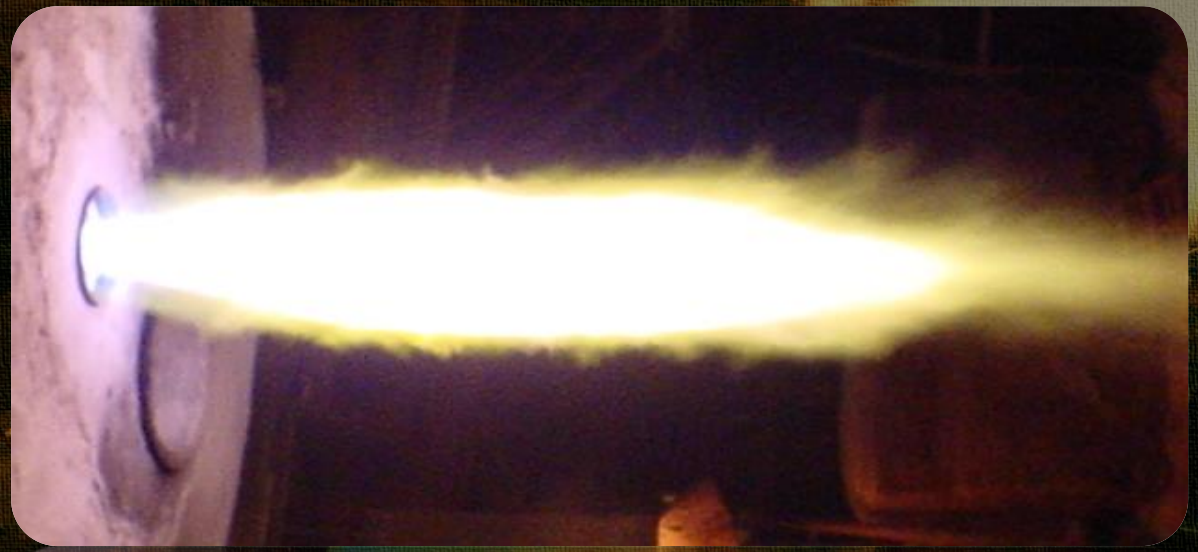
Oxyfuel Combustion

a.k.a. ‘Oxyfuels’



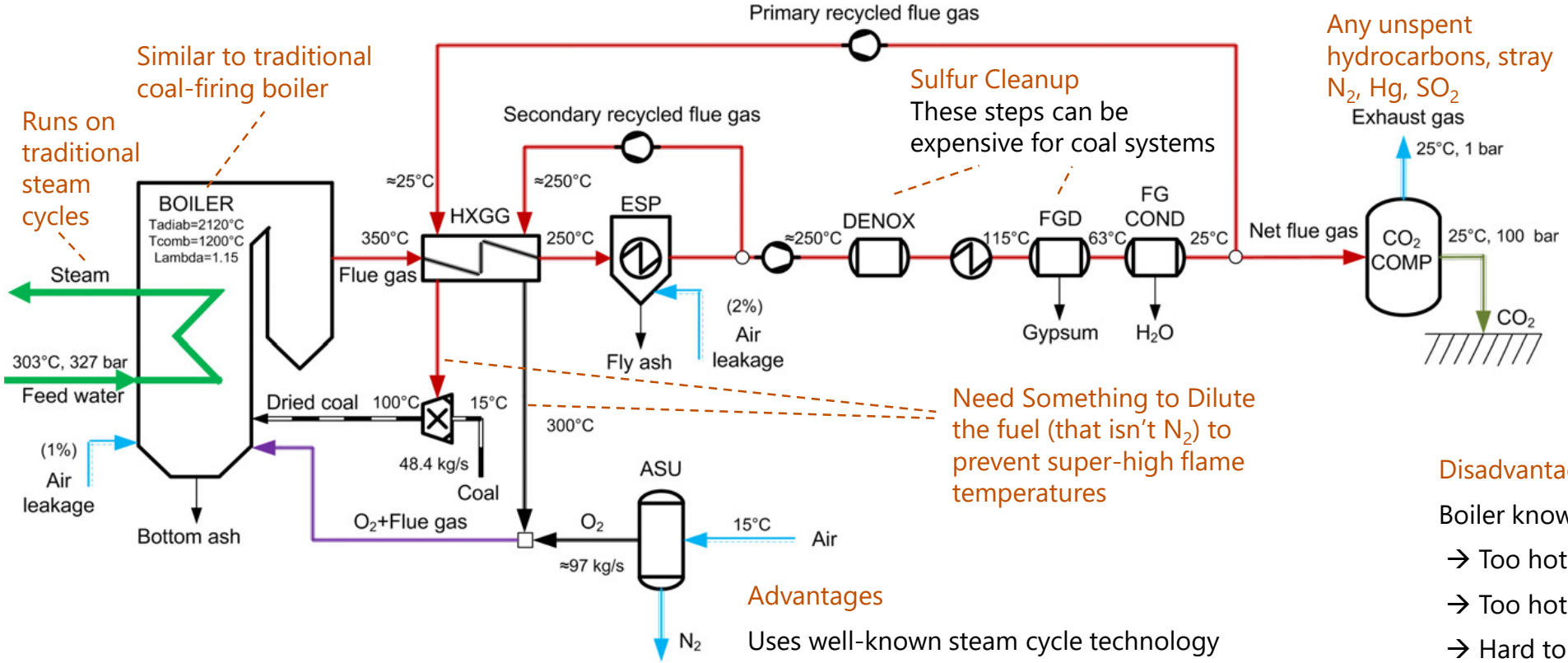
Thomas A. Adams II
McMaster University
Department of Chemical Engineering
McMaster Advanced Control Consortium
McMaster Institute for Energy Studies

Lecture 4.3 – 2018 Edition

1. Oxyfuel boilers

Process Basics

Concept: Avoid N_2 mixing



Sulfur Cleanup
These steps can be expensive for coal systems

Any unspent hydrocarbons, stray N_2, Hg, SO_2

Need Something to Dilute the fuel (that isn't N_2) to prevent super-high flame temperatures

Advantages

Uses well-known steam cycle technology

Only limited N_2 enters fuel

→ Cheaper CO_2 capture, 95% feasible. (CO2/impurities)

→ Limited NO_x potential.

Potential cost savings (maybe)

Disadvantages

Boiler knowledge limits flame temperature

→ Too hot: melts ash

→ Too hot: much more NO_x formation

→ Hard to prevent air leakage (unwanted N_2!)

Low N_2 combustion environment significantly affects combustion mechanisms.

Requires lots and lots of O_2.

