Solid Fuel Gasification

and the Integrated Gasification Combined Cycle (IGCC)

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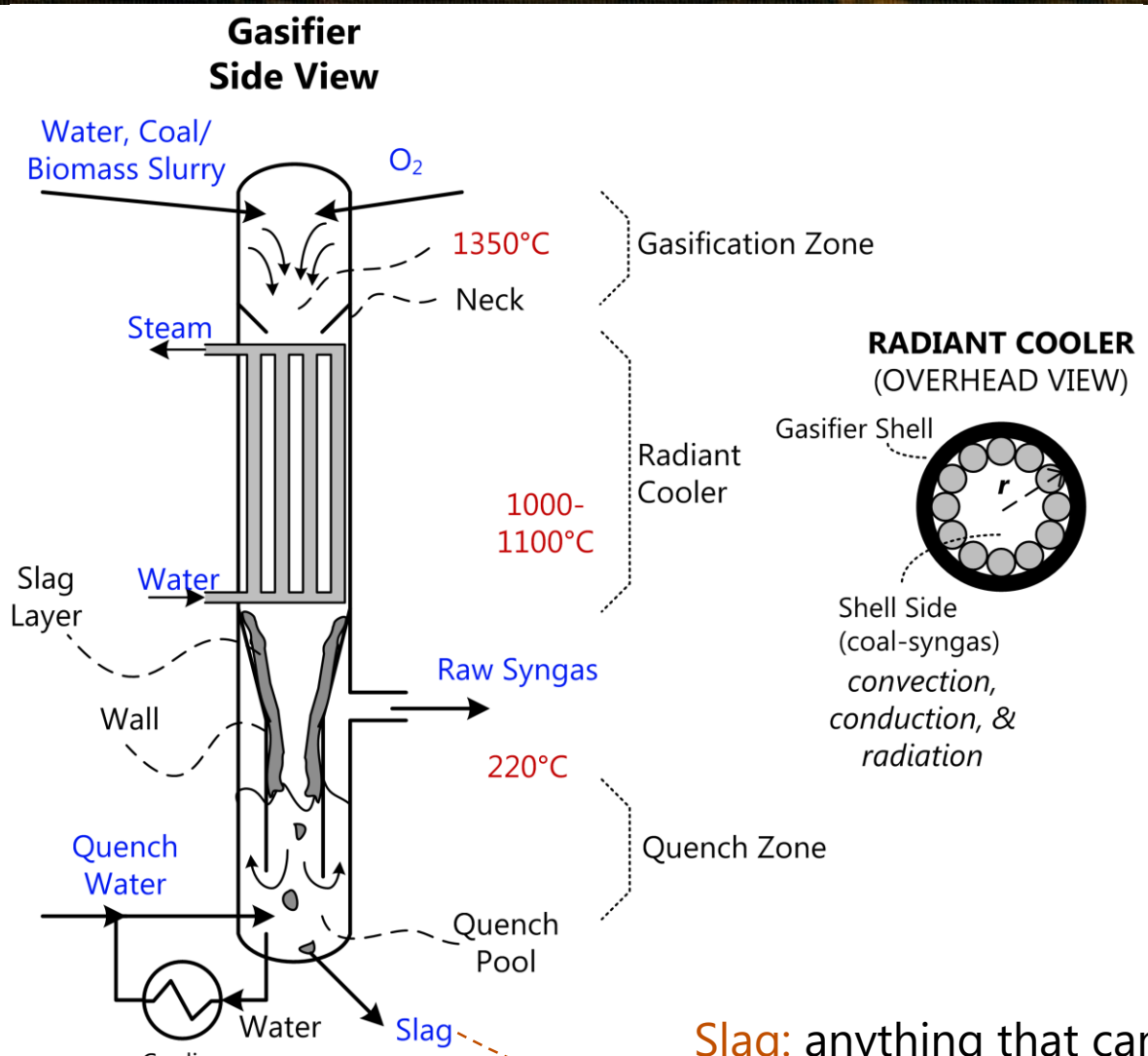
Lecture 4.1 – 2018 Edition

1. Background

Gasification Basics

Gasifier Example (GE / Texaco Design)



- Many variants (shown is GE's Downward Entrained Flow with Radiant Cooling)
- Convert carbonaceous solids into syngas
- Use some of the energy in the solid to get temperatures high
- High pressure: up to 60 bar.

Slag: anything that can't be volatized. (Oxides of metals)

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Fundamental Goal: Produce Syngas from Solids

- Can gasify many kinds of solid fuels
  - Coal
  - Petroleum Coke
  - Biomass
  - Rubber
  - Solid Wastes
- Syngas Composition
  - Hydrogen
  - Carbon Monoxide
  - Methane (limited)
  - Carbon Dioxide (waste)
  - Water (waste)

Solid Gasification Reactions

Coal decomposes when hot into solid carbon bits (char) and volatile matter. The char reacts with various gases to become gas phase products.

$$\text{Coal} \rightarrow C_{(\text{in char})} + \text{Volatiles}$$

$$C_{(\text{in char})} + 0.5O_2 \rightarrow CO$$

$$C_{(\text{in char})} + CO_2 \rightarrow 2CO$$

$$C_{(\text{in char})} + H_2O \rightarrow H_2 + CO$$

Oxidation Reactions (heat producing)

Energy Originating in Coal Converted to Heat

$$C_{(\text{in coal})} + O_2 \rightarrow CO_2$$

$$\text{Volatiles} + O_2 \rightarrow CO_2 + H_2O$$

$$\text{Volatiles} = CH_4, CO, H_2, \text{etc}$$

Syngas Producing Gas Phase Rxns

Partial Oxidation of Methane

$$CH_4 + 0.5O_2 \rightarrow CO + 2H_2$$

Steam Reforming of Methane

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

Water Gas Shift Reaction

$$CO + H_2O \rightarrow CO_2 + H_2$$

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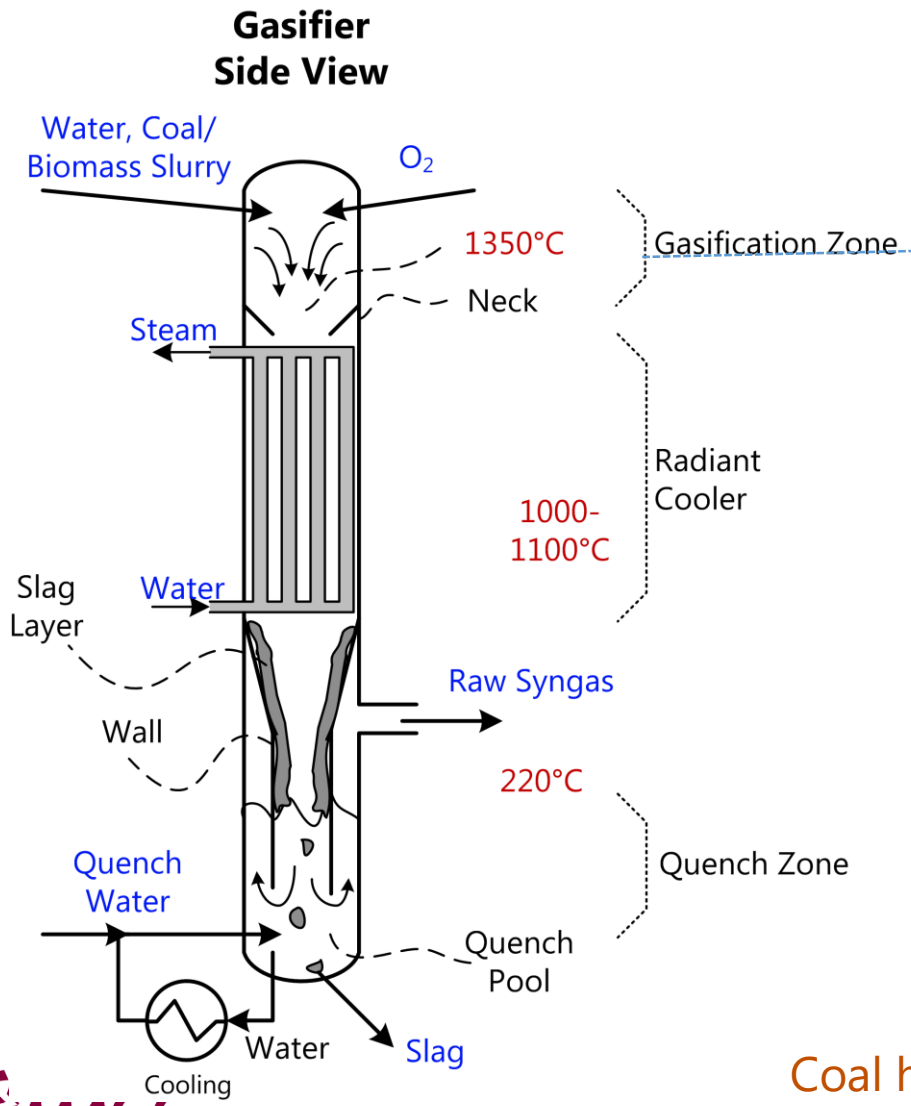
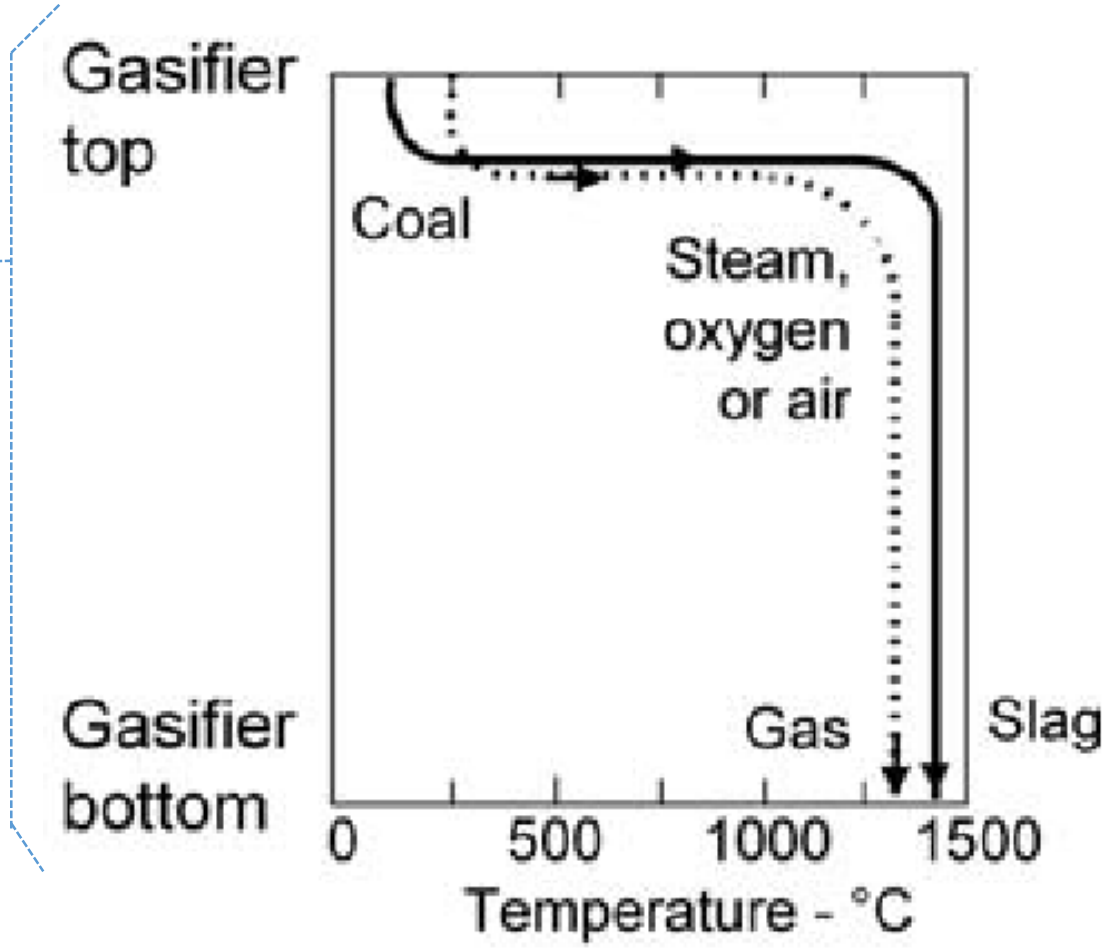
Sources: Watanabe H, Otaka M. Fuel 85 (2006) 1935–1943

