Coal Firing to Electricity

Classic Pulverized Coal Power Plants

jfr photography

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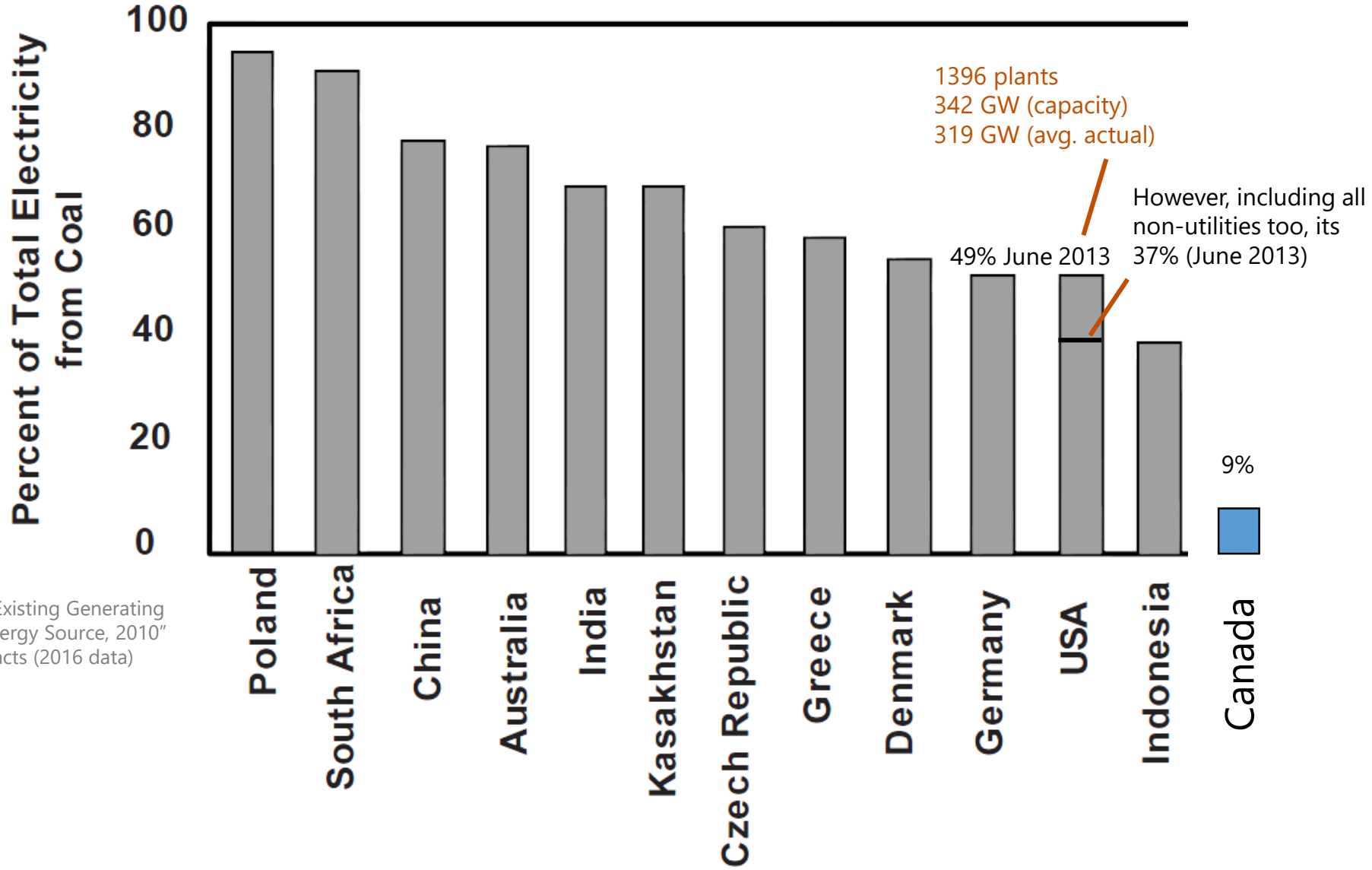
Lecture 3.1 – 2018 Edition

1. Background

Current state of the industry

Coal Power: Ubiquitous



Sources: Ghosh 2009, Ch 6
US Energy Information Administration, "Existing Generating Unit in the United States by State and Energy Source, 2010"
Natural Resources Canada – Electricity Facts (2016 data)

