Flexibility Improvements from Process Engineering

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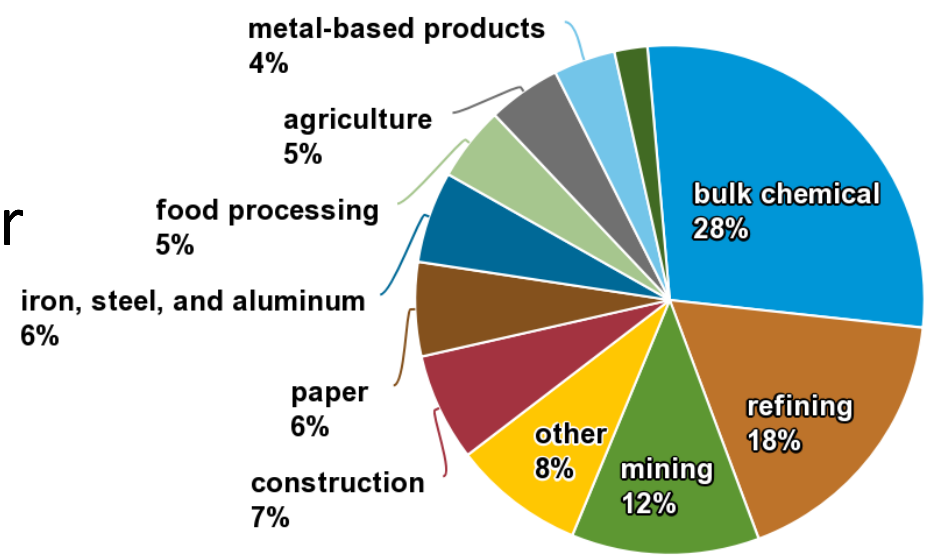
What Is a Chemical Process?

A system that turns raw materials (often “harvested” from nature – oil, natural gas,…) to value-added products through a combination of chemical reactions and physical transformations

Examples:

- Oil refinery
- Aluminum smelter
- Ethylene plant
- Glass furnace

U.S. industrial sector energy consumption by type of industry, 2018



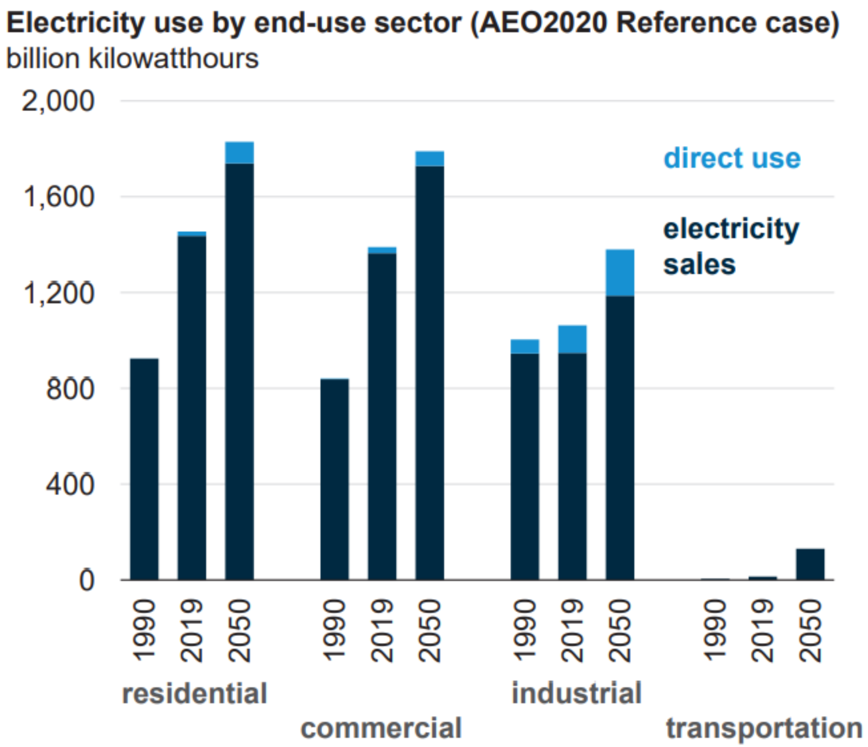
https://www.eia.gov/energyexplained/use-of-energy/industry.php

Chemical Process Interactions with the Grid?