Extra propensity for CO emissions

Source: R. Castillo / Applied Energy 88 (2011) 1480–1493
See also Rubin, Edward S.; Rao, Anand B.; and Berkenpas, Michael B., "Technical Documentation: Oxygen-based Combustion Systems (Oxyfuels) with Carbon Capture and Storage (CCS)" (2007). Department of Engineering and Public Policy. Paper 75. http://repository.cmu.edu/epp/75
Ting T, Stanger R, Wall T. International Journal of Greenhouse Gas Control 18:15-22 (2013)
D. Liu et al. / International Journal of Greenhouse Gas Control 19 (2013) 462–470

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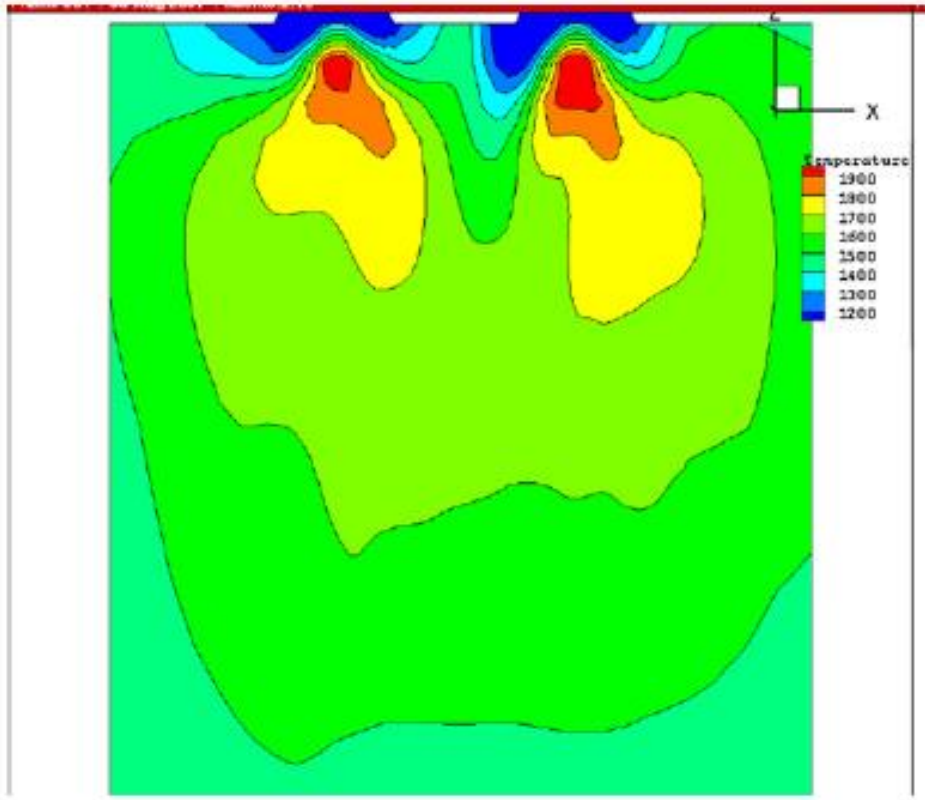
Key Differences

	Air Combustion	Oxyfuels
Flue Gas Density	Lower	Higher CO_2 more dense than N_2
Flue Gas Heat Capacity	Lower	Higher More efficient heat source for steam cycles
O_2 Diffusivity	Higher	Lower by 80% O_2 takes longer to penetrate gases (so much CO_2), requires longer burning
Radiation of Heat	Lower	Higher Emitting Power heat transfer rates are higher
Flue Gas Volume	Higher	Lower by 80% Smaller pipes, smaller stacks Lower costs downstream

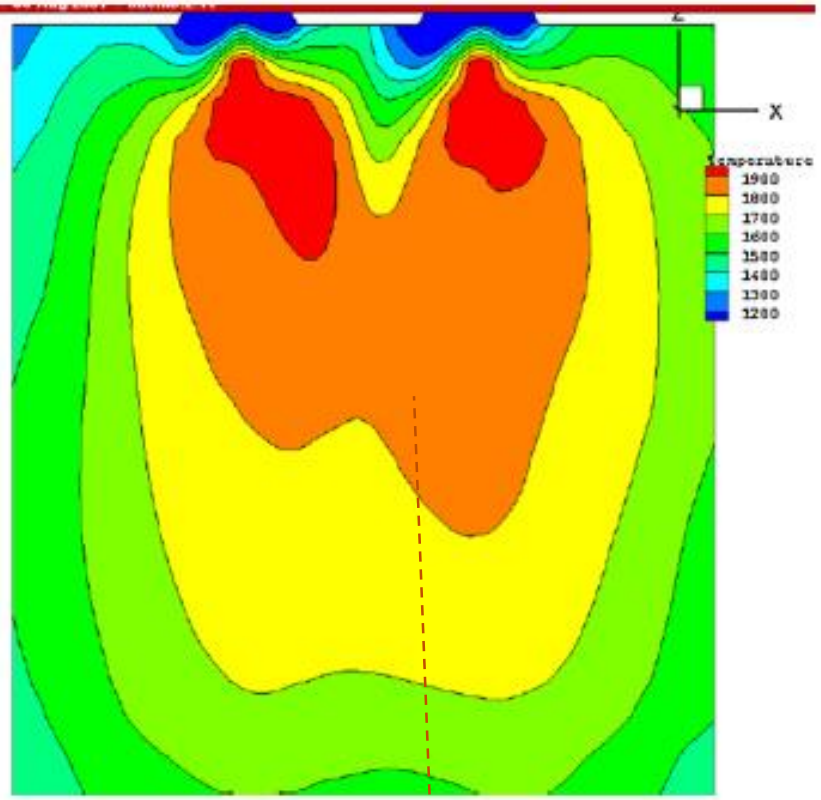
Source: Wall 2009. Chem Eng Res Des 87 (2009) 1003-1016.