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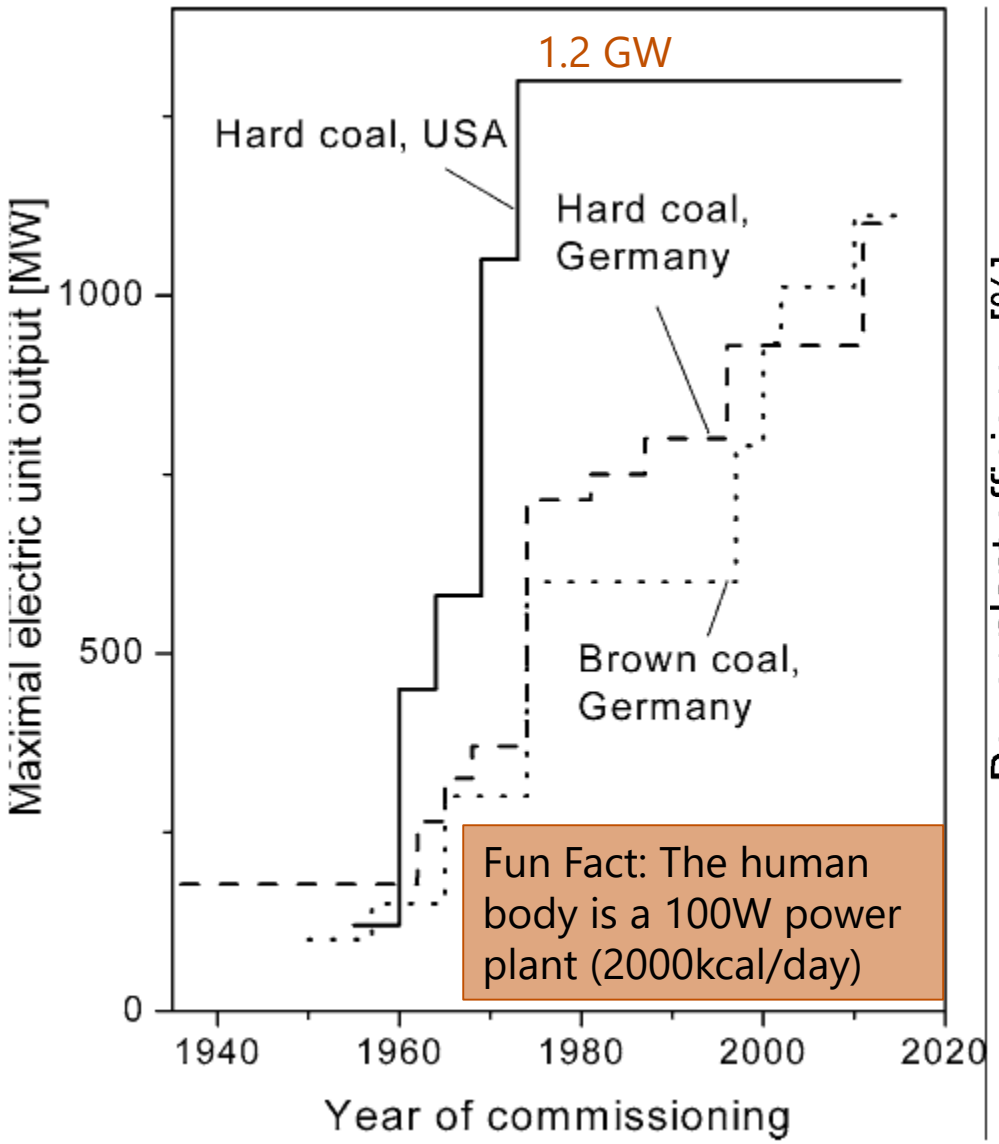
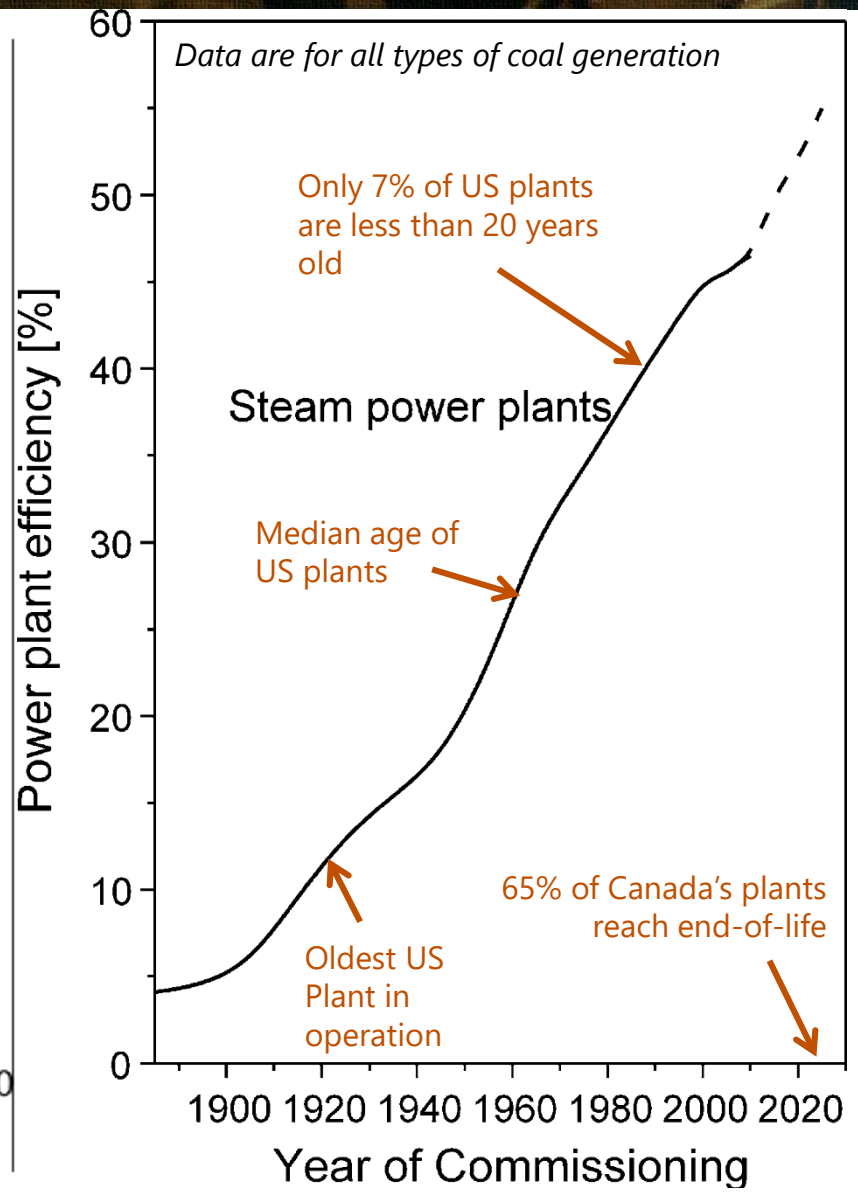
Scale, Efficiency, & Age



Fun Fact: The human body is a 100W power plant (2000kcal/day)



Sources: Spliethoff 2010, Ch 4
Environment Canada, "Canada moves to reduce emissions in the electricity sector." (2010)
US Energy Information Administration, "Existing Generating Unit in the United States by State and Energy Source, 2010"

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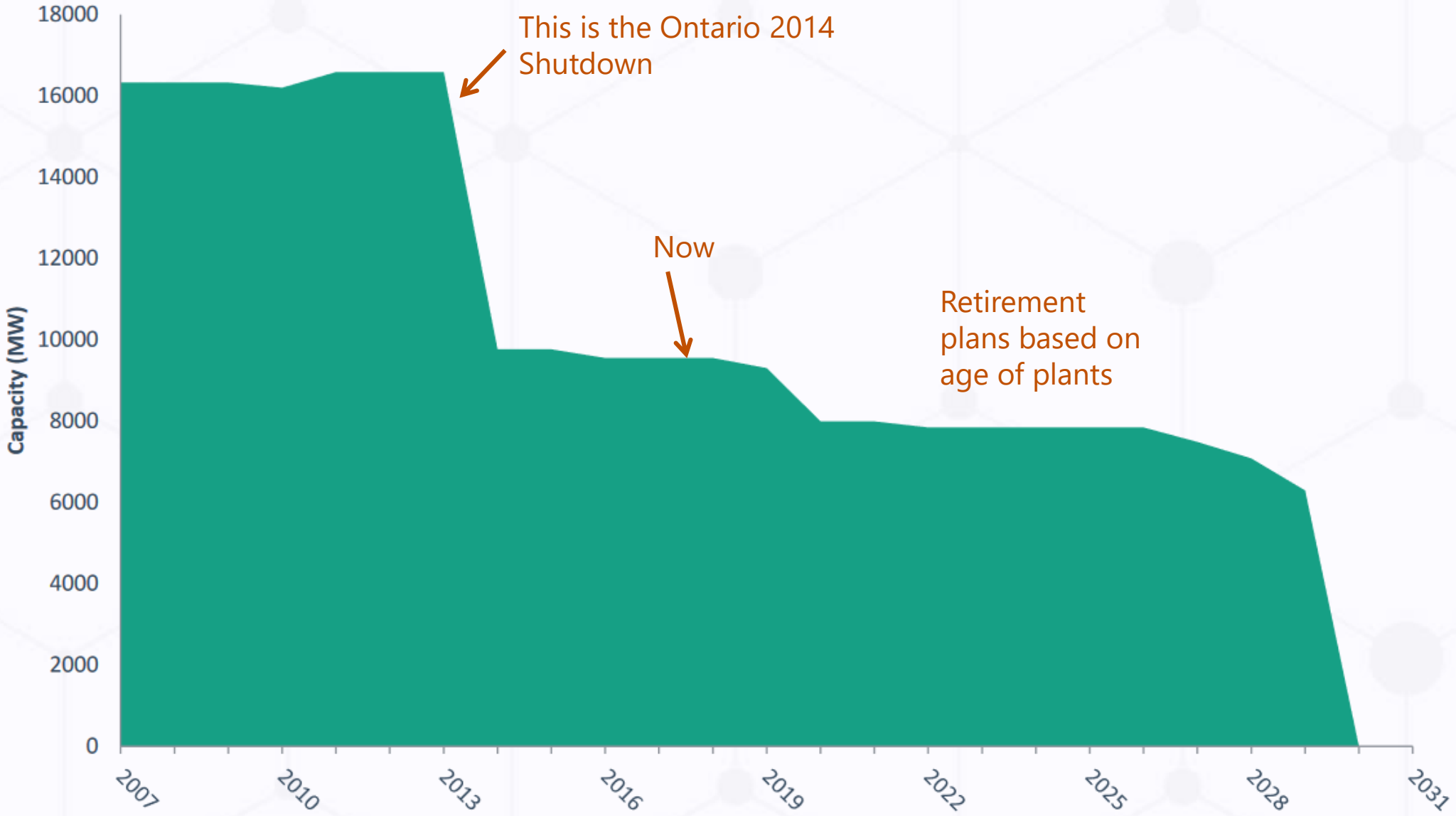
Canada Coal Production Predicted / Legislated



