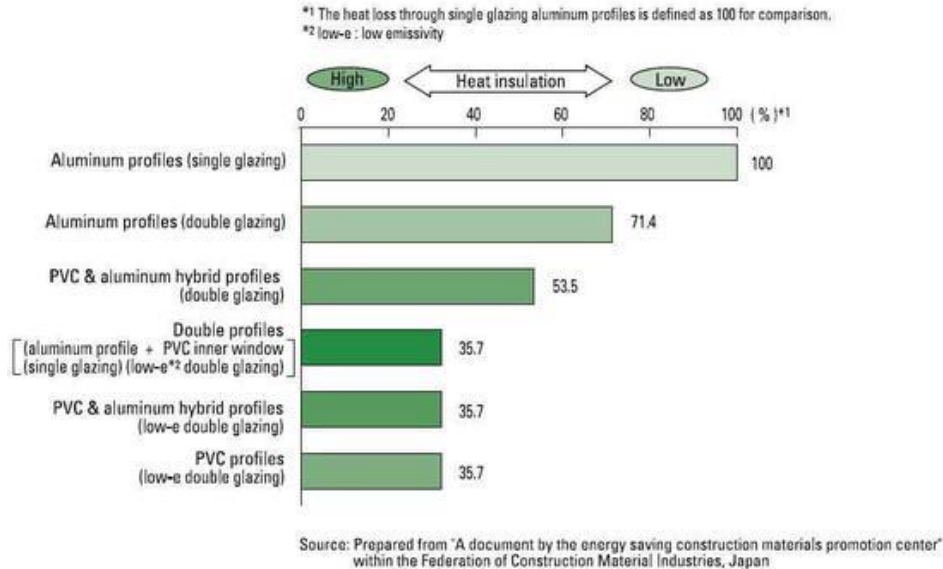
Energy Efficient



Source: Prepared from "A report on LCI data for petrochemical products", PWMI

Atom efficient – most inputs end up in the product

Energy Savings Over Lifetime



Long lifetimes during use in infrastructure.

WHAT I HOPE I'VE LEFT YOU WITH

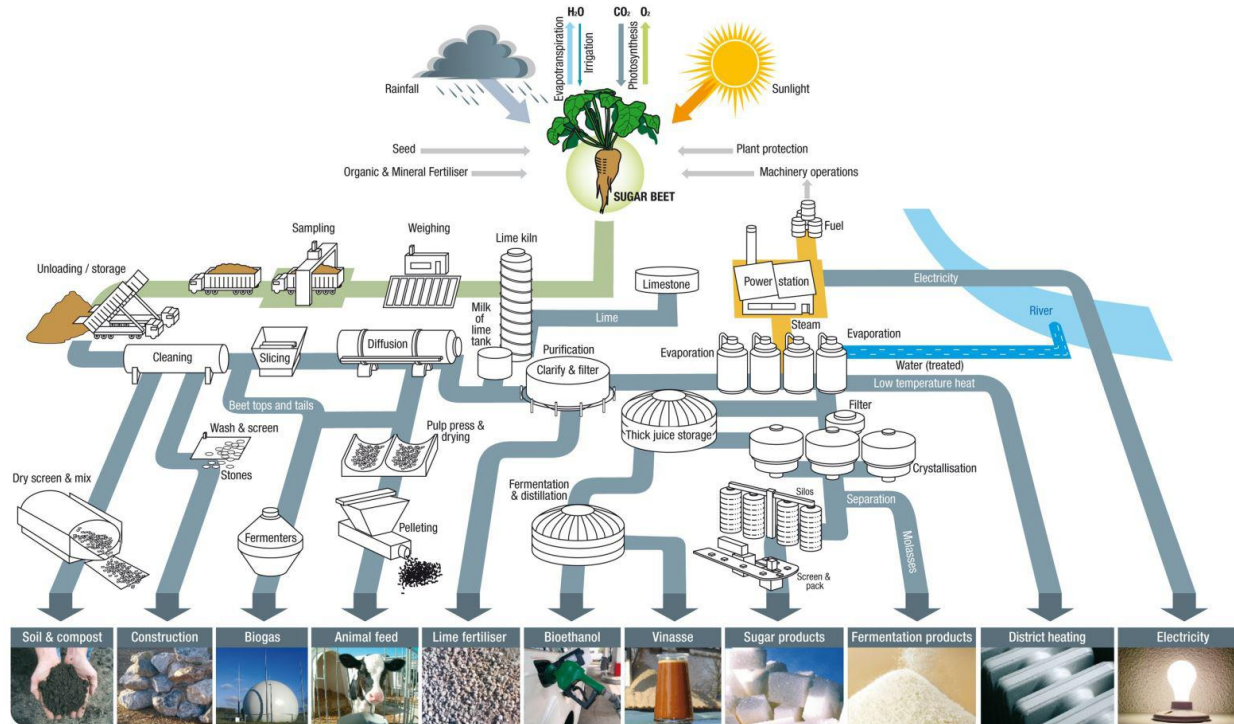
- Inorganic chemistry created the chemical industry and remains important, but not particularly valued
vinyl and caustic are critical, just not particularly profitable
chlorine has largely been replaced as an oxidant
- Scale remains the major source of competitive advantage in commodity chemicals
for undifferentiated materials, production cost is king and scale lowers production cost
- Sustainability is multifaceted and complex with hidden interactions.