Hot Burnin’

Burning Coal in Air



Oxycombustion

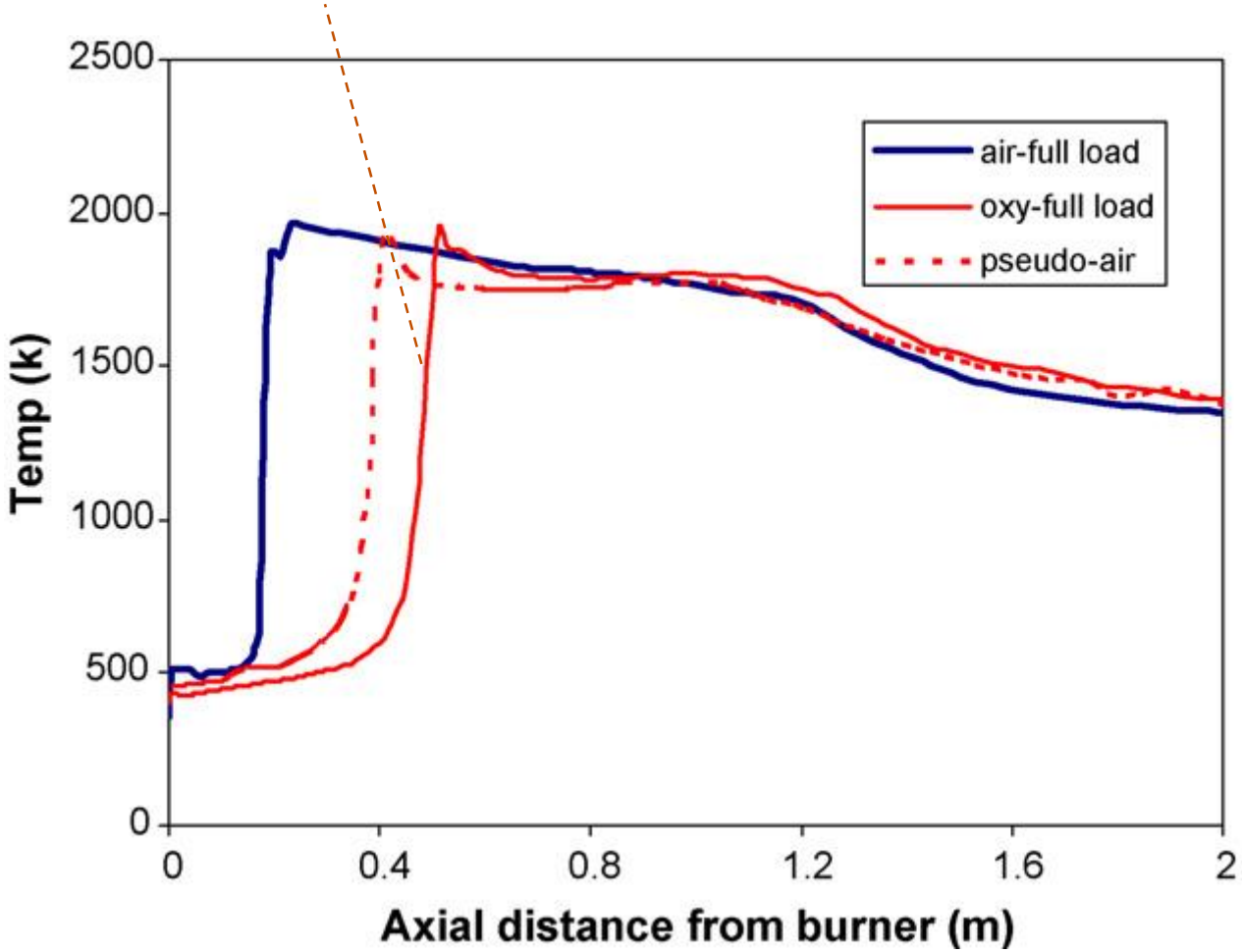


Flame bigger, hotter.
Causes profound design and operational challenges.

Source: Source: Wall 2009. Chem Eng Res Des 87 (2009) 1003-1016.

Delayed Burning

Slower diffusivity means longer oxidation delay (0.5 m distance vs 0.2m).
Mean you need much bigger firing equipment, more expensive.



Source: Wall 2009. Chem Eng Res Des 87 (2009) 1003-1016.