Types of Gasifiers: Entrained Flow





Coal has residence times less than a second!

Sources: Spliethoff 2010, Ch 7, p587

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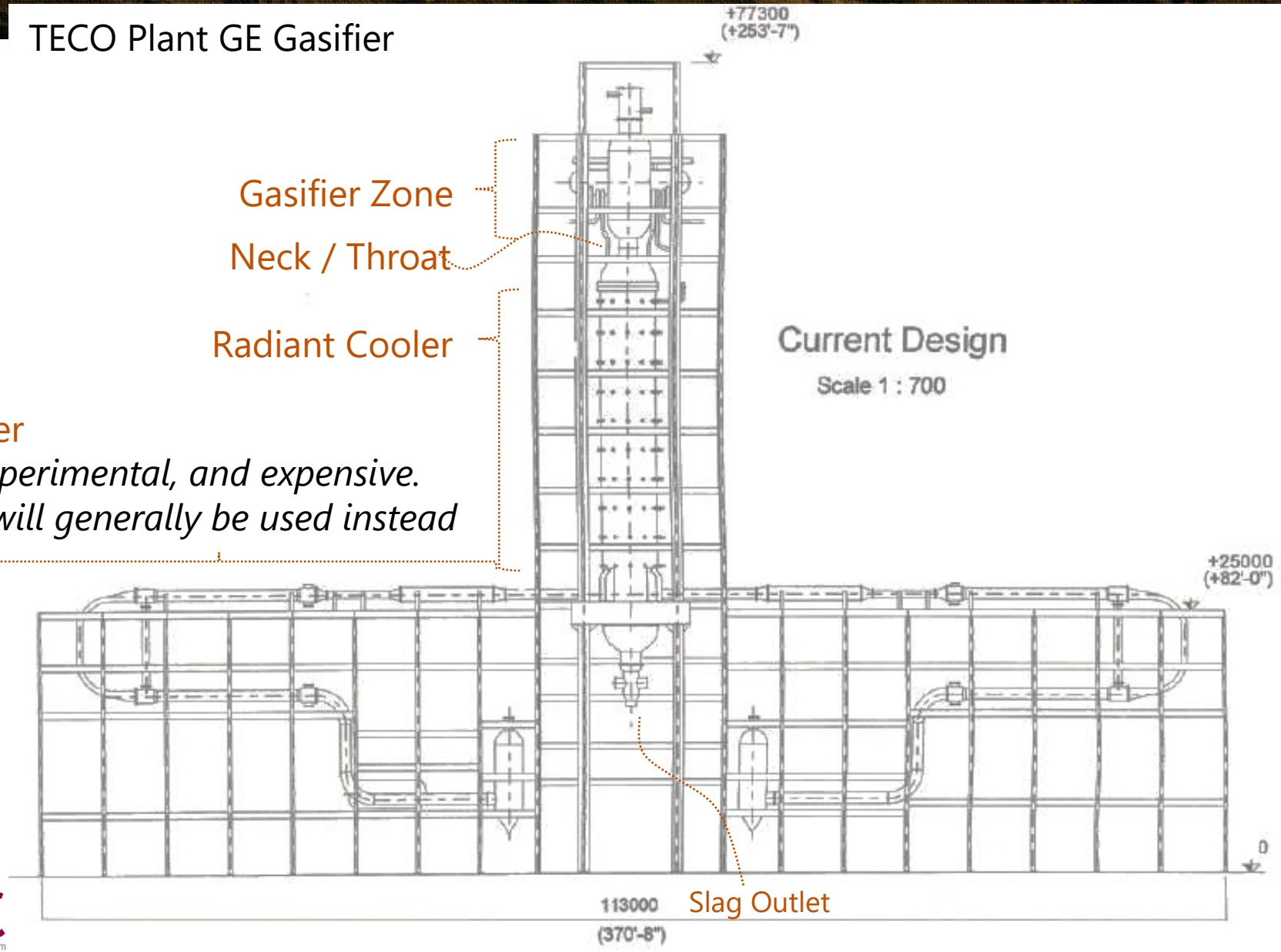
Scale: Entrained Flow

TECO Plant GE Gasifier



Gasifier Zone

Neck / Throat

Radiant Cooler

Convective Cooler

Note: this was experimental, and expensive.
Quench cooling will generally be used instead

Slag Outlet

Sources: Holt 2006.