Sources: Canadian Electricity Association, Electricity 101 (2018)

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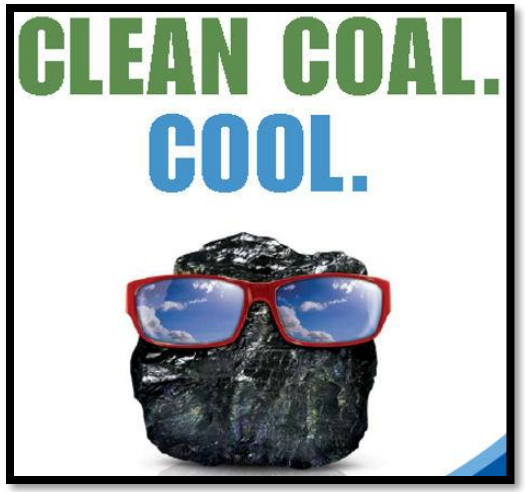
US Politics

- Social & Political War against "Clean Coal":
  - "Clean Coal" buzzword defeated by "No Such Thing As Clean Coal" buzzword (2009)
  - V.P. Biden pledges to stop new coal plants during campaign (2008).
  - Gov. Granholm (MI) bans all new coal plants with executive order regardless of "clean coal" status. Generally a state-level battle. (Also in ID, ME, NJ, GA, & TX).



Policy, Courts, and Regulations

- No US law regulates CO_2
- 2007 US Supreme Court says CO_2 counts as air pollutant
  - Therefore Environmental Protection Agency can regulate
- 2009 EPA declares CO_2 harmful air pollutant
  - Means they have authority to act without oversight
- 2012 EPA announces future strict limit on CO_2 for power, effectively preventing all coal without CCS
- 2012: EPA acknowledges commercial CCS technologies not available … effectively bans new coal power
  - (But also doesn't think anyone would build new ones anyway due to prices…)
- June 29, 2015 → US Supreme Court orders change: not "appropriate" (no evidence of cost/benefit ratio).
- Aug 3, 2015 → EPA Finalizes new standards
  - 1 lb per kWh limit for new large base-load nat gas plants (>25 MW)
  - 1.4 lb per kWh limit for new coal plants (requires 20% carbon capture
    - Significant because 20% capture already exists commercially. Previous rule required 90% capture, which did not.

Sources: Environmental Protection Agency, Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles. *Federal Register* 2011, 76, 57106.
Environmental Protection Agency, Standards of Performance for Greenhouse Gas Emissions for New Stationary Sources: Electric Utility Generating Units. *Federal Register*, 2012, in-press. Docket No. EPA-HQ-OAR-2011-0660.
http://www.nytimes.com/2015/06/30/us/supreme-court-blocks-obamas-limits-on-power-plants.html?_r=0
http://www3.epa.gov/airquality/cpp/fs-cps-overview.pdf

Then

- 2016: Supreme court fully shuts down rules
- Aug 21, 2018: POTUS moves to remove EPA rules finally
  - (never really did anything),
  - shifts regulatory power to the states

- Meanwhile, US coal power closing down anyway
  - 40% of capacity of US fleet closed or marked for shutdown since 2010
  - Only one tiny plant under construction in US.
- But everyone else…
  - 700 new plants in construction in China or by Chinese companies
  - 1600 total new in world under construction / planned.

Sources: Toronto Star. Ellen KnickmeyerThe Associated Press Seth Borenstein. "Trump plan scales back Obama's coal emissions standards". Aug 21. 2018
L. Michael Buchsbaum. Energy Transition. America's coal plants closing despite Trump. June 2018
Hiroko Tabuchi. As Beijing Joins Climate Fight, Chinese Companies Build Coal Plants. New York Times. July 1, 2017.

Coal and CCS In Canada

- Canada Legislation effective 2015
  - All existing coal-fired plants must meet 375 tonne/GWhr upon end of economic life (45 years) ➔ Compare: US is 454 tonne/GWhr
  - New coal permitted if it uses CCS, same emissions standards.
  - Law only takes effect "only if compliance is achievable".
- Sept 5, 2012: Quest Project Begun
  - Royal Dutch Shell paid for ~40% of $2bln project in Alberta
    - Rest paid by Canada.
  - 1st CCS Project for Oil Sands . Has captured ~3MtCO_2 (less than one Dofasco refinery in a year)
  - 80 km transportation distance from refinery
  - 2km deep injection into porous rock site – meant for storage
- Oct 2 2014: SaskPower's Boundary Dam first world's carbon capture from coal at commercial scale
  - 90% capture, amine solvent based
  - Some CO_2 sold for EOR, rest stored at Aquistore (underground sandstone)

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Sources: CBC news, "Shell OKs oilsands' 1st carbon capture project.". Sept 5, 2012. Carbon Capture @ Sequestration Technologies @ MIT. Sequestration.mit.edu
Canadian Electricity Association, Electricity 101 http://saskpowerccs.com/ccs-projects/carbon-storage-and-research-centre/
http://www.shell.ca/en/aboutshell/media-centre/news-and-media-releases/2012/0905quest.html
Shell Canada. Quest Carbon Capture and Storage. https://www.shell.ca/en_ca/about-us/projects-and-sites/quest-carbon-capture-and-storage-project.html

North American CCS Projects

	Power Plant CCS Projects
	Pilot CCS Projects
	Commercial EOR Projects
	Non-Power CCS Projects

Sources: Carbon Capture @ Sequestration Technologies @ MIT. Sequestration.mit.edu