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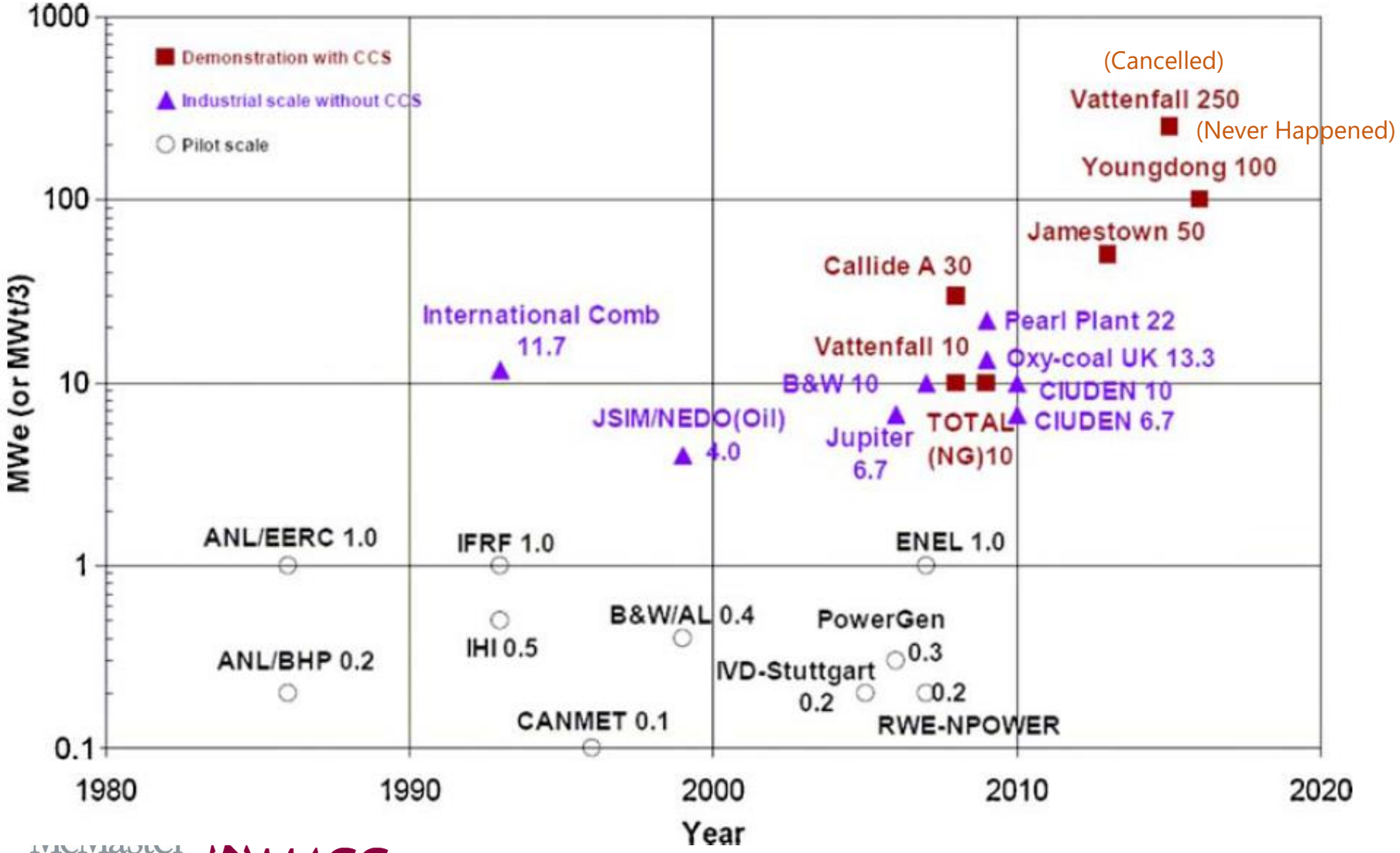
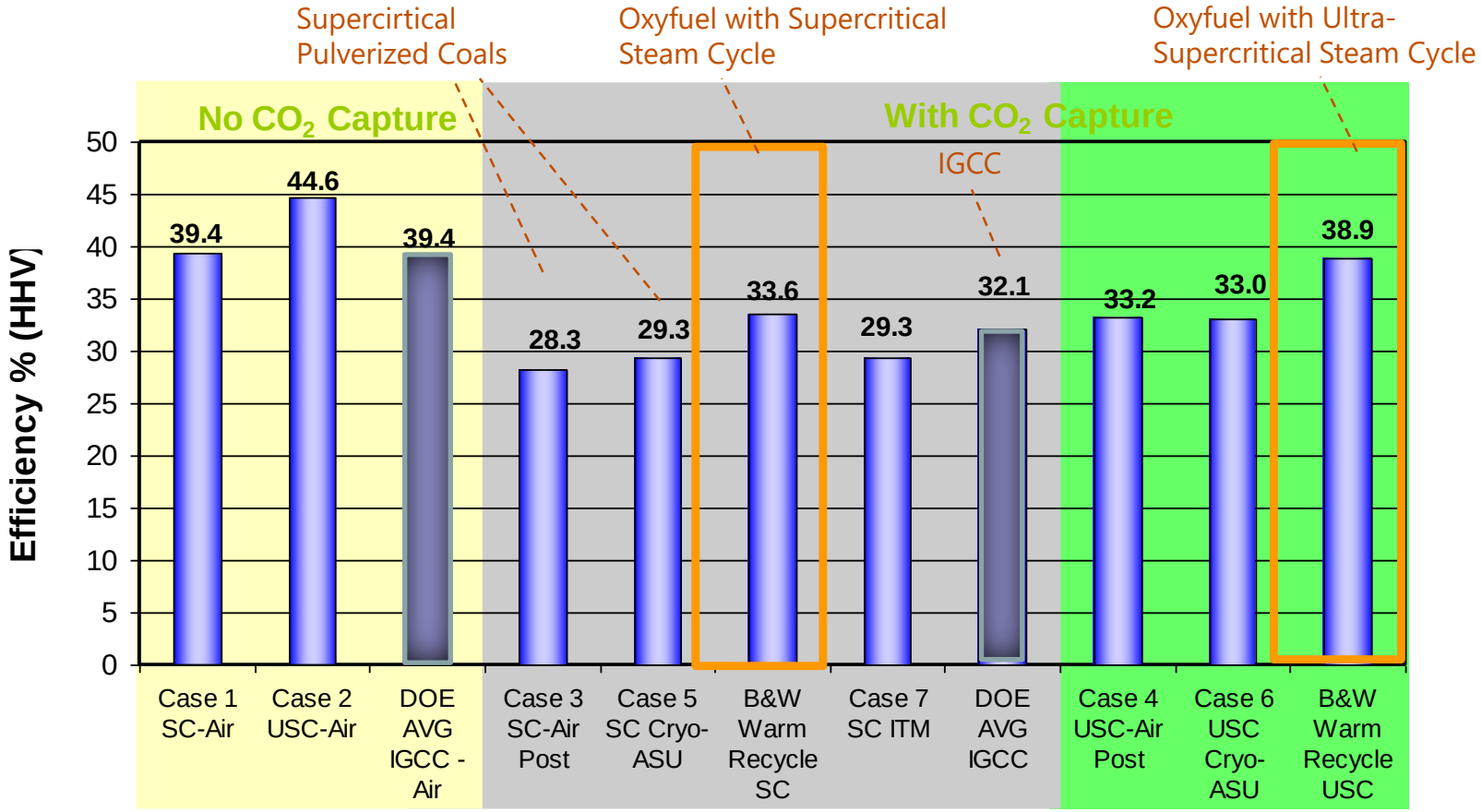
Technology Progress



Note, there have been several recent attempts at Oxyfuel Combustion projects (from coal) but they all have been cancelled before completion.

Source: G. Scheffknecht et al. / International Journal of Greenhouse Gas Control 5S (2011) S16–S35
Perrin N et al. App Therm Eng. 74:75-85 (2015)

Efficiencies: Comparing Advanced Systems



References: DOE/NETL 2007 - 1291 "Pulverized Coal Oxy-combustion Power Plants" Rev. 2, DOE/NTL 2007-1281 "Cost and Baseline for Fossil Energy Plants" Rev.1 , and B&W/AL Integration Study

Promising from an efficiency standpoint.

But, you'll notice that each lecture has a different set of data to compare A to B to C.

I'll show you a big-picture normalized comparison at a later time.