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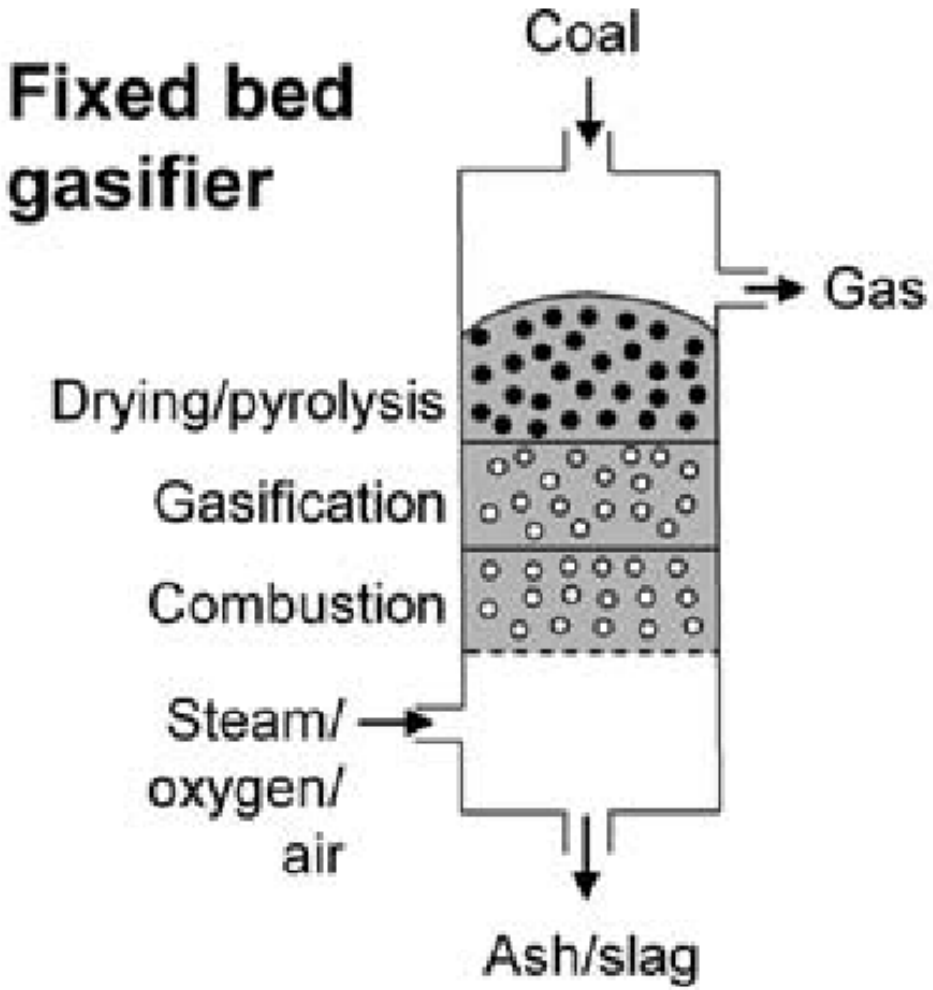
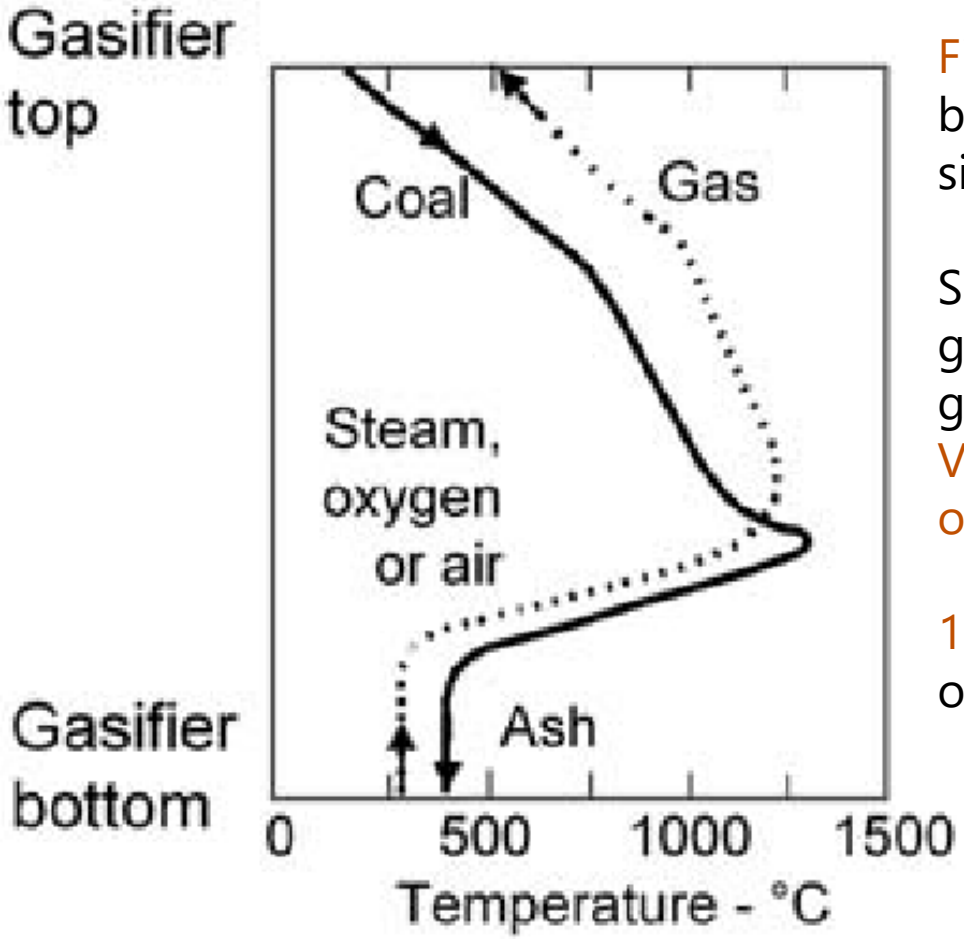
Types of Gasifiers: Fixed Bed





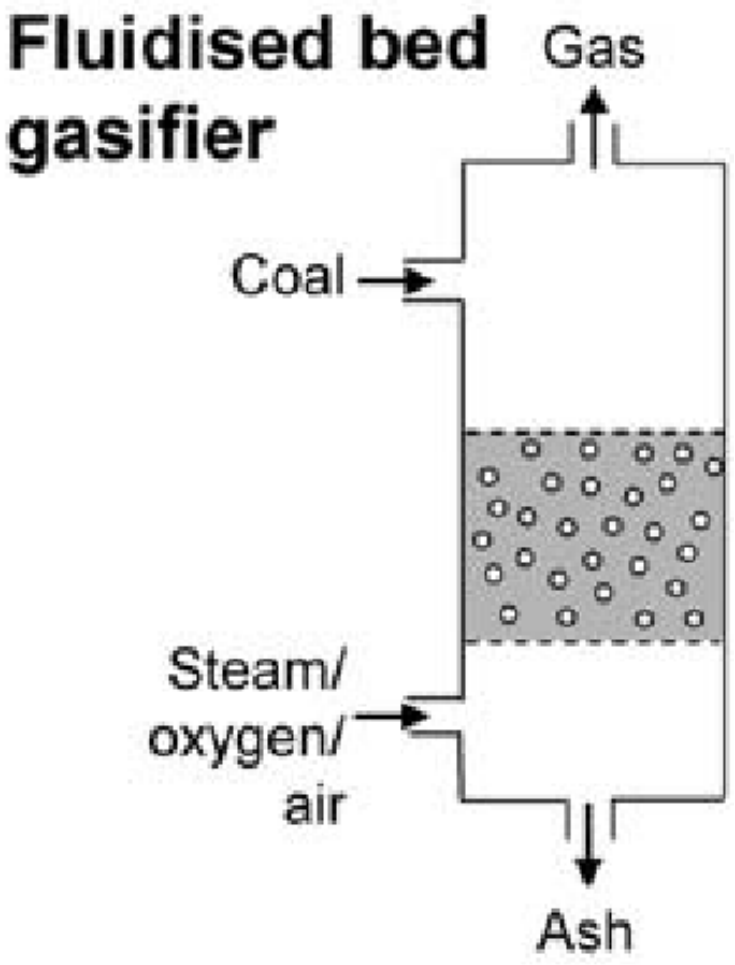
Fixed Bed: Maintain a thick bed of coal. Solids sit on sieves at various layers.

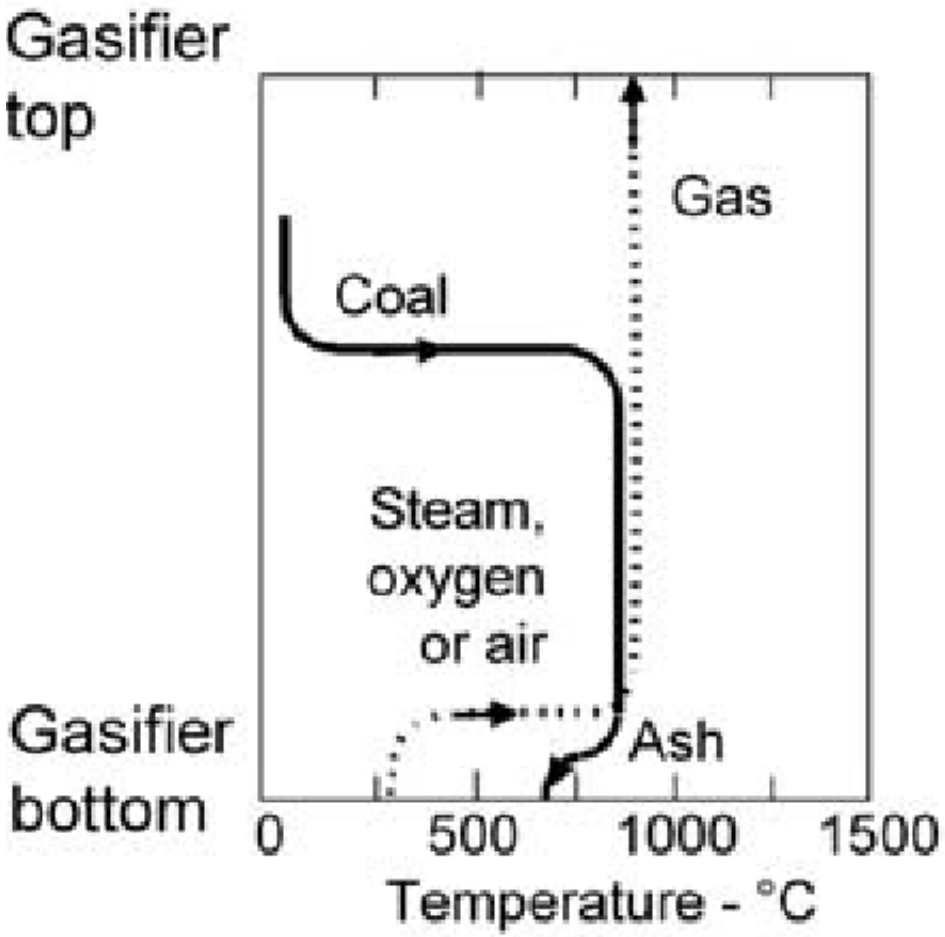
Solids filter downward gradually as they ash or gasify.
Very long residence time of solids