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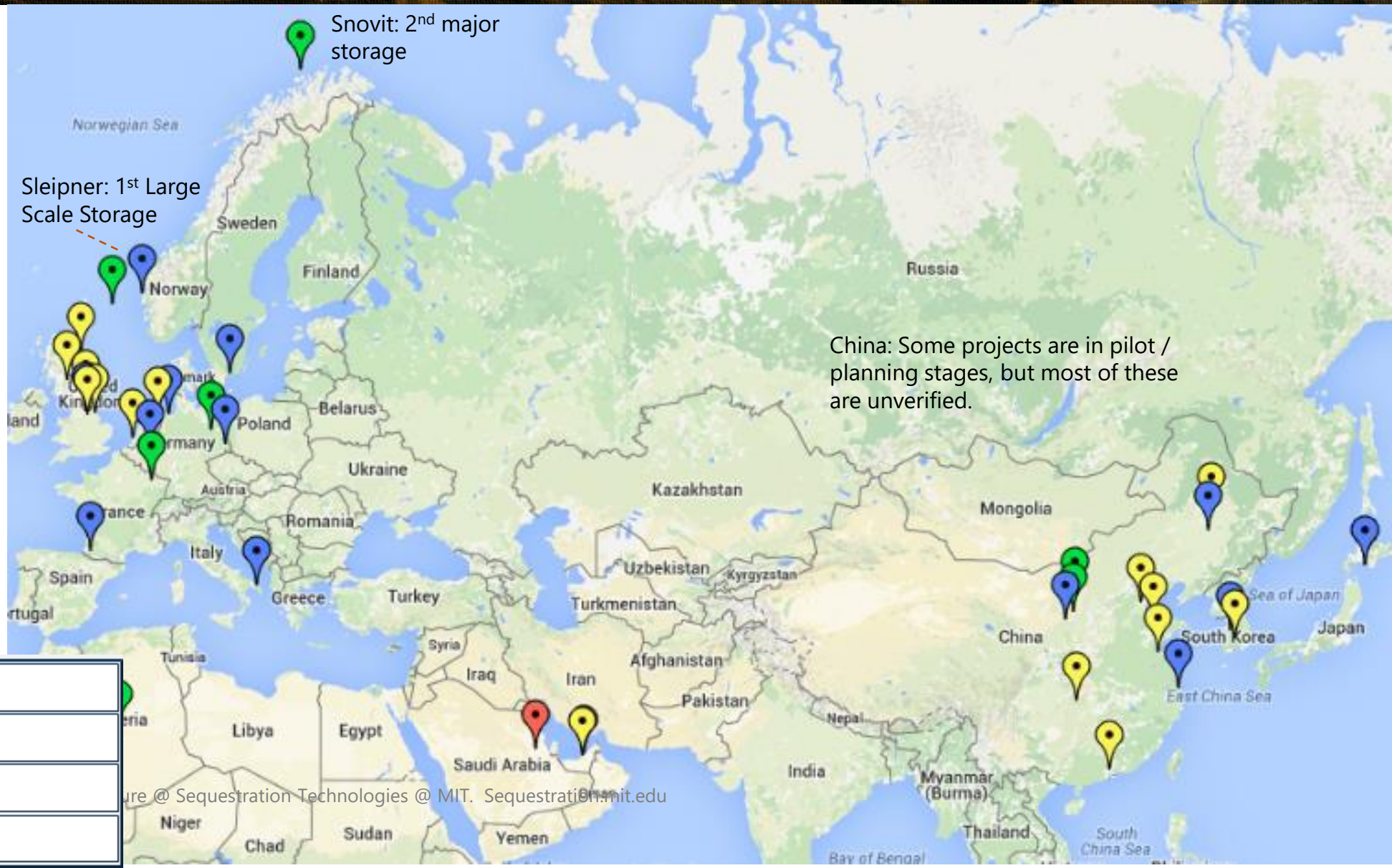
Eurasian CCS Projects

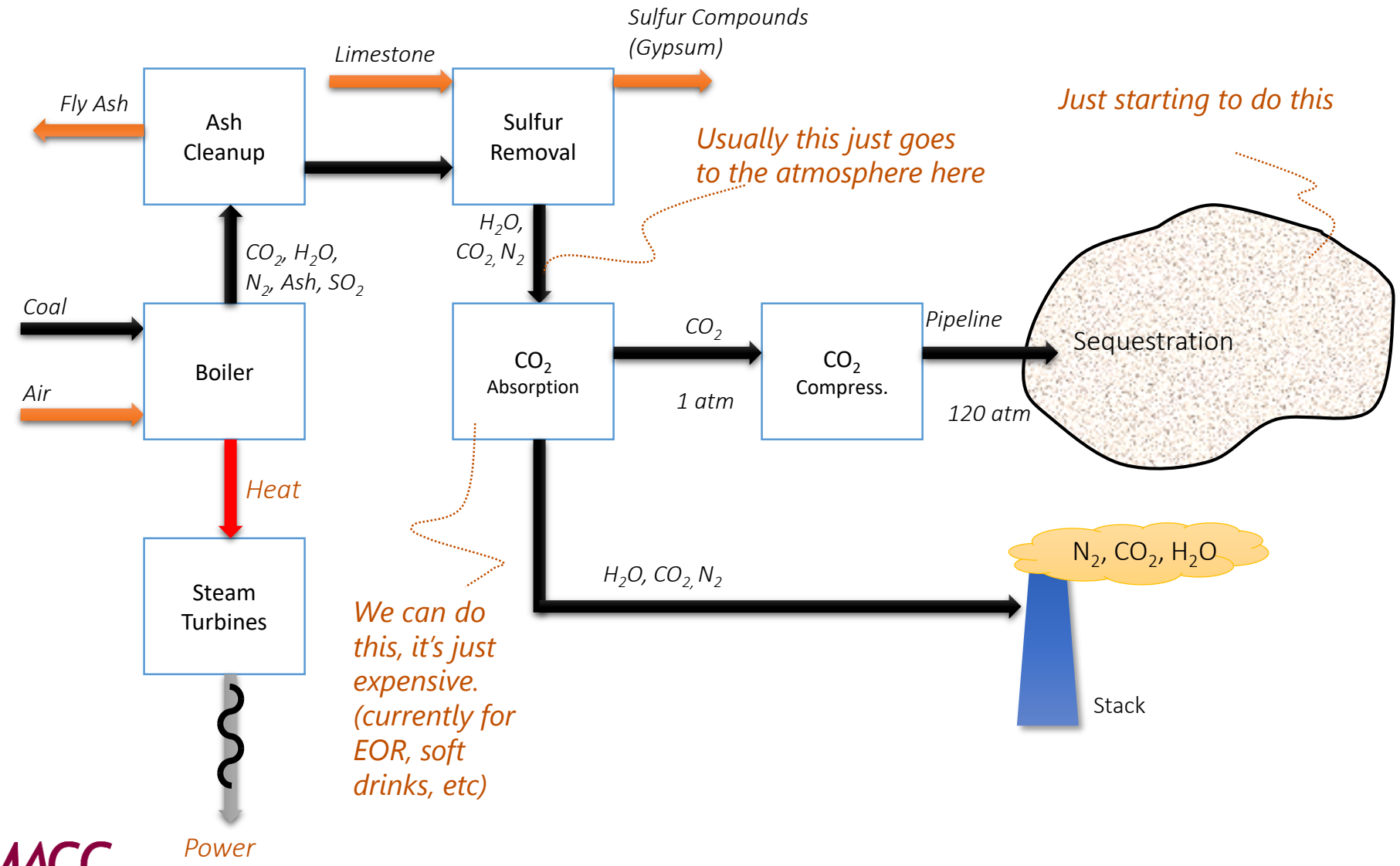
We will talk about CCS tech in lecture 3.7.