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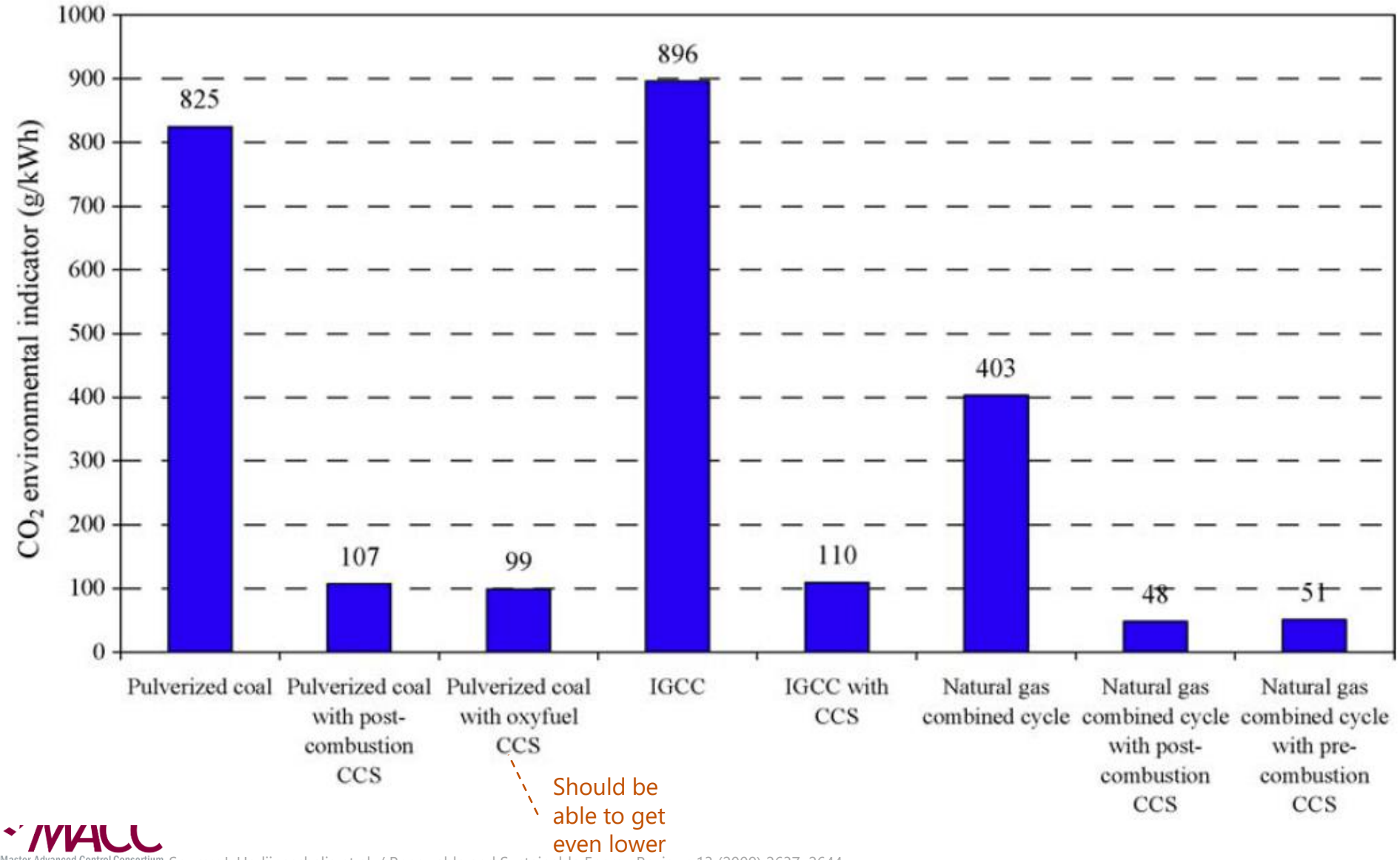
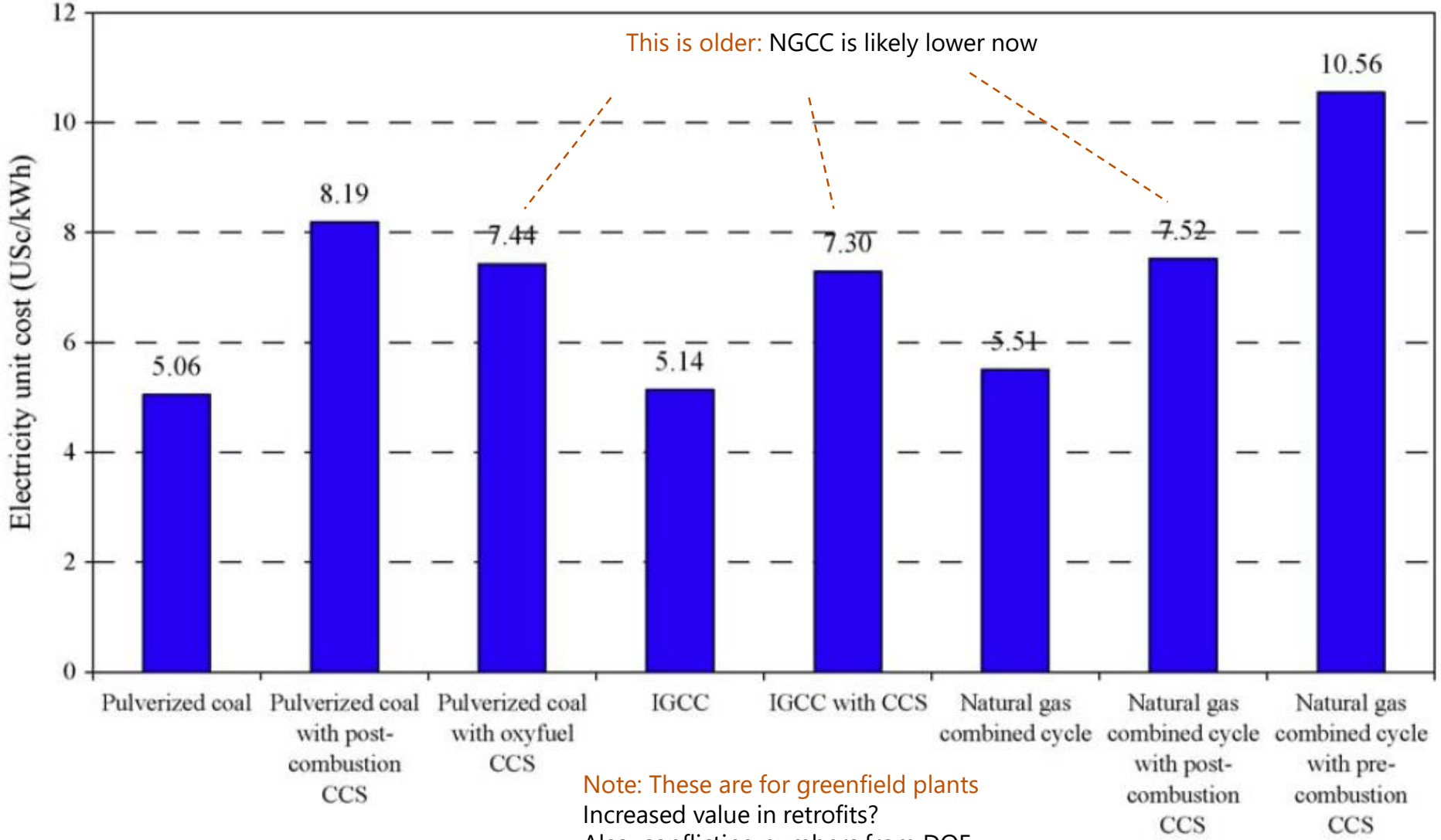
CO_2 Emissions Comparison



Source: I. Hadjipaschalis et al. / Renewable and Sustainable Energy Reviews 13 (2009) 2637–2644

Comparative Costs



Note: These are for greenfield plants
Increased value in retrofits?
Also, conflicting numbers from DOE

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Source: I. Hadjipaschalis et al. / Renewable and Sustainable Energy Reviews 13 (2009) 2637–2644

FutureGen 2.0 – The major demo proj.