152 fixed-bed gasifiers in operation worldwide

Sources: Spliethoff 2010, Ch 7, p587

Types of Gasifiers: Fluidized Bed





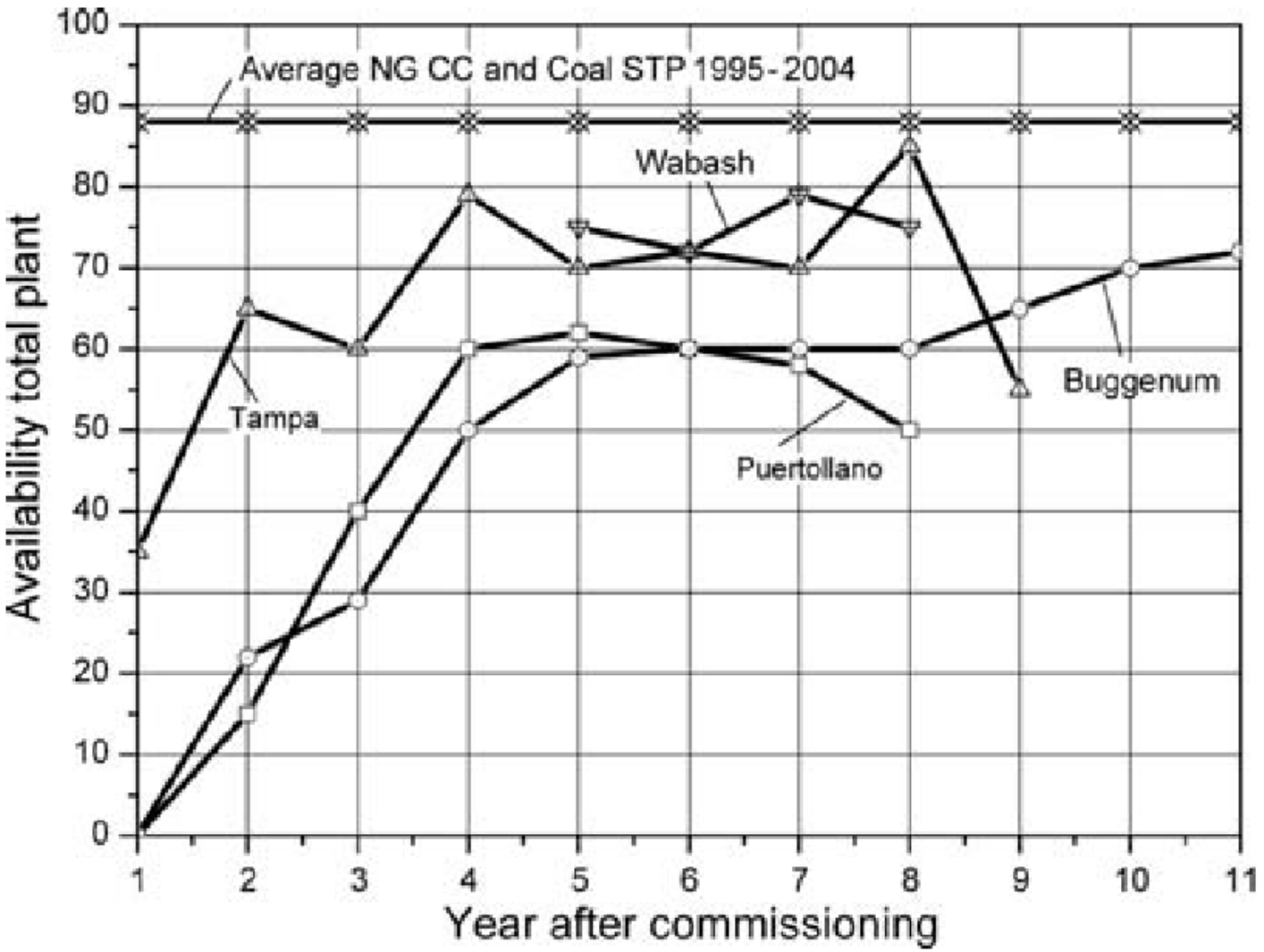
Fluidized Bed: Particles are suspended in air by upward gas flow.

10-30 minute residence time of solids

Sources: Spliethoff 2010, Ch 7, p587

Operational Challenges and Limits

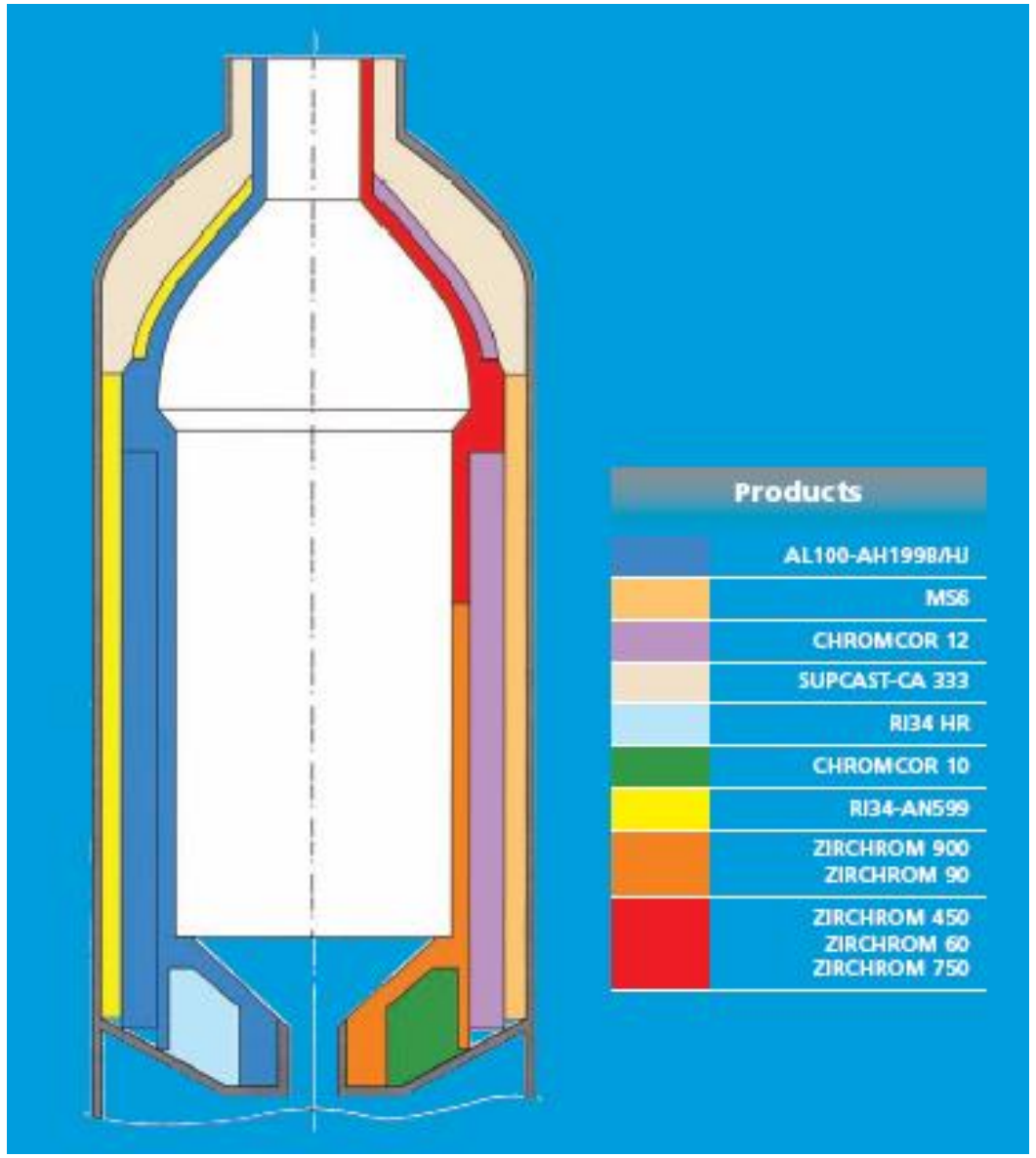
- Running a gasifier is as much an art as it is a science
  - At best, 80% uptime
  - Can't see inside
  - Melts thermocouples → can't see temperature profiles
  - Multi-day startup from cold. 1-6 hour startup from hot
    - Have to burn natural gas to get it hot & keep it warm during shutdown



Sources: Spliethoff 2010, Ch 7, p587

Operational Challenges and Limits (2)

- Very inflexible: Steady-state only
- Have to re-brick every two years
  - Refractory insulation literally gets burnt up alongside the coal
  - Several feet of refractory burnt up each year…
- So, typically have multiple gasifiers in parallel
  - Backup gasifier on standby, kept hot with natural gas