MJPhD

INTEGRATED BIOREFINERY

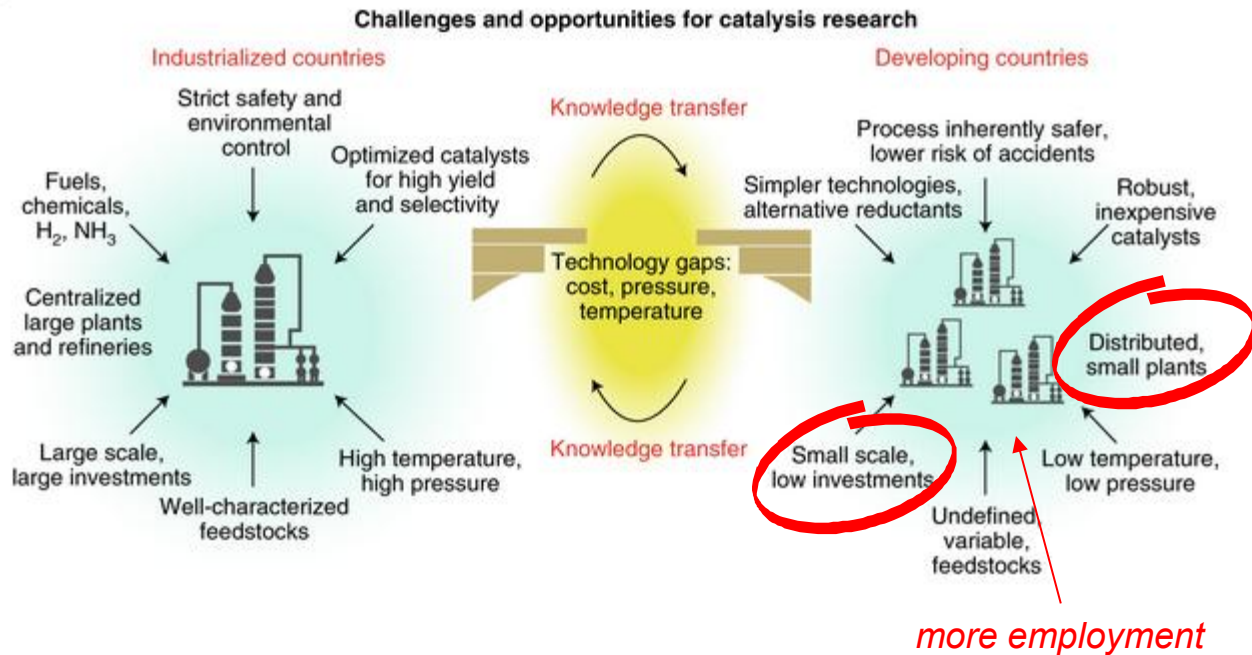
FROM BEET FIELD TO SUGAR FACTORY



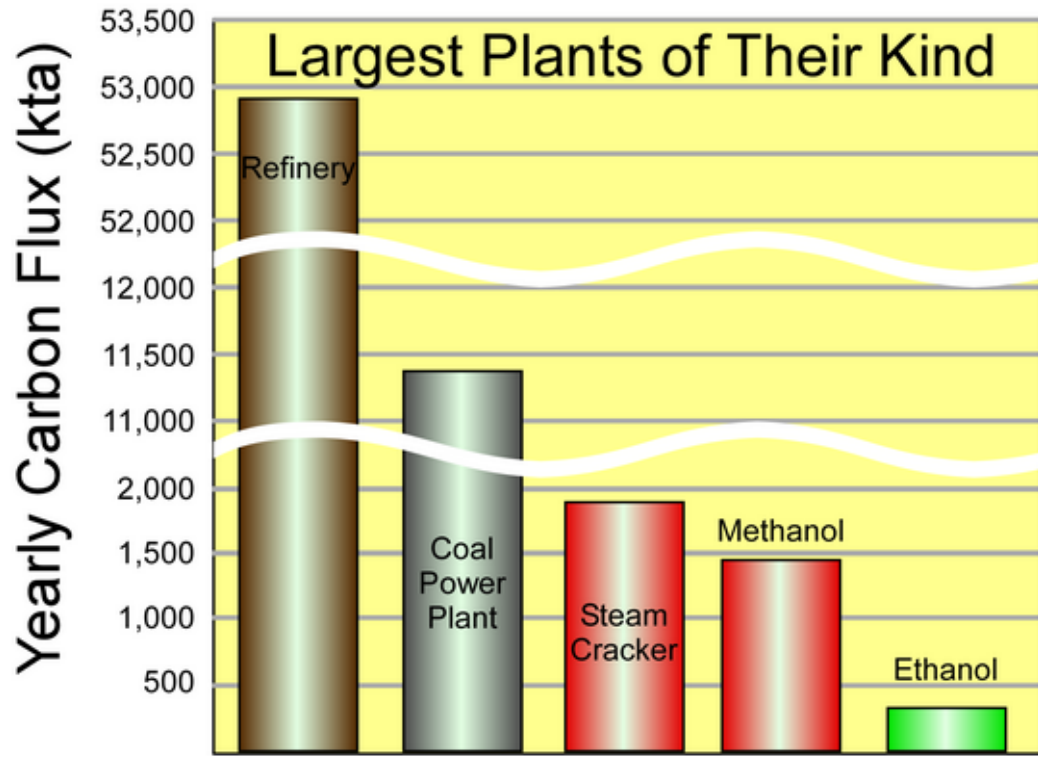
Source: CIBE and CEFS (after British Sugar)

prokris.nl/production/

DISTRIBUTED MANUFACTURING



Resasco DE, Wang B, Sabatini D. Distributed processes for biomass conversion could aid UN Sustainable Development Goals. *Nature Catalysis*. 2018 Oct;1(10):731.



AG VERSUS CHEMICAL COMPARISON