2. The process

Current state of the industry

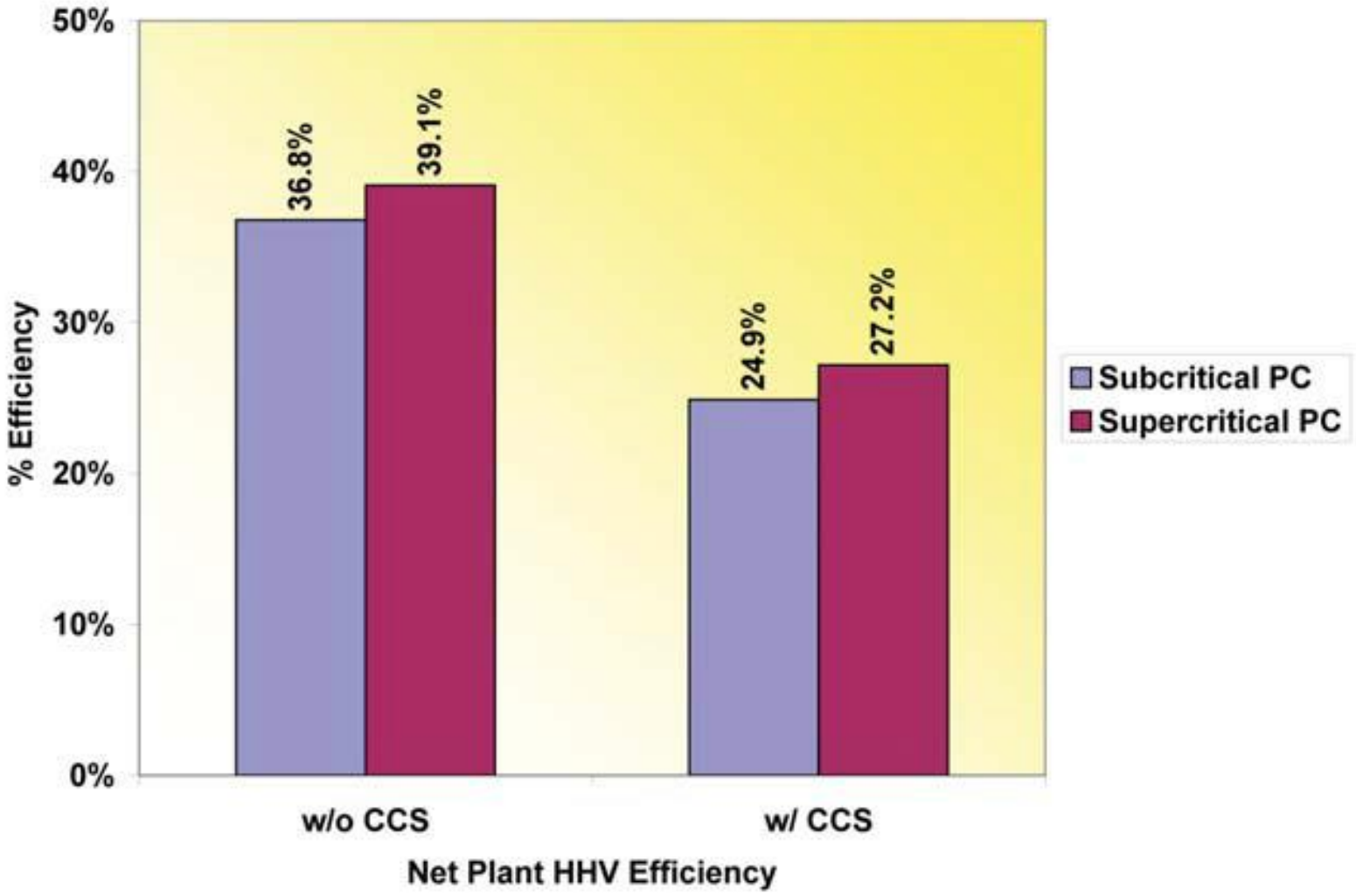
Basic Process (Subcritical & Supercritical)



Source: NETL 2007 - Bituminous Baseline

Subcritical & Supercritical

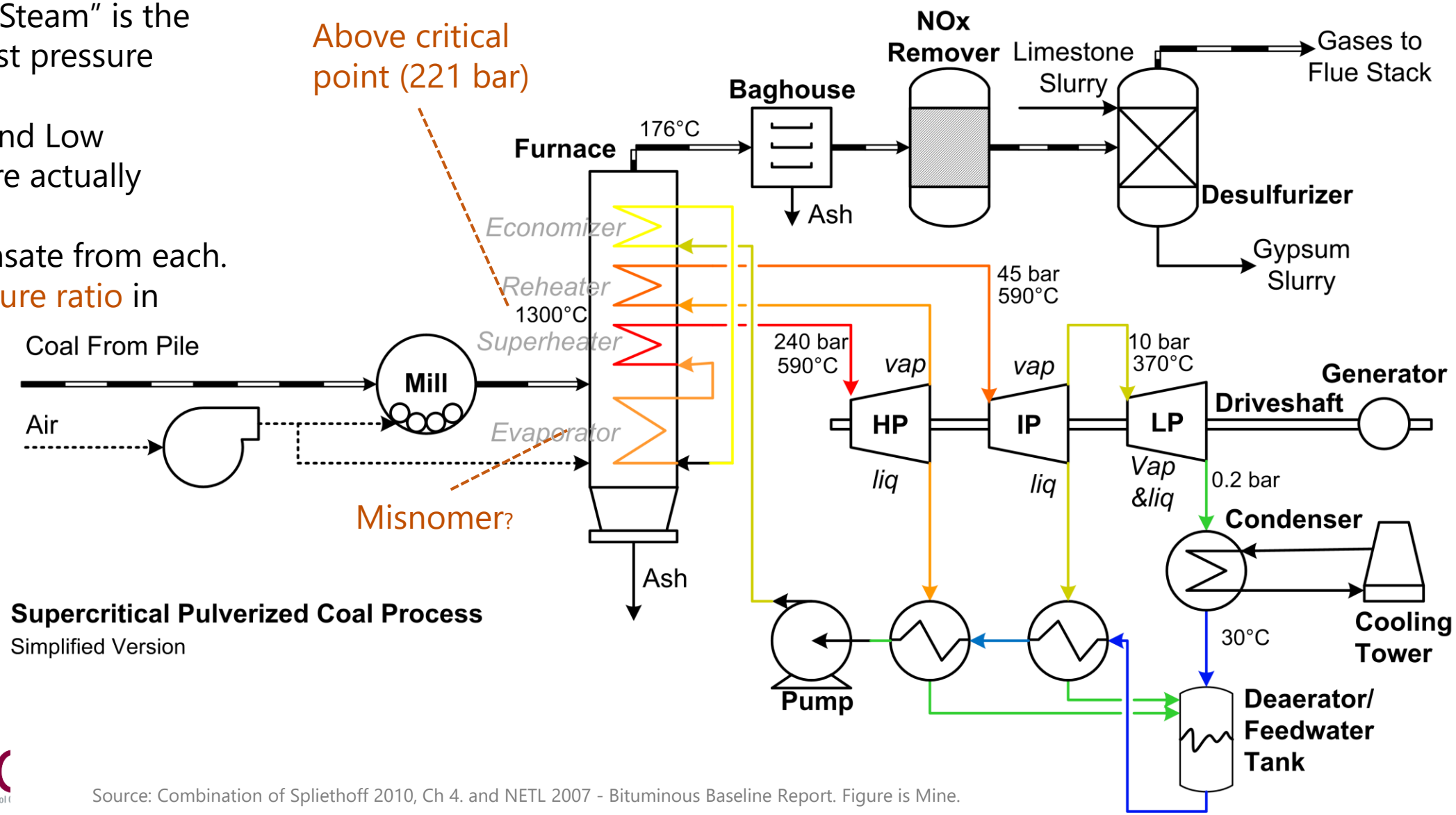
- Basic process is essentially the same between them
- Just uses different maximum steam pressure levels:
- **Subcritical**: 165 bar, 566°C
- **Supercritical**: 240 bar, 593°C (above critical point)



Sources: NETL 2007 - Bituminous Baseline Repor
NETL, Klara J and Wimer J. Pulverized Bituminous Coal Plants With and Without Carbon Capture & Sequestration (ref's same work)

Detailed Process (Supercritical)