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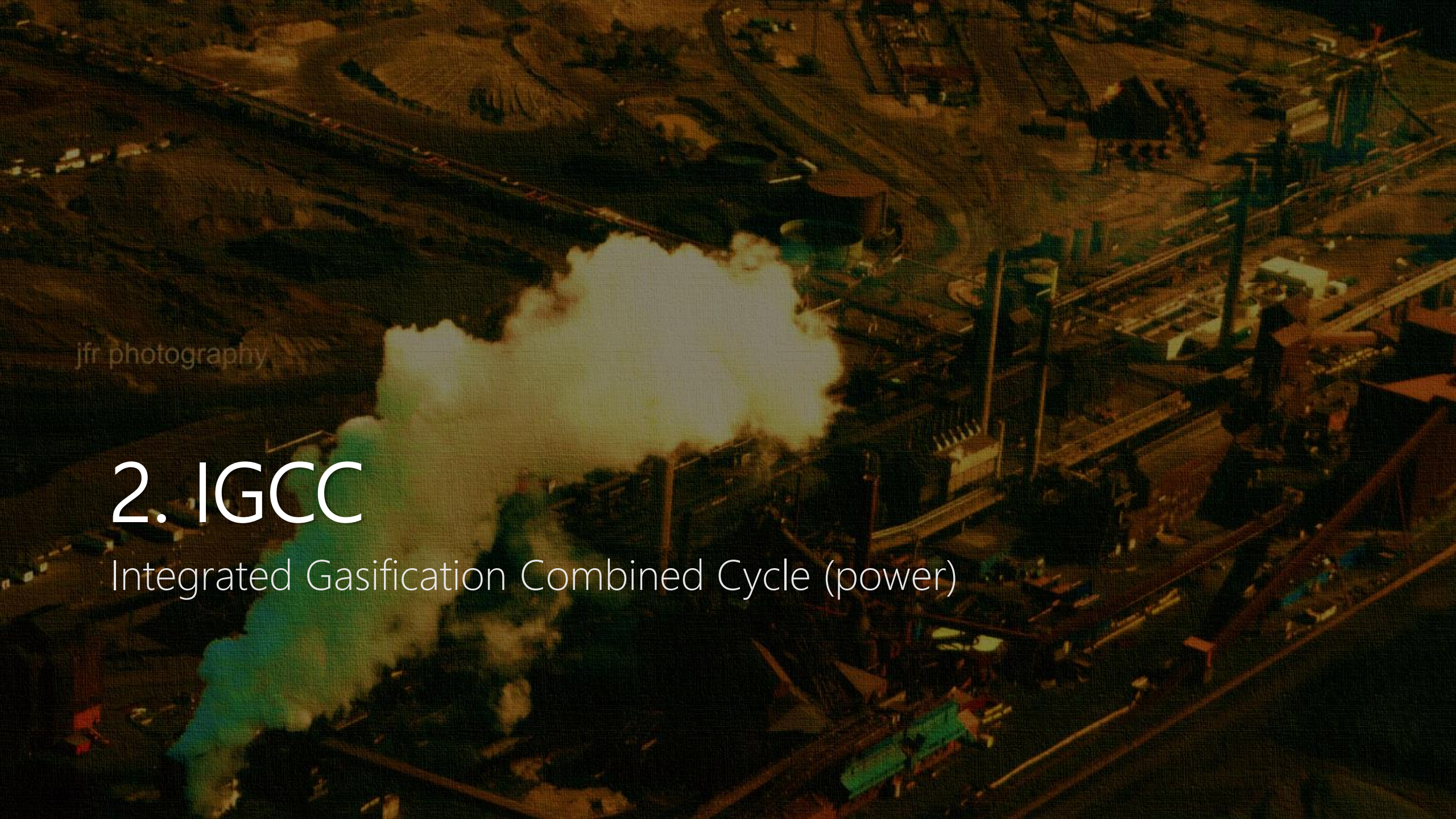
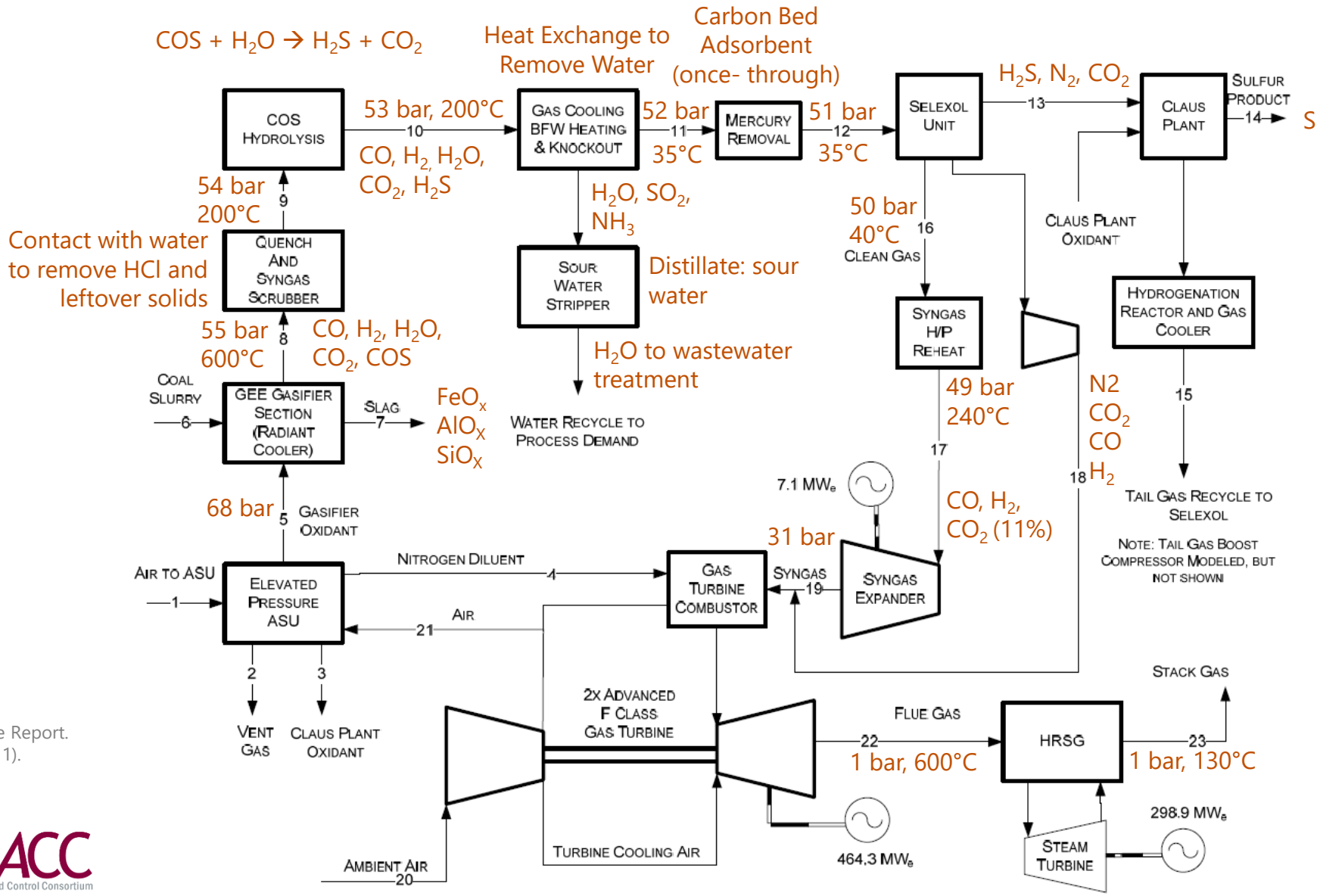


2. IGCC

Integrated Gasification Combined Cycle (power)

IGCC Process



Sources: NETL Bituminous Baseline Report.
See also Field and Brasington (2011).

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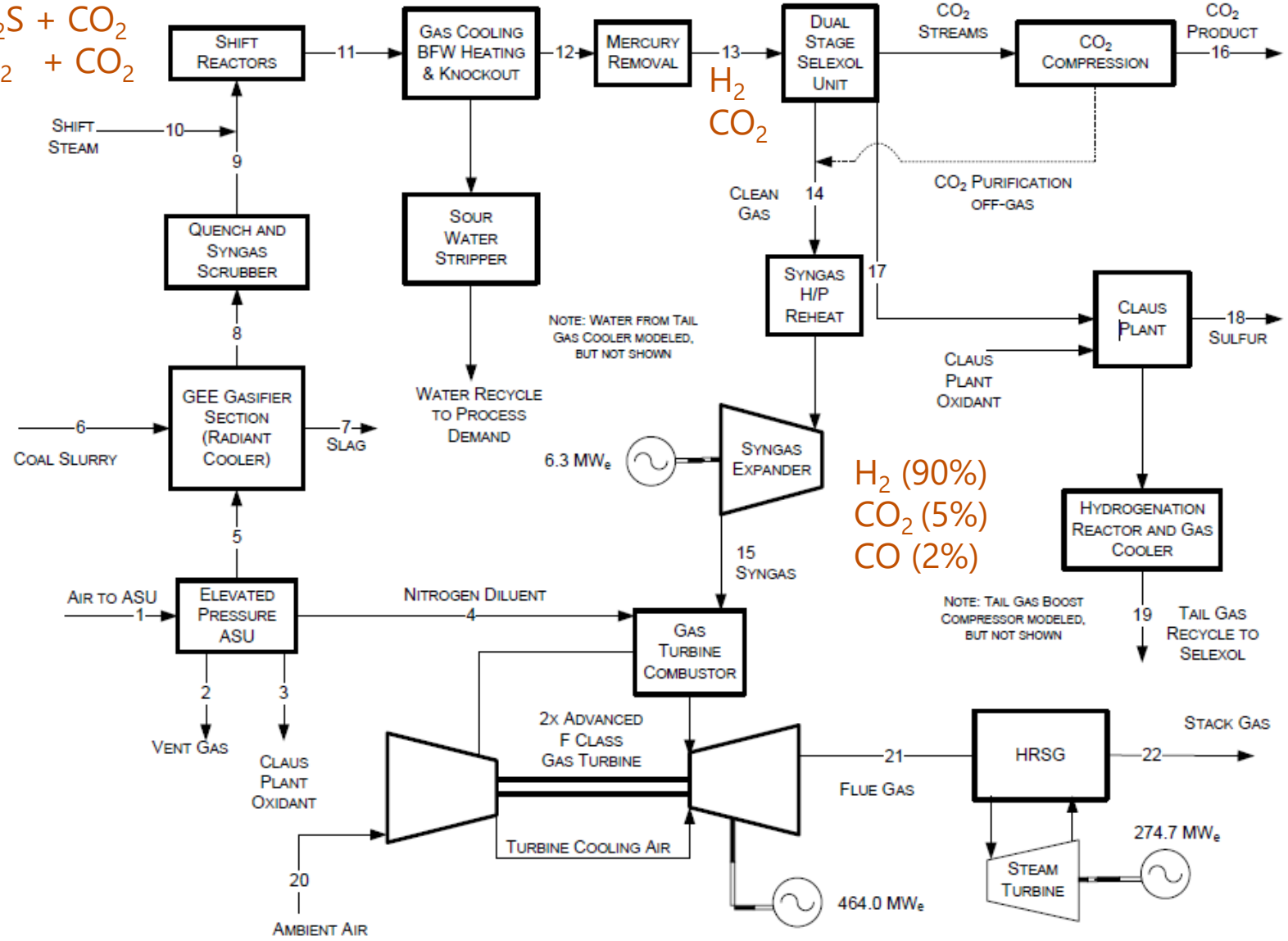
IGCC with CO_2 Capture

$COS + H_2O \rightarrow H_2S + CO_2$

$CO + H2O \rightarrow H_2 + CO_2$



Sources: NETL Bituminous Baseline Report. See also Field and Brasington (2011).