- The well touted "FutureGen" project cancelled late 2010
  - Major IGCC w/ CCS project by US Department of Energy
  - Cancelled after seeing massive costs for IGCC at Edwardsport
  - Switched to Oxycombustion with CCS → FutureGen 2.0! 168 MW_e Gross
- New key value is in coal plant retrofits
  - Main goal is to replace existing boilers with oxyfiring
  - Use existing balance of plant with some modifications
- Will demo CO_2 geologic storage and a CO_2 pipeline
- Construction hasn't happened yet. (Pushed back every year)
  - March 2013: Purchased a defunct power plant to do the testing
  - Sept 2013: Expect $1.65 billion capital cost ($1 billion from US DOE)
  - Sept 2014: US EPA approves the CO_2 storage portion.
  - 2015: US DOE gives up. All of the engineering design work was finished but they couldn't negotiate funding and various contract negotiations.
- Leading partners mention conflicting politics between federal & state, elections uncertainties, anti-coal mentality

Source: futuregenalliance.org. See also FutureGen 2.0 (Sept 2013)
Ameren Energy Resources, FutureGen 2.0, Oxy-Combustion Large Scale Test, Oct 23, 2010
Kenison LV, et al.. FutureGen 2.0 Oxy -Combustion Large Scale Test Project B.01 - Final Scientific -Technical Report

Air Separation – Major Cost Barrier

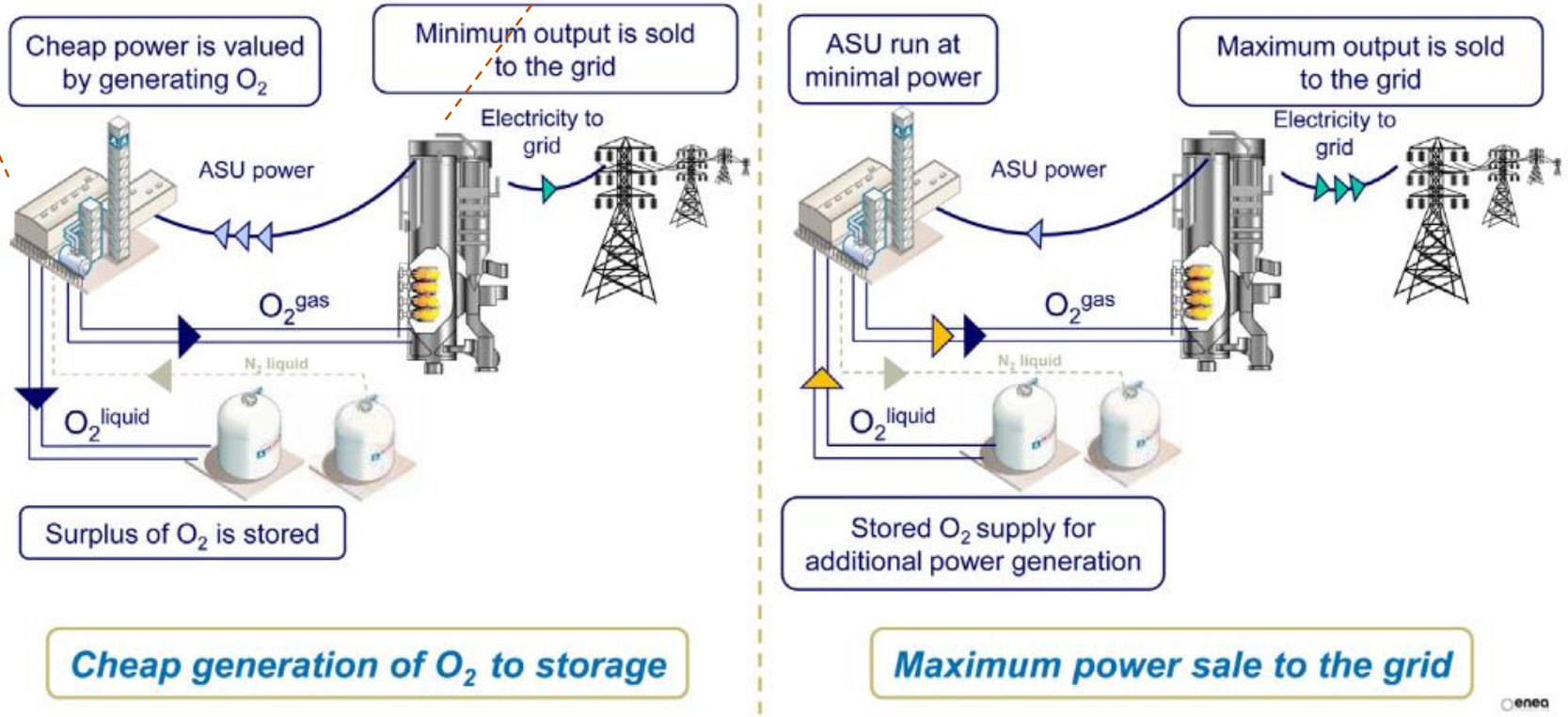
- Recall: IGCC requires O_2/N_2 separation to use high purity (95%) O_2 in the gasifier.
  - Expensive and energy intensive (parasitic load)
  - Only oxidizing roughly 10-20% of the carbon in the gasifer
- Oxyfuel Combustion needs 5-10 times more of the same:
  - Purity must be higher (closer to 98%)
  - Need to oxidize all of the carbon (5-10x) in the boiler
  - Causes 5-7 percentage points of efficiency loss (i.e, 40% HHV efficient to 33-35% HHV efficient)

Source: Perrin N et al. Applied Thermal Engineering 74:75-82 (2015)