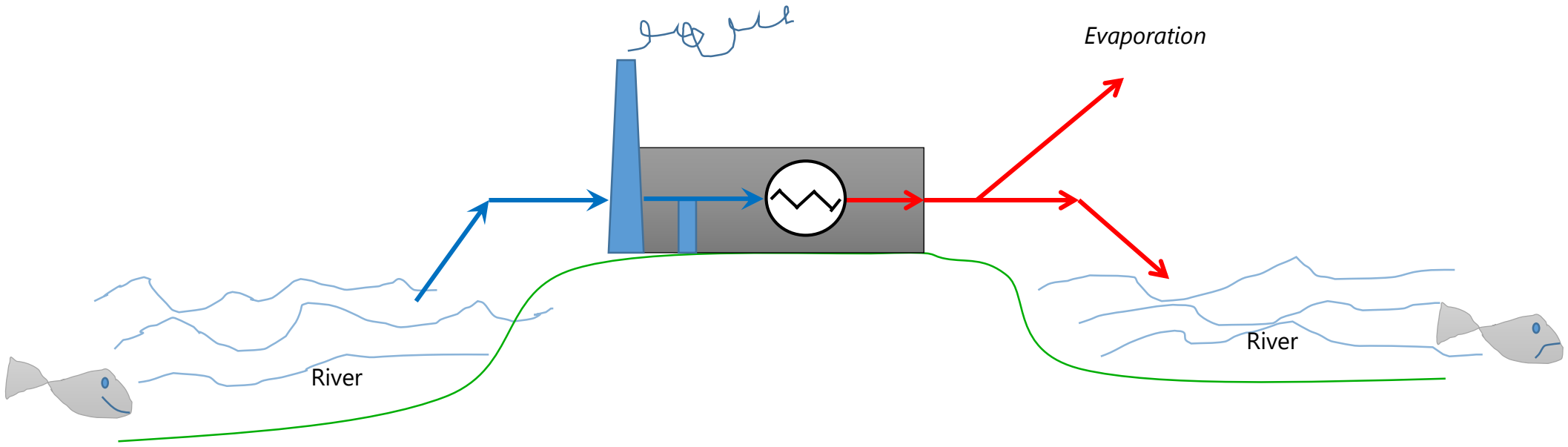
Other Notes: "Live Steam" is the name for the highest pressure level.
The Intermediate, and Low Pressure turbines are actually multi-stage, with some liquid condensate from each.
Heuristic: Use pressure ratio in range of 2 to 5.



Supercritical Pulverized Coal Process
Simplified Version

Source: Combination of Spliethoff 2010, Ch 4. and NETL 2007 - Bituminous Baseline Report. Figure is Mine.

Once-Through Cooling



- Heavily limit outlet temperatures to avoid killing everything.
  - Need huge flows through due to small temperature difference of water

- Cheap to implement.. Pump water through heat exch.
- Local bans in place or proposed
- Half of US coal plans using this strategy.

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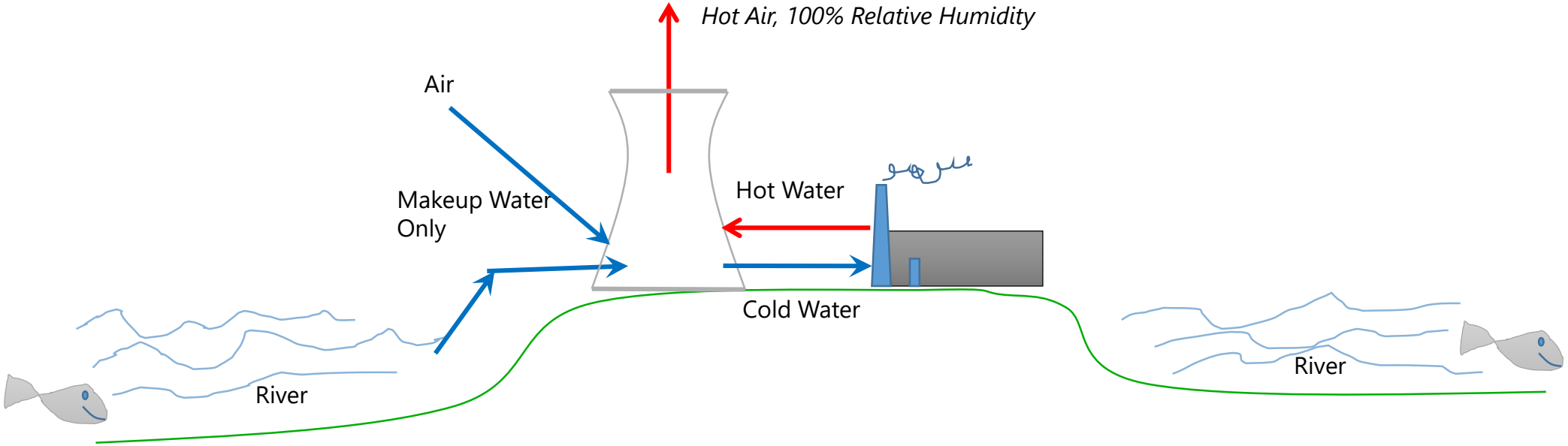
Wet Cooling Towers



- Contact air and water together to facilitate heat transfer
  - A.k.a "evaporative" cooling
- Uses about 1.7% of plant output this
- More capital cost.

Sources: US EPA. Energy Penalties, Air Emissions, and Cooling Tower Side Effects. http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase1/upload/2009_04_02_316b_phase1_technical_ch3.pdf
Adams & Barton, AIChE J, 2010.

- Much less water consumption – some water allowed to evaporate but uses considerably less.
- River water mixes with process water… need extra treatment!
- Can pollute the air with stuff in the river water.