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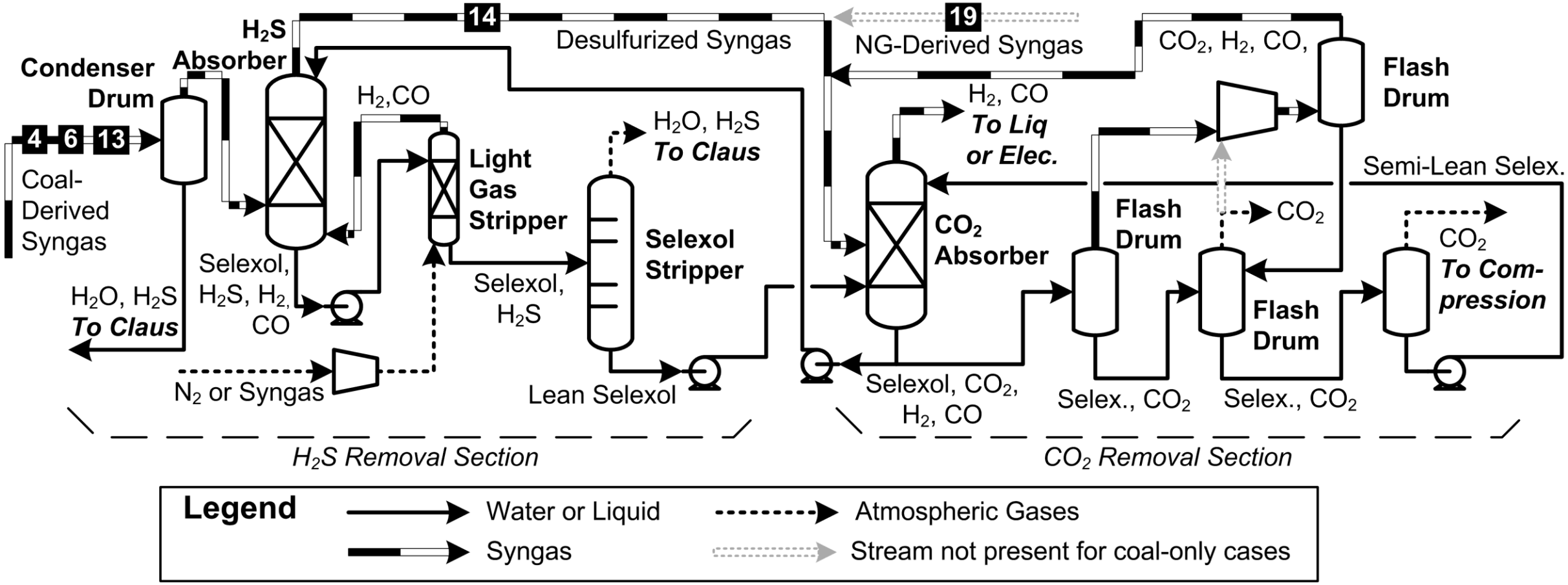
Combined Sulfur and CO_2 Removal



Sources: Adams & Barton. Combining coal gasification and natural gas reforming for efficient polygeneration. *Fuel Process Tech* (2011).

- "1-Stage" Selexol: Removes just the H_2S
- "2-Stage" Selexol: Removes the CO_2 as well.
  - Integrated the two stages with a single solvent train.

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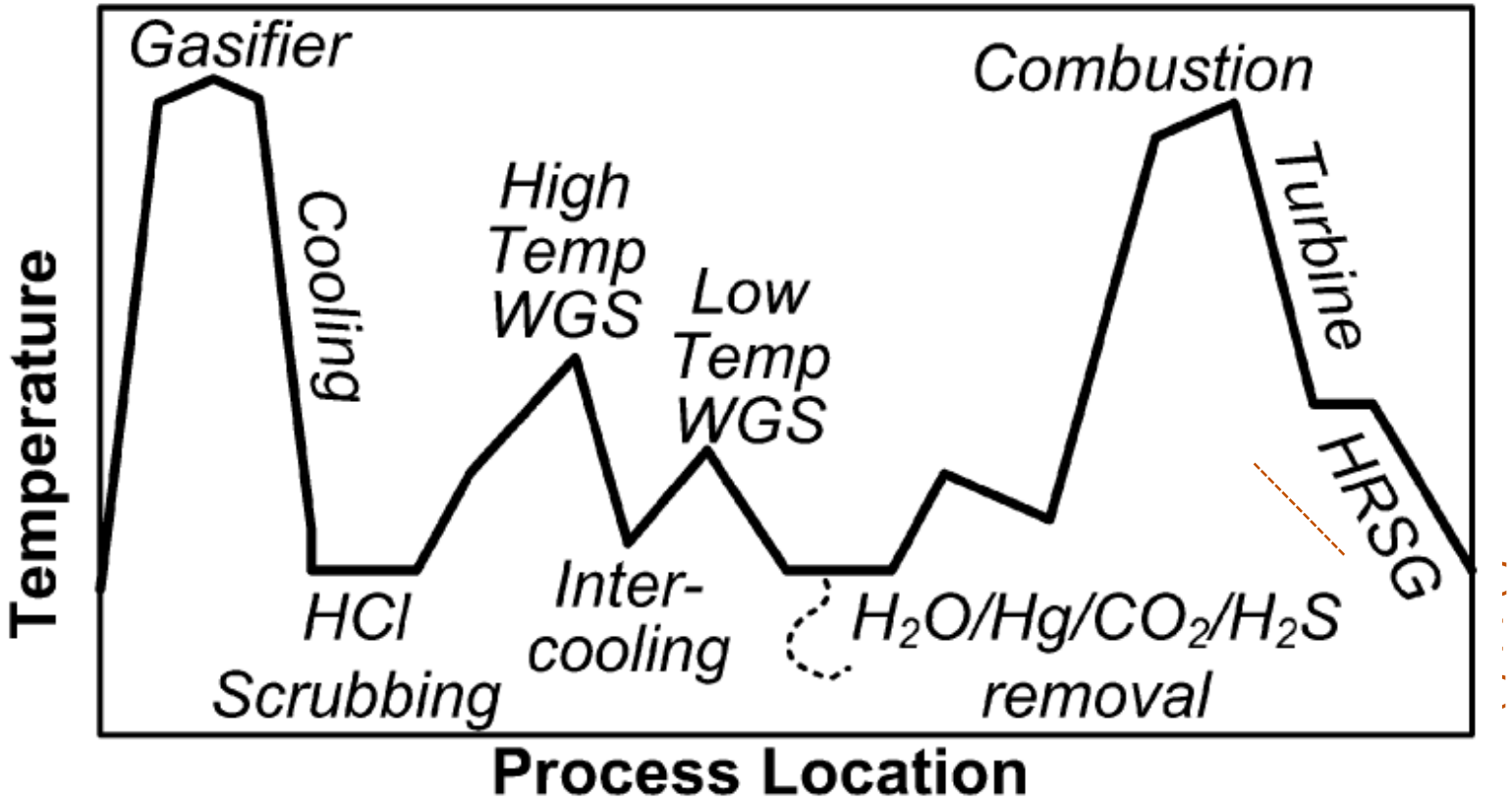
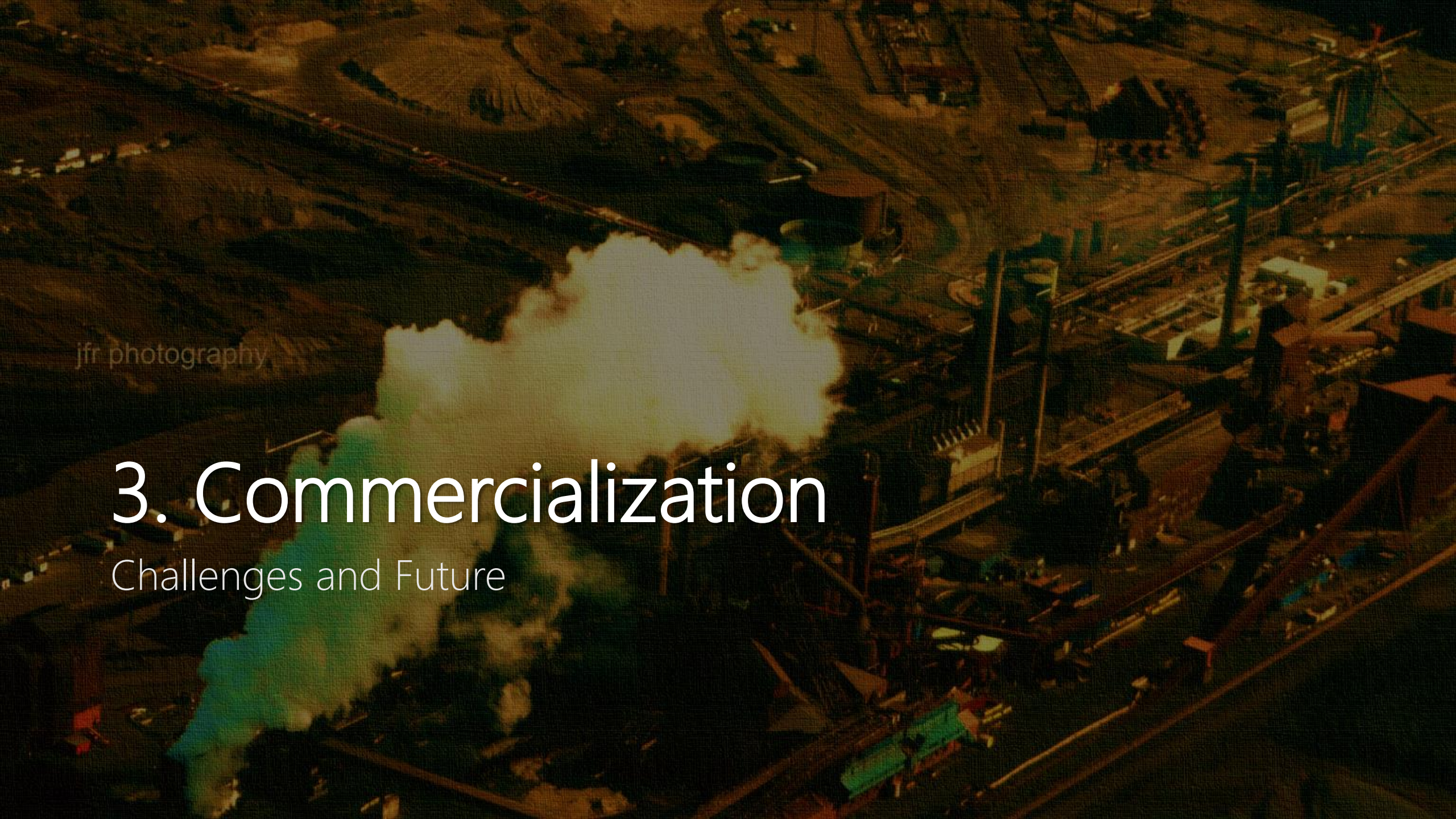
Cleanup Challenges, Future Directions