Recent Advancement

The power plant itself never changes output, it runs at steady state

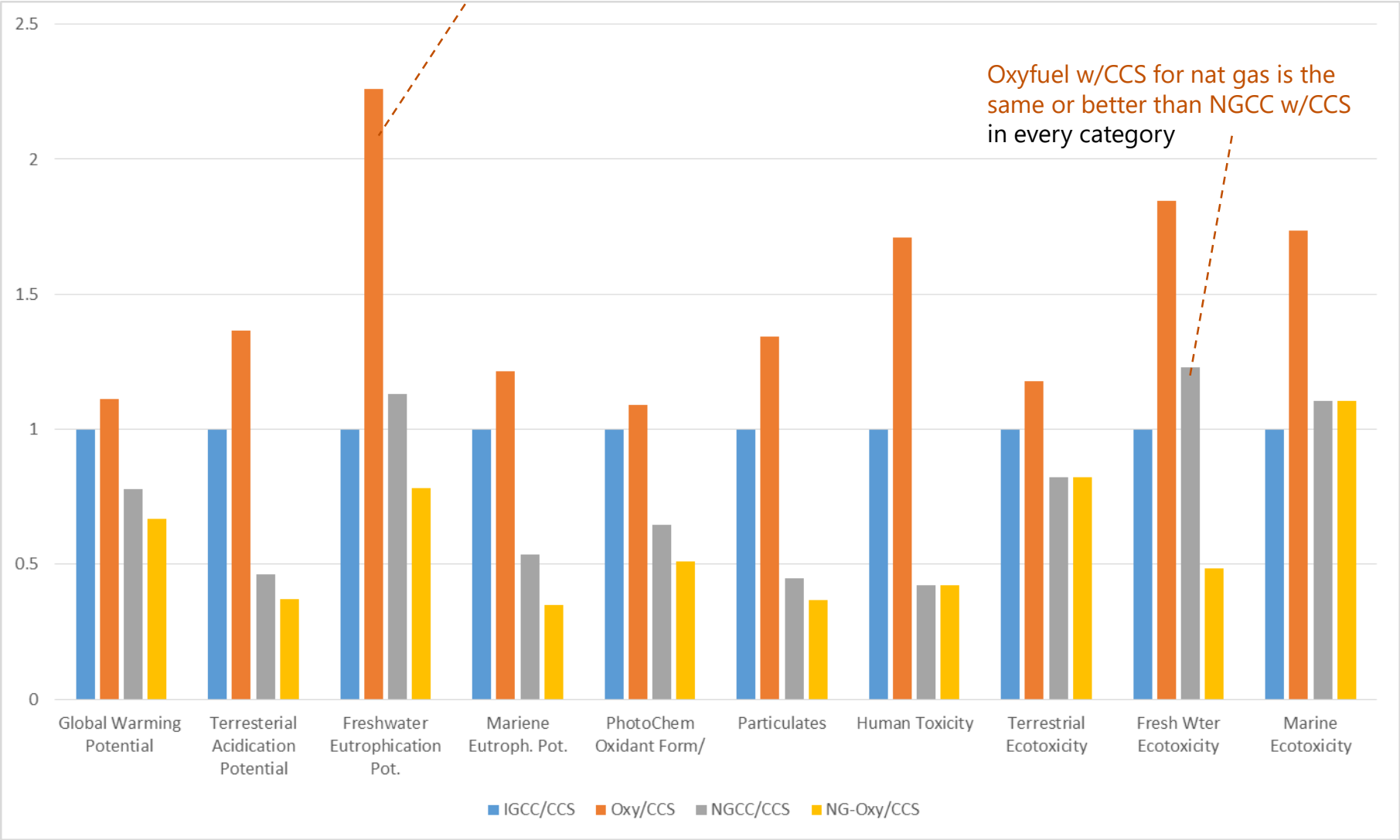
The ASU operates at high output
It changes twice daily.



Source: Perrin N et al. Applied Thermal Engineering 74:75-82 (2015)

Life Cycle Analysis

Oxyfuel w/CCS for coal is worse than IGCC w/CCS in every category



Source: B Singh et al. / International Journal of Greenhouse Gas Control 5 (2011) 911–921

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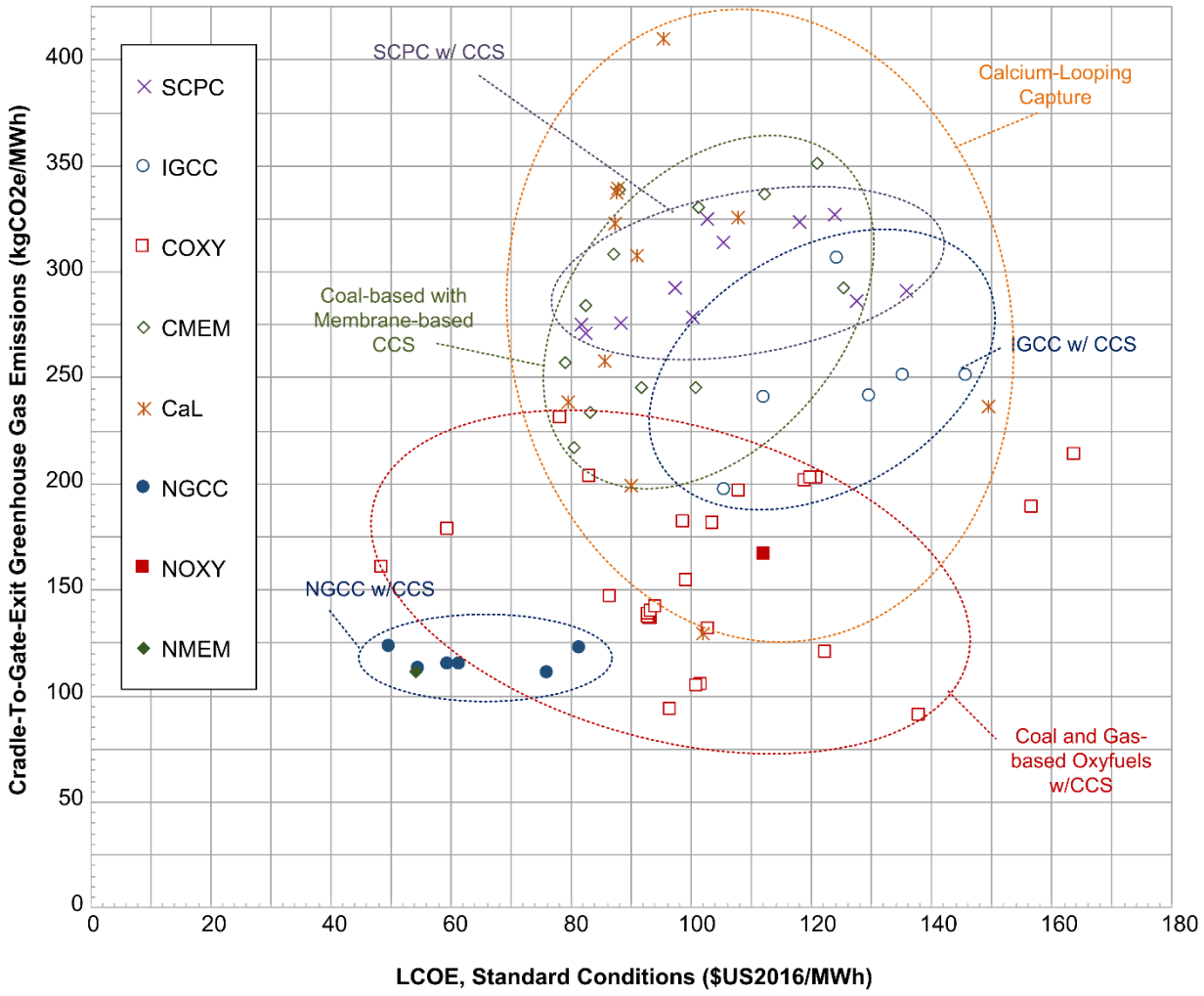
Our own calculations