Chemical/physical transformations require energy input

Examples:

- Heating – arc furnace
- Electrochemical reactions: (chlorine, aluminum)
- Compression work (air separation, natural gas liquefaction)



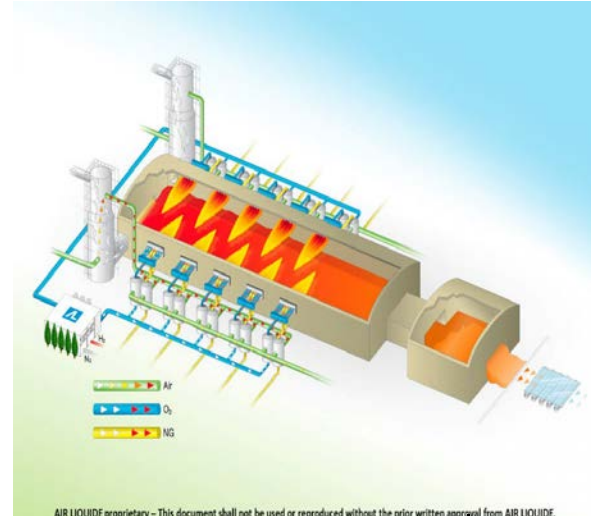
Each use case comes with challenges and opportunities:

- Magnitude: large
- Response time: generally slow
- Location: depends…

Process Power Demand: Magnitude

wikipedia

Essentialchemicalindustry.org



www.agc-glass.eu

Air separation:

Cryogenic (- 180F) distillation to produce oxygen, nitrogen, argon from air

350 kWh/t Oxygen
Single plant up to 5000 ton/day (~73MW load)

Chlor-alkali:

Brine electrolysis to produce chlorine and caustic

2300 kWh/ton Cl2
Single plant up to 2500 ton/day (~240MW load)

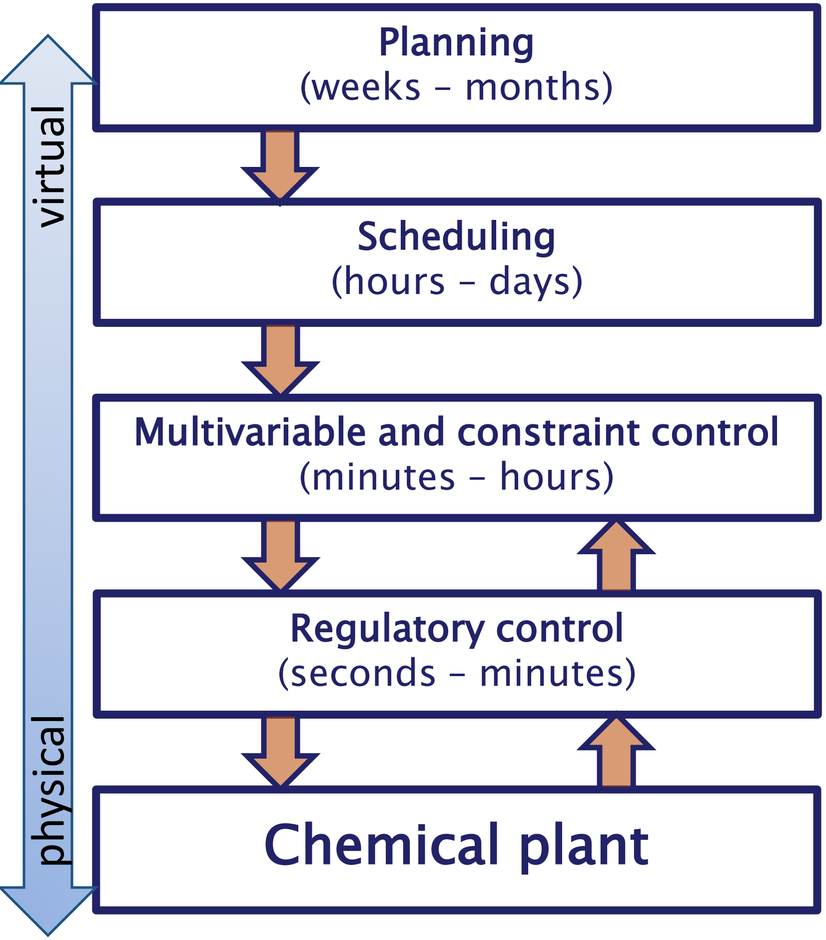
Glass:

Melting of silicate material to produce glass

1300 kWh/ton
Single furnace >160 ton/day (~9MW)

T. F. O'Brien, T. V. Bommaraju, and F. Hine, Handbook of Chlor-Alkali Technology, Springer Science & Business Media, 2007, vol. 1; Kelley, Baldick, Baldea, Applied Energy, 222, 951-966, 2018; Seo, Edgar, Baldea, in prep.

Response Time: Answer to a Higher Authority…



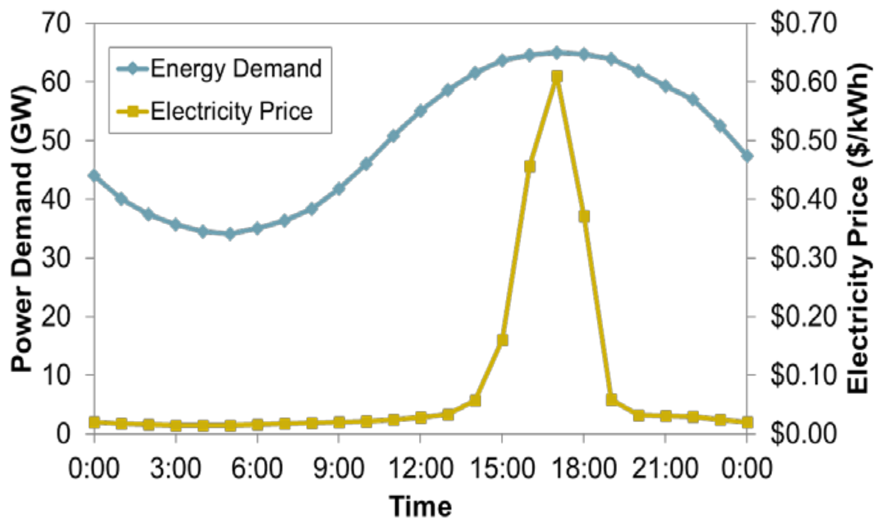
Production management

- *"what to make, how much and when"* to maximize profit: market-driven
- Business drivers take precedence; incentives for grid engagement must be HIGH

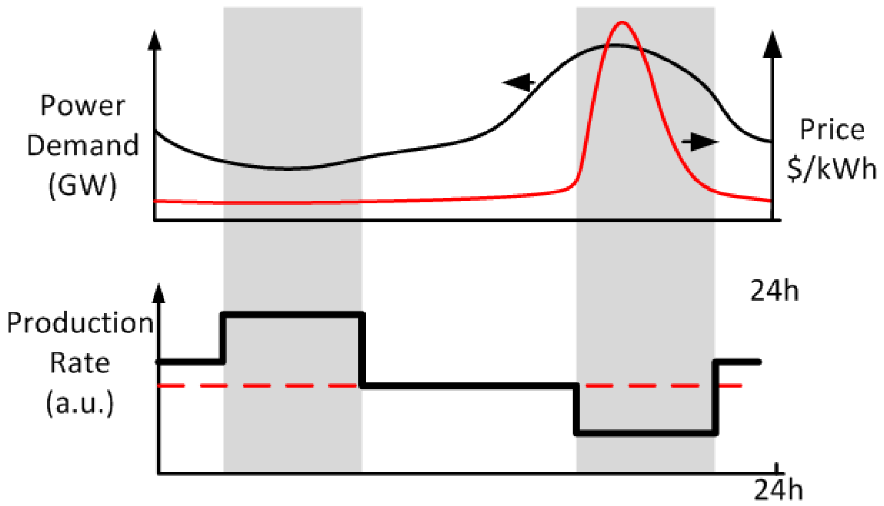
Control

- *"how to run the plant to implement production targets"*
- Focus on safety, stability and rejection of disturbances, account for process dynamics
- CANNOT COMPROMISE SAFETY AND PRODUCT QUALIT