- "Warm Syngas Cleanup"
  - Lots of entropy losses from heating/cooling cycles for cleaning
- Active research to avoid these cooldowns
- Membranes & adsorbents for CO_2, H_2S, Hg that work at higher temperatures.
  - Note: current thinking is that only warm CO_2 removal will be helpful.



Sources: NETL Bituminous Baseline Report. See also Couling, Prakash, & Green, I&EC Res 50:11313-11336 (2011). Adams TA II, Computers and Chemical Engineering 81 (2015) 94–103



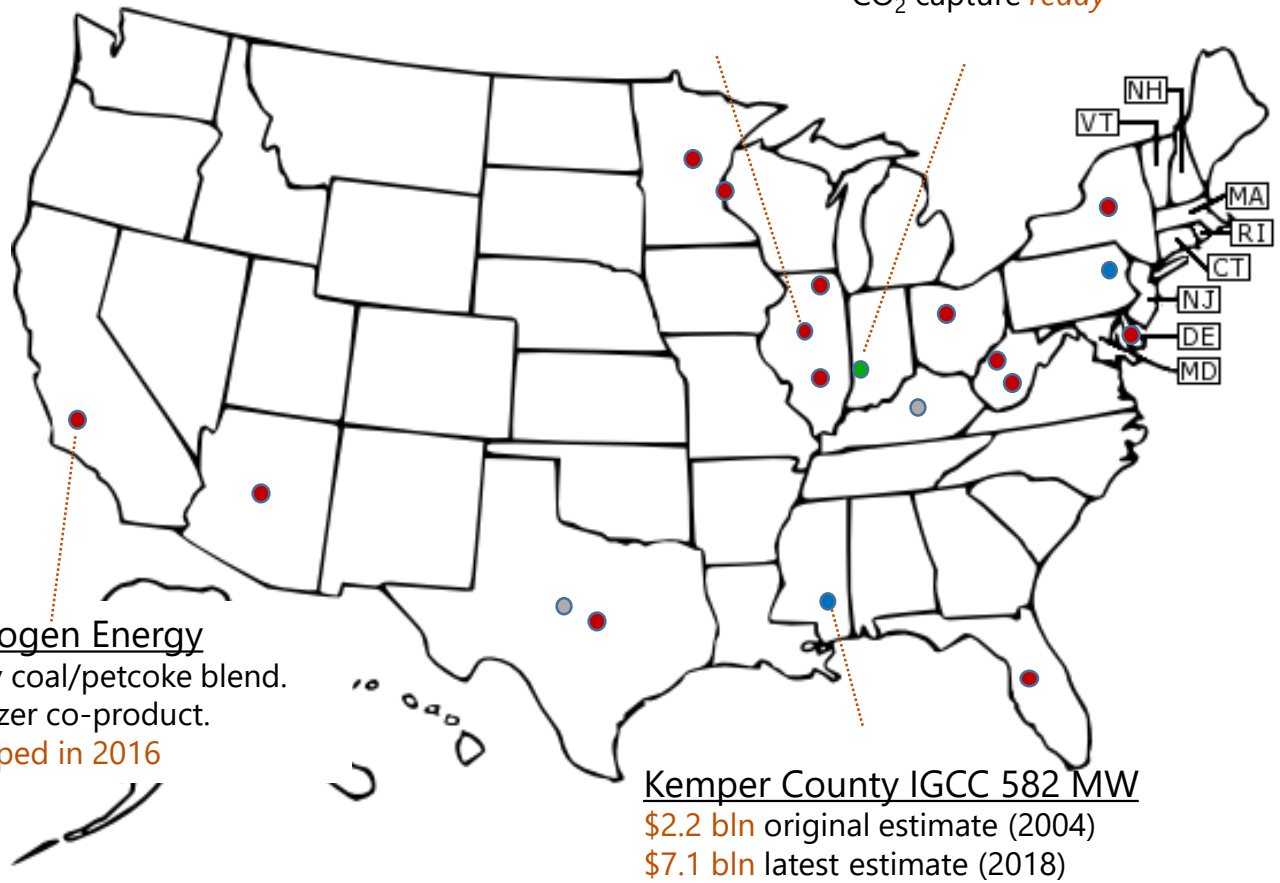
3. Commercialization

Challenges and Future

IGCC Commercialization Status

- 7 "Industrial Scale" IGCC plants in existence
  - Puertollano (Spain)
  - Nakoso (Japan)
  - Wabash (Indiana)
  - Polk (Florida)
  - Buggenum (Netherlands)
  - 26 gasifier facility in Czech Republic
  - Edwardsport (USA)
- In US, only 1 of original 36 proposed projects remain (Massive slate of announcements in 2007).

- *In construction*
- *Planning / Proposed*
- *Notable Cancellations*
- *Switched to Gas*



Taylorville
Big announcement, got permits. Scrapped 2013. Cited price difference & regulatory uncertainty.

Edwardsport 618MW
$0.9 bln mature costs
$2.0 bln original estimate
$2.6 bln revised estimate
$3.4 bln final
CO_2 capture *ready*

Hydrogen Energy
Gasify coal/petcoke blend.
Fertilizer co-product.
Scrapped in 2016

Kemper County IGCC 582 MW
$2.2 bln original estimate (2004)
$7.1 bln latest estimate (2018)
Ditched the gasification section and now runs the back end on natural gas

Sources: J Phillips (EPRI), S. Jenkins (CH2M Hill), D. Peters (Schlumberger), D. Simbeck (SFA Pacific).
InsideIndianaBusiness, July 2, 2012. http://www.insideindianabusiness.com/newsitem.asp?ID=54467
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IEEE spectrum 2018 https://spectrum.ieee.org/energywise/energy/fossil-fuels/the-three-factors-that-doomed-kemper-county-igcc
California Energy Commission. Order Terminating Application for Certification Proceeding and Notice of Cancellation of Hearing (@016)