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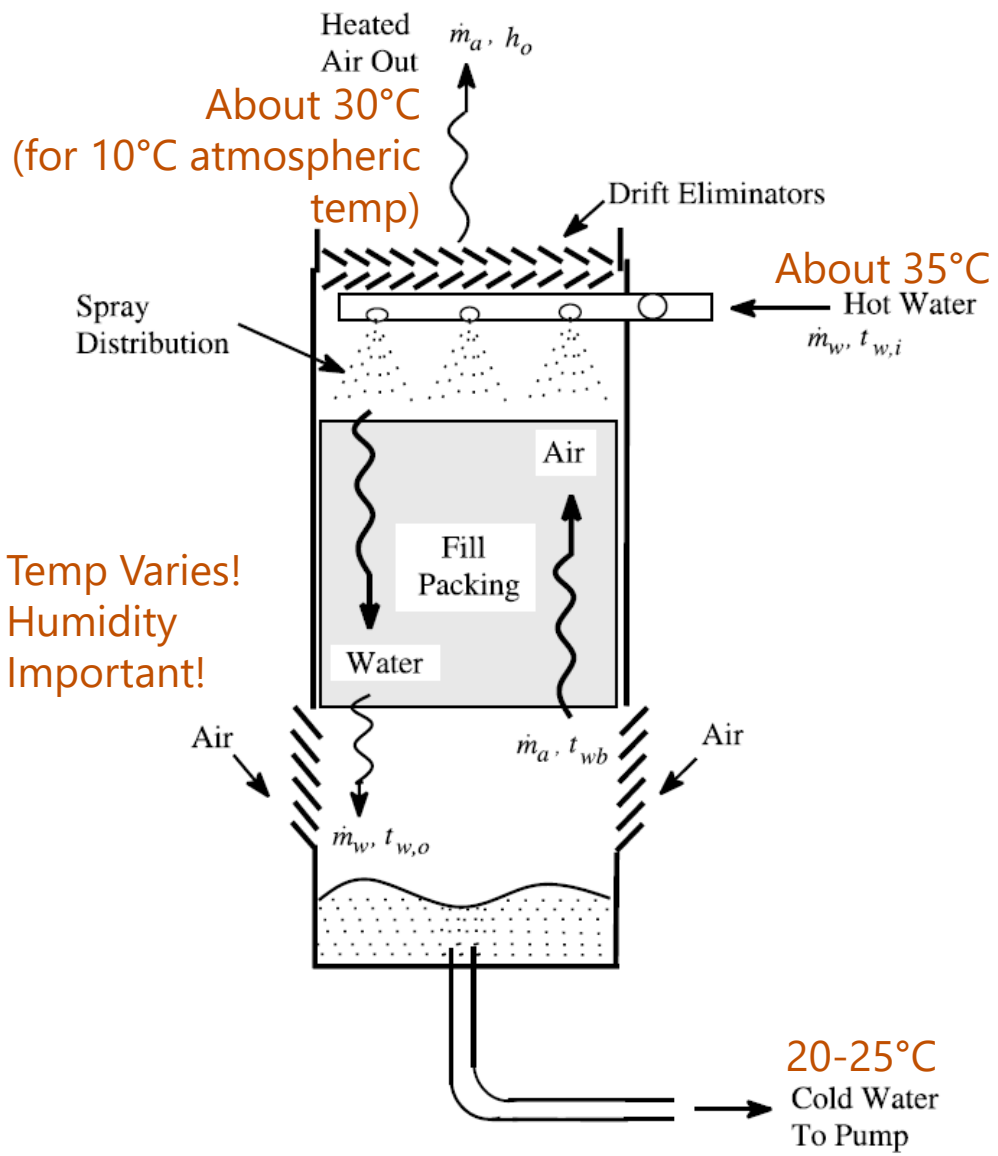
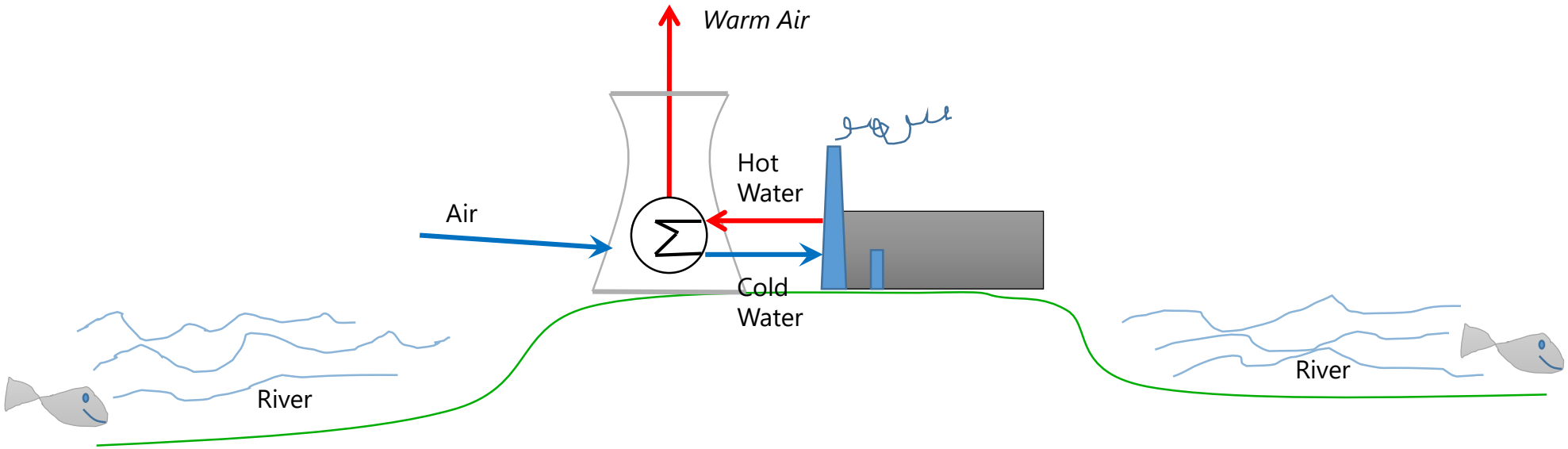
Wet Cooling Tower Details



- Variations in air temperature and humidity has major impact.
- In "natural draft" towers (shown), we don't use fans for air intake
  - chimney effect draws air in, pushes it upward
  - save on electricity but lose a degree of freedom for control (air flow rate)
  - big optimization problem

Sources: Khan et al.. Energy Conv. Manage. 44, 2073-2091 (2003)
J. Smrekar et al. / Energy Conversion and Management 47 (2006) 1086–1100

Dry-Cooling



- Heat-exchanger based (water and air don't mix)
  - But need much more surface area per J of cooling → more expensive
- No water consumption

- Huge energy penalty… up to 8.6% of your power just for cooling.
  - Both natural convection and forced convection possible
  - Forced (sometimes just extra wind is enough)

Sources: US EPA. Energy Penalties, Air Emissions, and Cooling Tower Side Effects. http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase1/upload/2009_04_02_316b_phase1_technical_ch3.pdf
Adams & Barton, AIChE J, 2010.

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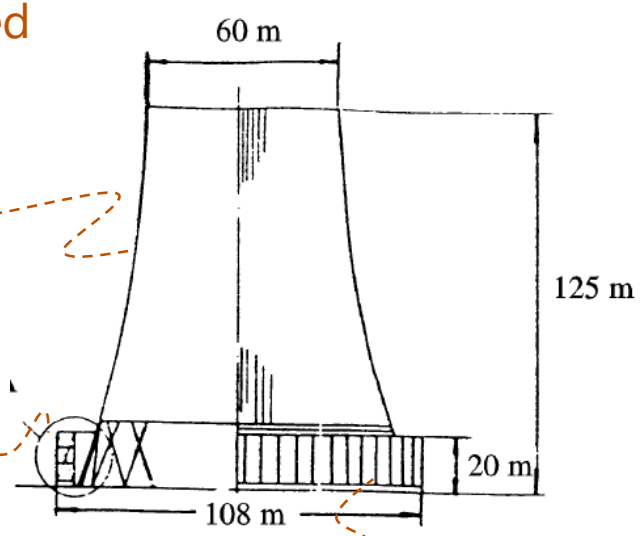
Dry Cooling: Size and Scale