Response Time



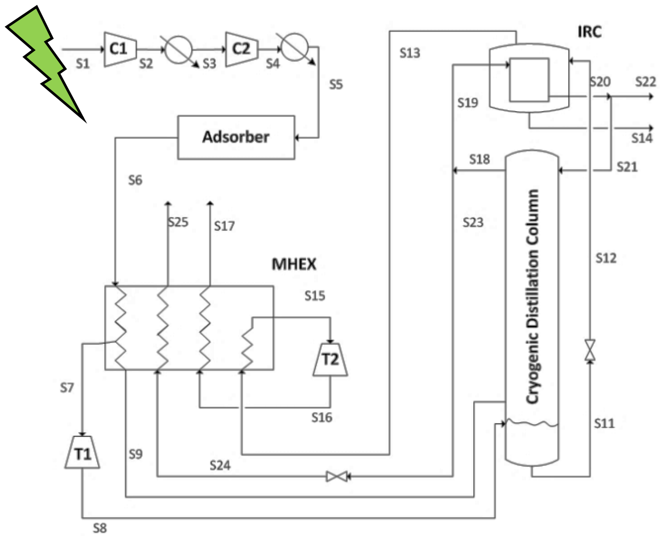
ERCOT demand and day ahead settlement point prices for June 25, 2012 from www.ercot.com

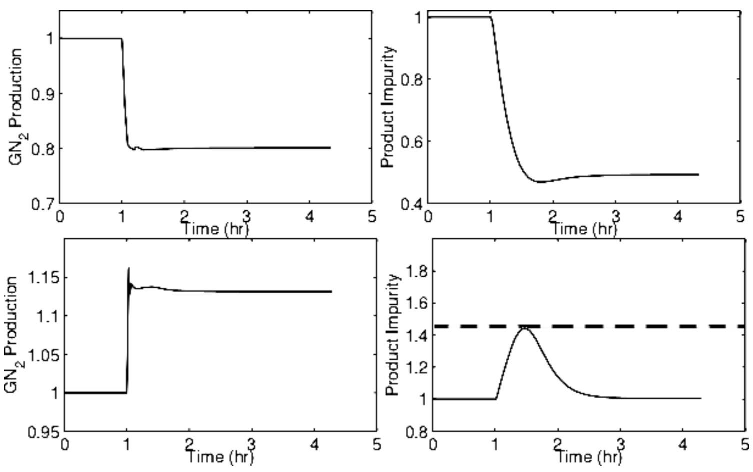


Taking advantage of such fluctuations requires frequent changes in the production rate, product grade; should use product storage:

- Must coordinate production scheduling, process control
- Amounts to storing electricity in the form of chemical products

Example 1: Air Separation





Air separation unit (ASU):

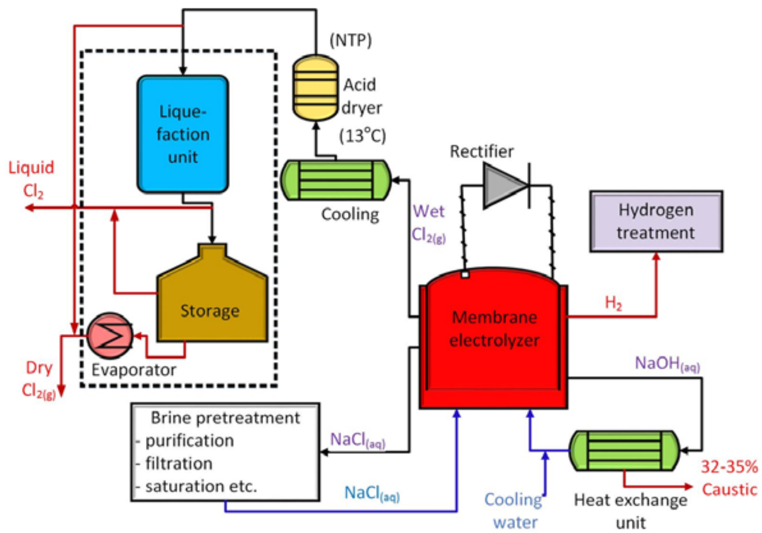
- **About 2% of US industrial electricity demand**
- Production scheduled on an hourly basis
  - Production levels
  - Liquid vs. gas products
  - Dominant time constant: **hours**