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Source: Adams, T. A. II, Hoseinzade, L., Madabhushi, P. B., Okeke, I. Comparison of CO2 Capture Approaches for Fossil-Based Power Generation: Review and Meta-Study, Processes,, 5 (3) 44 (2017)

2. Oxyfuel with gasifiers

Future concepts

2nd Generation (Gasification)

Like IGCC, but N_2 no longer used for GT diluent

Could also make steam here with radiant cooler

Have to get stoichiometric O_2 in real time to meet strict O_2 limits for CO_2 pipelines
Tough control challenge too

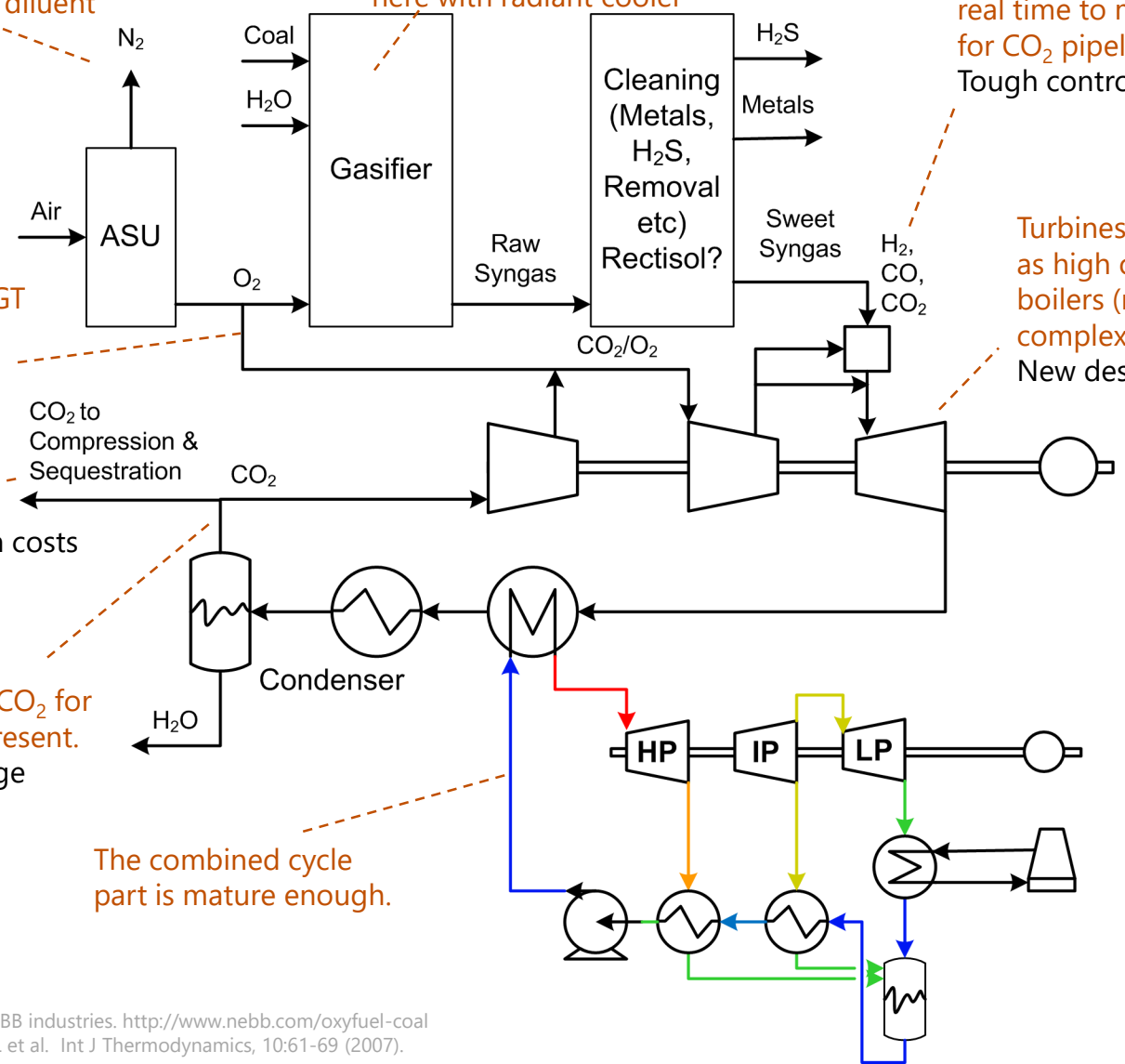
Air no longer used in GT
Need a lot more high purity O_2 than IGCC.

Turbines cannot operate at as high of temperatures as boilers (moving parts, complex shape, etc).
New design challenges

Low pressure.
High CO_2 compression costs

Need lots and lots of CO_2 for diluent when no N_2 present.
High recycle rates, large equipment.

The combined cycle part is mature enough.



Tom's Thoughts:
The company NEBB is advancing this technology for commercialization.

Results from systems research though doesn't look promising (Duan 2007).

Not a lot of attention

Overall looks very difficult…

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Sources: NEBB industries. http://www.nebb.com/oxyfuel-coal
Also Duan L et al. Int J Thermodynamics, 10:61-69 (2007).

Final Notes

- Materials limits are a huge uncertainty
- Having to relearn combustion all over again
  - Mixed $O_2/CO_2/H_2O$ environments mess things up
  - Flames look different
  - Delayed combustion
  - Carbon monoxide intermediates from Boudouard Reaction
    - $CO_2 + C \rightleftharpoons 2CO$
  - Many unknown variables, huge sensitivies
- But, this is much closer to large scale commercialization (compared to other advanced methods)
- 2nd Gen: Probably a ways off
  - A logical combination of the concepts we have learned so far
  - But not on the radar for most people.

Source: I. Hadjipaschalis et al. / Renewable and Sustainable Energy Reviews 13 (2009) 2637–2644