180-270 MW
Delivered

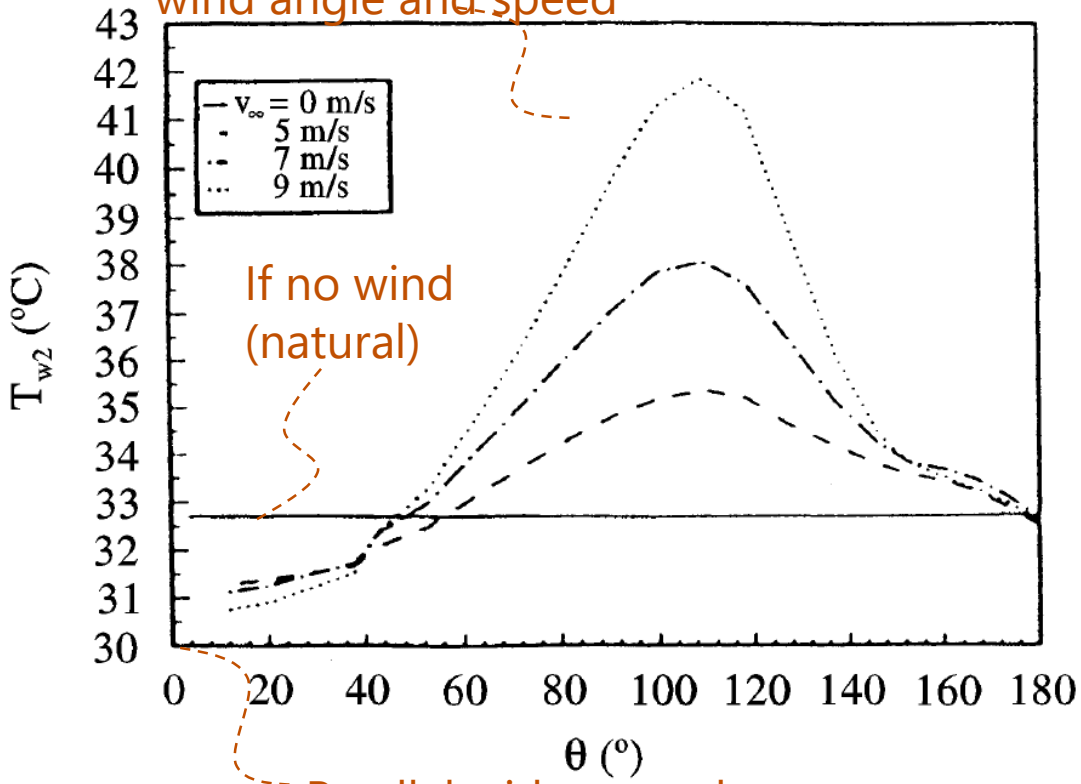
Large size needed
for chimney effect

Air Enters at
Base



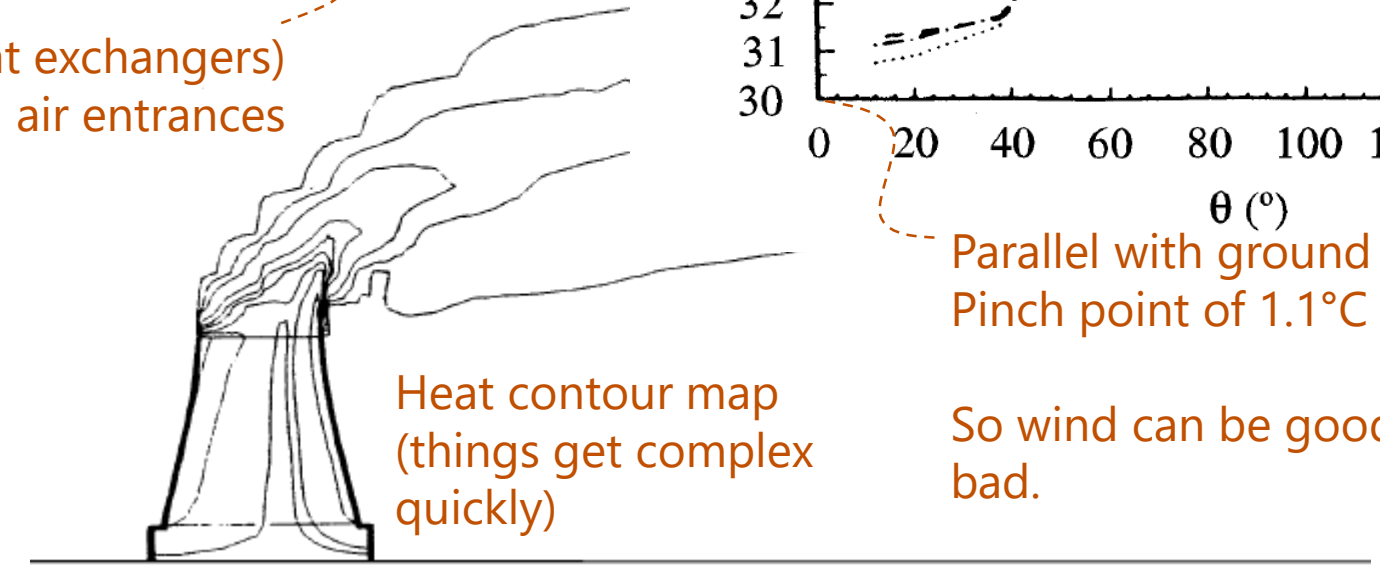
Ring of radiators (heat exchangers)
located around air entrances

outlet water temperature depends on
wind angle and speed



If no wind
(natural)

Parallel with ground
Pinch point of 1.1°C



Heat contour map
(things get complex
quickly)

So wind can be good but also can be
bad.

Sources: Su MD et al. J Wind Eng Ind Aerodyn
79:289-306 (1999).

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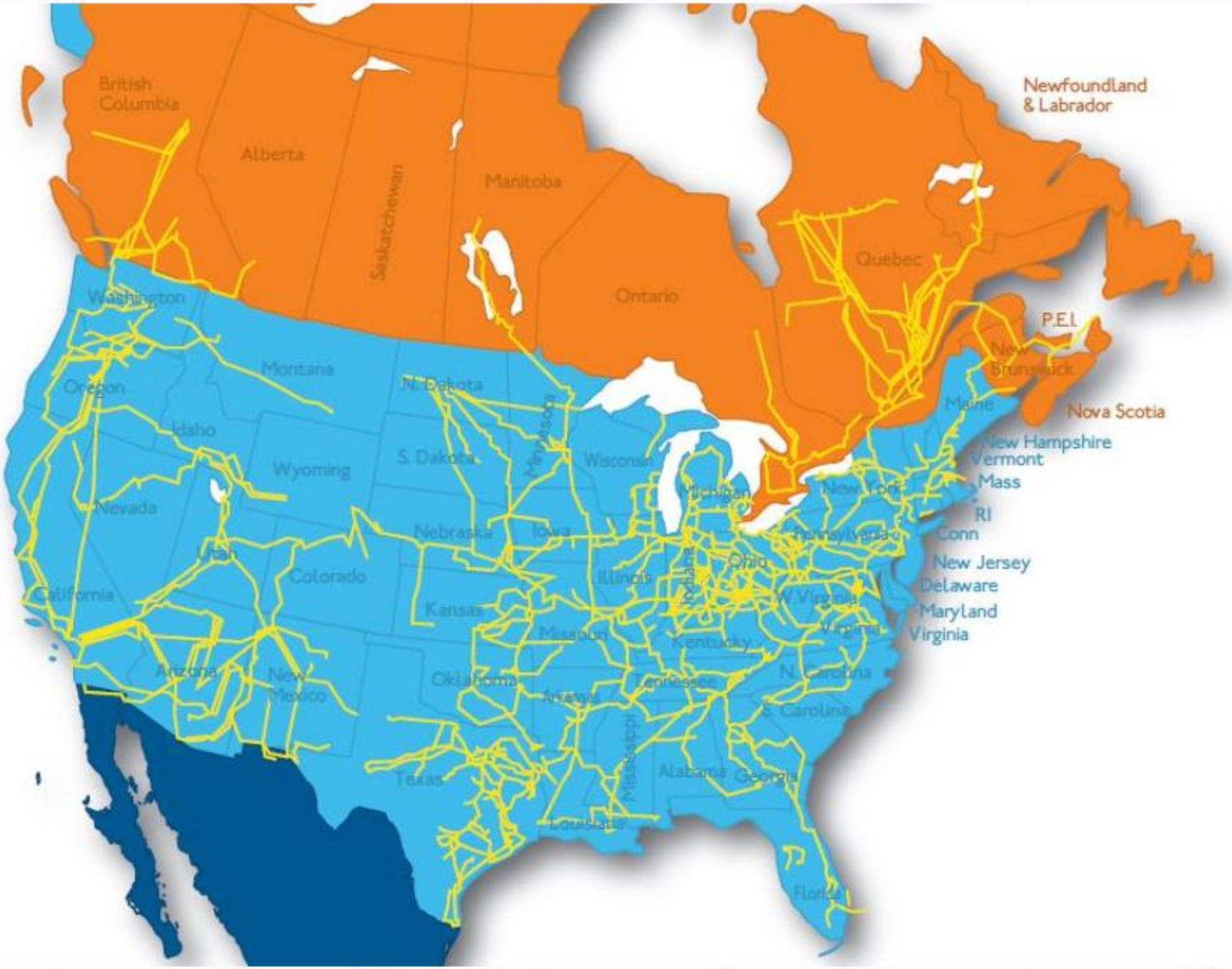
Elec Transport



Sources: Canadian Electricity Association. Electricity 101 (2018)

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