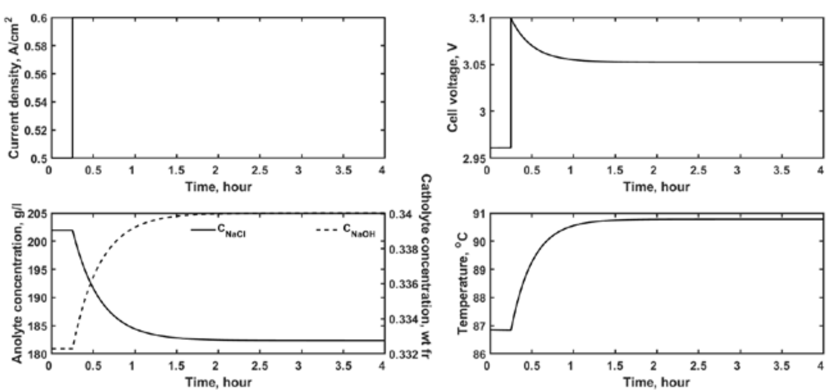
<u>Grid implications:</u>

- Participate in price-based demand response (1-2% cost reduction)
- Can provide interruptible power at a cost (restarting plant can take days…)

Cao, Swartz, Baldea, Blouin, J. Proc. Contr., 54 (24), 6355–6361, 2015; Pattison, Touretzky, Harjunkoski, Johansson, Baldea, Ind. Eng. Chem. Res., 55, 4562-4584, 2016; Tsay and Baldea, Contr. Eng. Prac., 94, 104201, 2020

Example 2: Chlor-Alkali





Otashu and Baldea, Comput. Chem. Eng., 121, 396-408, 2019

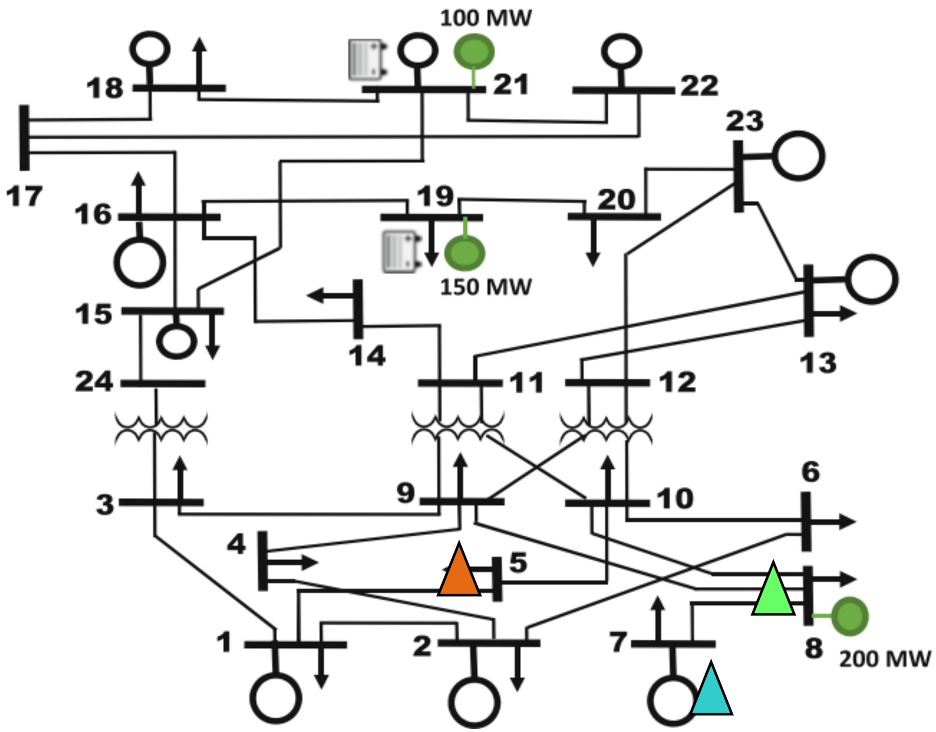
Electrolyzer:

- **About 2% of US industrial electricity demand**
- Current density (and power demand can be changed quickly)
  - Liquid vs. gas products
  - Dominant time constant: hours, due to thermal inertia

Grid implications:

- Participate in price-based demand response (~7% savings)
- Can provide frequency regulation or interruptible power

Location, Location, Location



Modified IEEE 24 bus RTS (Soroudi, 2017)
(3 wind farms, 2 batteries, peak load 2850MW)

B5: 71 MW load

B7: 350MW generator, 125 MW load

B8: 200 MW wind turbine, 171 MW load

Based on the magnitude and dynamics of its power demand, the

location of a chemical plant will define its impact on the grid:

- **Congestion**
- **Cooperative vs. independent operation**
- **Dealing with variable renewable energy**

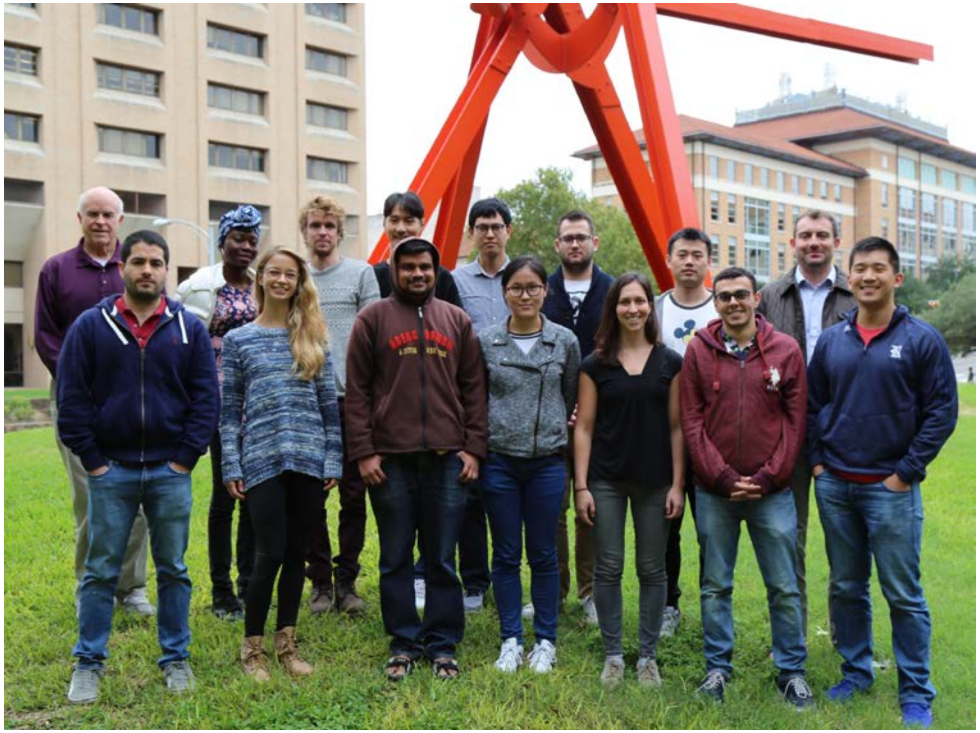
Open questions:

- Representing the dynamics of the plant in optimal power flow problem?
- **How much information are chemical plant operators willing to share with the grid? How much control will they give up?**

Conclusions

- Chemical plants are significant users of electricity
- Can support grid operations
  - Dynamics vary on the type of plant: can engage in demand response, frequency regulation
  - Safety and product quality remain critical concerns and take precedence over grid support
  - Plant location in grid topology will influence benefit to the grid
- Open questions remain:
  - OPF scheme utilizing chemical plant as "battery?"
  - Plant operators will not want to cede control to the grid or share critical information
  - How do we "share the spoils" in an equitable way: pricing schemes

Acknowledgments



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