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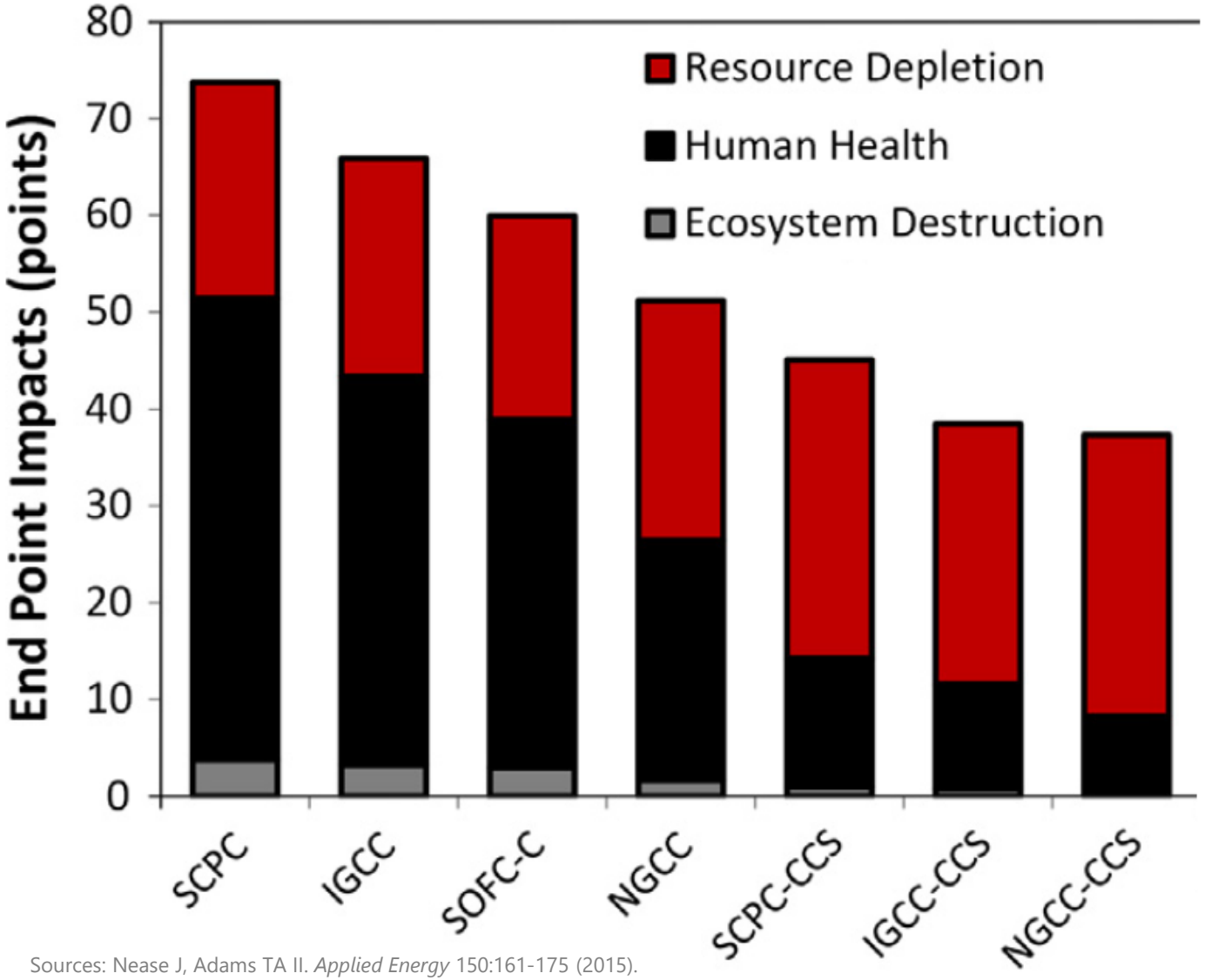
LCA

Note. Edwardsport IGCC claims they reduce CO_2 emissions by almost half even without CO_2 capture.

(This is compared to the very old plants they shut down, which were likely terrible, as noted two lectures ago)



Sources: Nease J, Adams TA II. *Applied Energy* 150:161-175 (2015).

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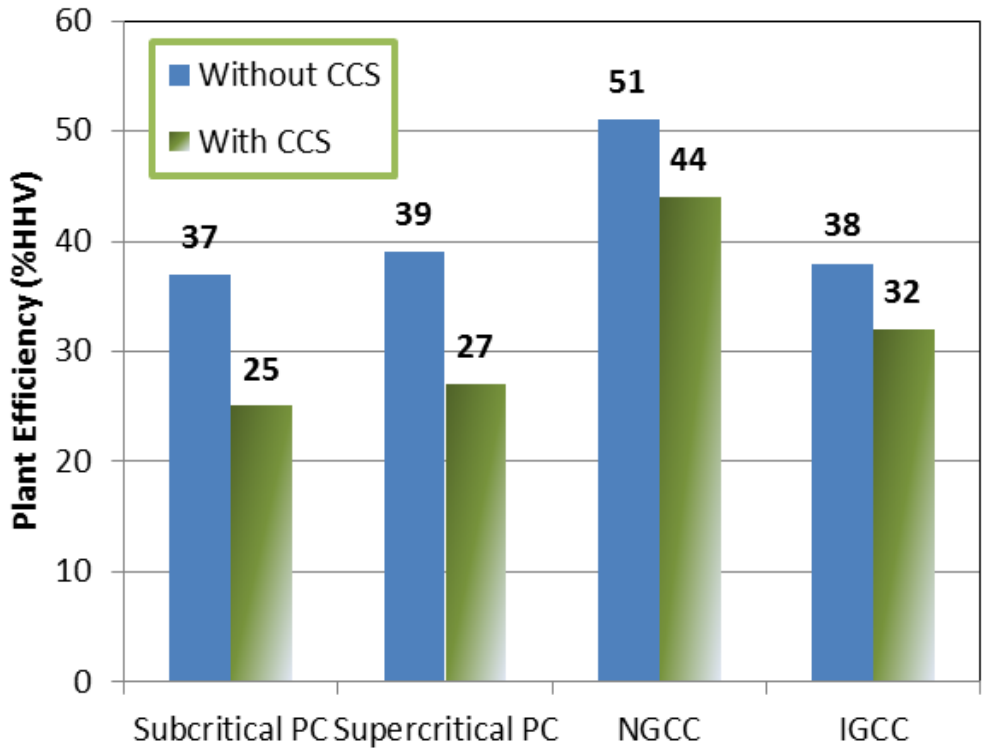
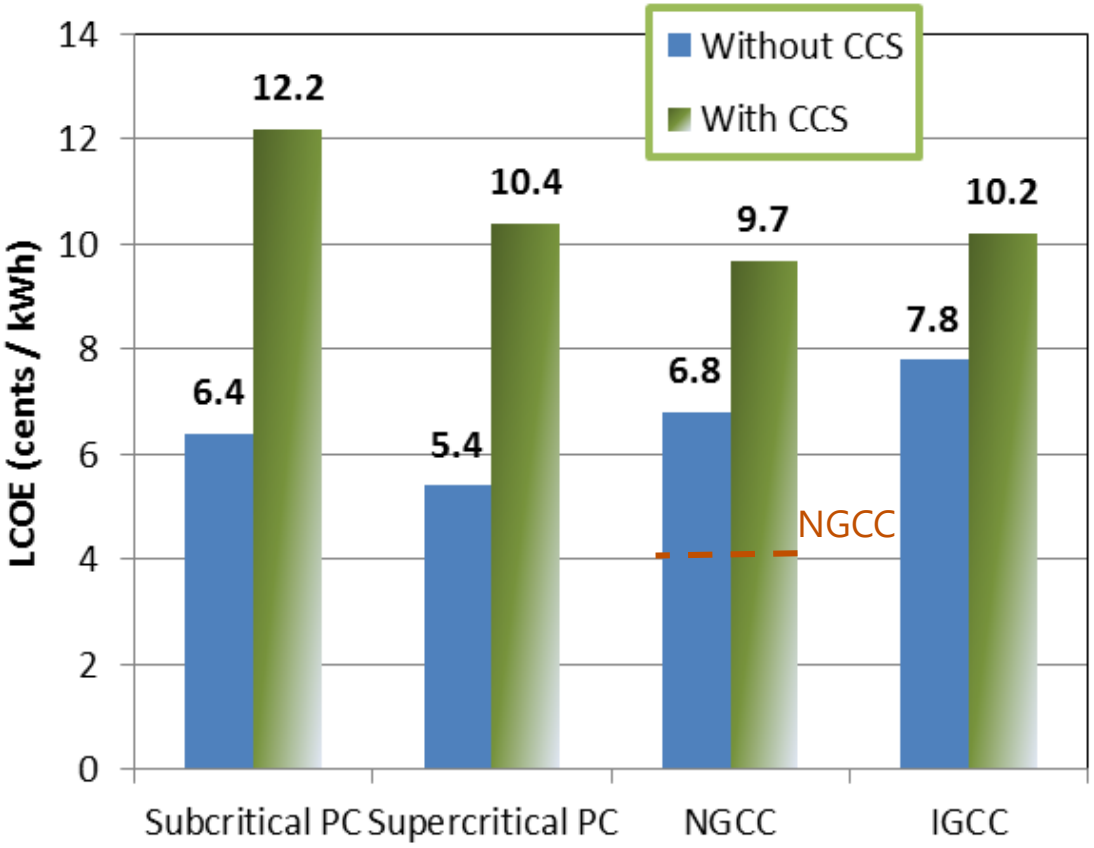
Cost & Efficiency Comparisons

Plant Thermal Efficiencies
%HHV Basis
NGCC is for post-combustion only



Electricity Prices
These are 2008 dollars



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Sources: NETL Bituminous Baseline Report.

Market Conditions

- Profit-motives drive business, even government utilities (must wisely use taxpayer money)
- No CO_2 regulations means no reason to use CCS?
  - Still has value for Enhanced Oil Recovery
- Cheap gas means no reason to use coal right now?
  - Will it always be cheap? News filled with talk of switching to gas.

"Lack of regulatory clarity on emissions for coal-based electricity plants plus the immediate availability of natural gas provides a strong incentive to use natural gas as the primary fuel source"

– EmberClear (Canadian Company) in response to why they switched from IGCC to natural gas for their next build

Sources: http://www.bloomberg.com/article/2012-05-17/amA7BKRPpkOM.html

Big Picture

- Death of coal-gasification?
  - Seen as primary technology to enable environmentally acceptable coal energy conversion in long term future
  - There's a lot more we can do with it.... (future lectures)
  - China is very interested in this tech since they are coal-rich.
- Business decisions driven by short-term thinking.
  - Gasification research funding historically correlates with oil prices...
  - First-to-market big capital experimental projects don't happen without government funding.
- So, research continues to make it affordable and have systems ready when CCS gains traction and NG prices rise