

# Reducing CO<sub>2</sub> Emissions from Power and Transportation Sectors



**James Katzer**  
**October 28, 2011**

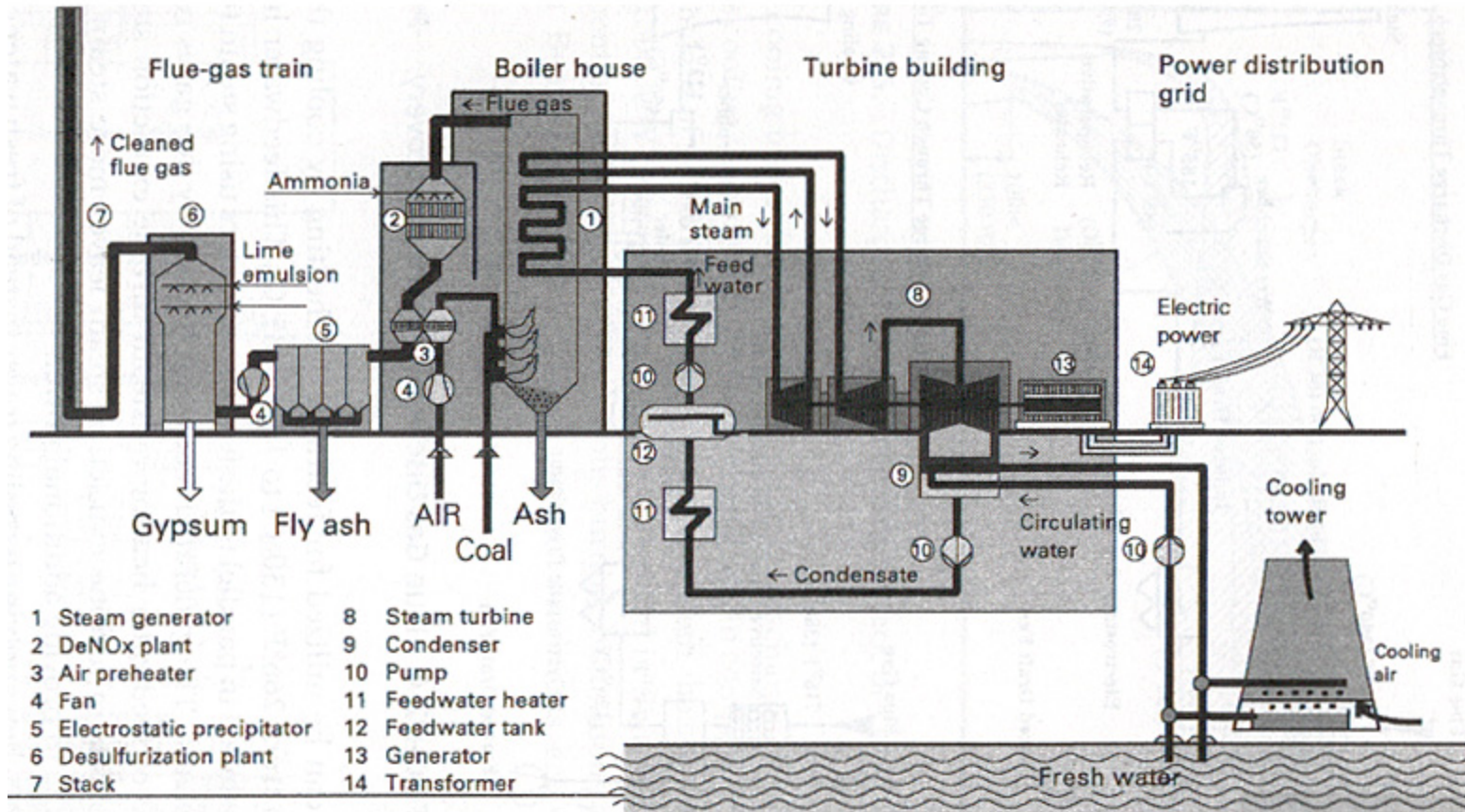
# Analysis Bases & Findings

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- Considered only commercial or “near-commercial” technology
  - Material and energy balances by Aspen Plus
  - Consistent capital and evaluation bases
  - Estimates for Nth of a kind plants (N = 5-7)
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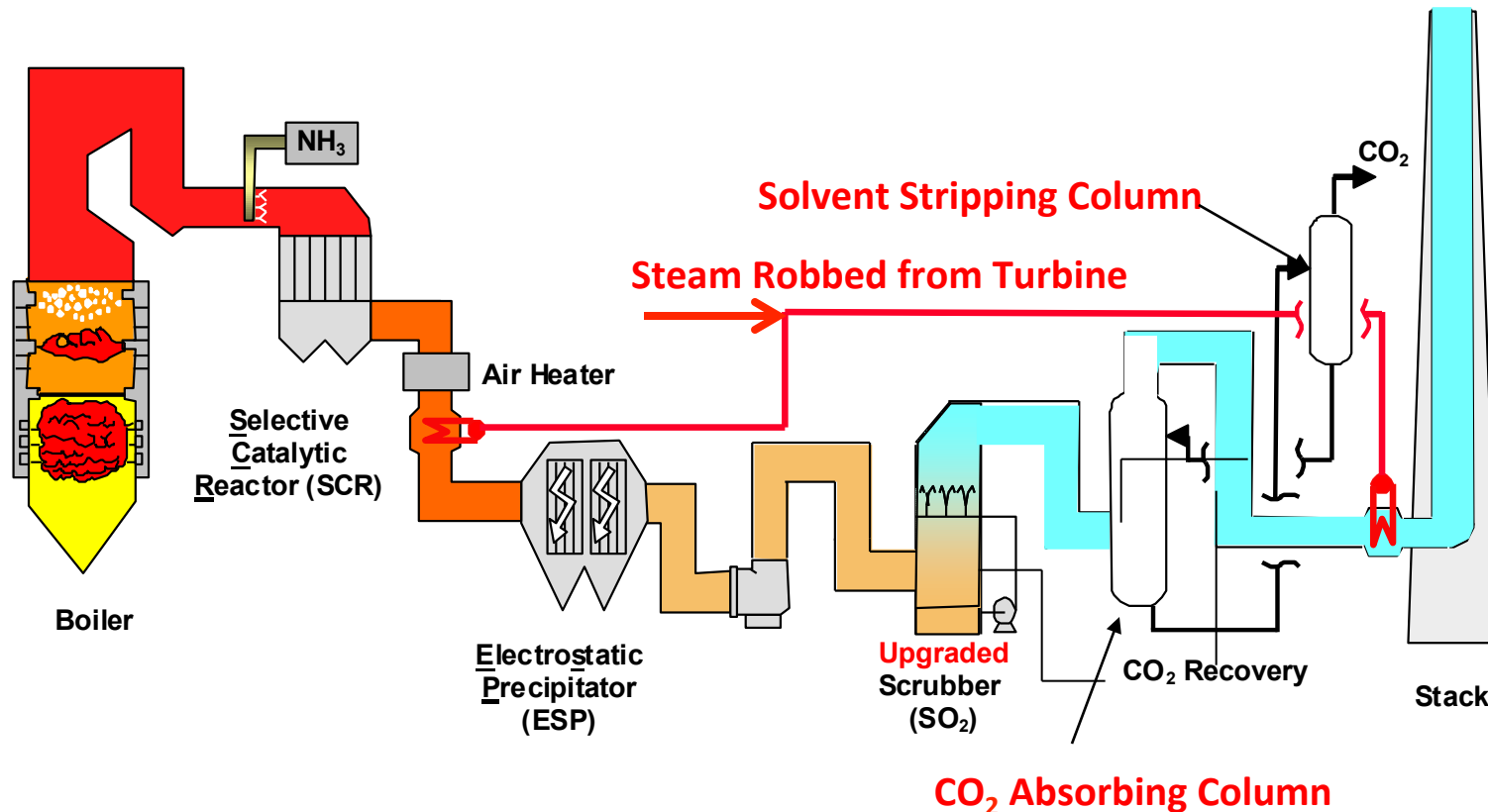
**Multiple technological approaches can address our CO<sub>2</sub> emissions and energy challenges with varying effectiveness and at varying costs; biomass and CCS are essential to achieve major impacts; co-production (fuels and electricity) can be economically viable, without subsidies, and go a long way to achieve the proposed 83 % CO<sub>2</sub> reduction.**

# Advanced PC Power Plant



- For a paid-off sub-critical plant, cost of producing electricity  $\sim \$35 / \text{MW}_e\text{h}$
- For new supercritical PC plant, cost of producing electricity  $\sim \$65 / \text{MW}_e\text{h}$

# CO<sub>2</sub> Capture for Pulverized Coal (PC) Plant



- Use strong chemical solvents to “scrub” CO<sub>2</sub> from dilute flue gases
- Requires relatively modest change in approach to coal power generation... but is energy-intensive, water-intensive, & costly,-- 11 to 12 percentage point efficiency loss
- Cost of GHG emissions avoided ~\$75/tonne, including CO<sub>2</sub> transport & injection
- For a new supercritical PC plant with CCS, cost of producing electricity is ~\$110/MWh

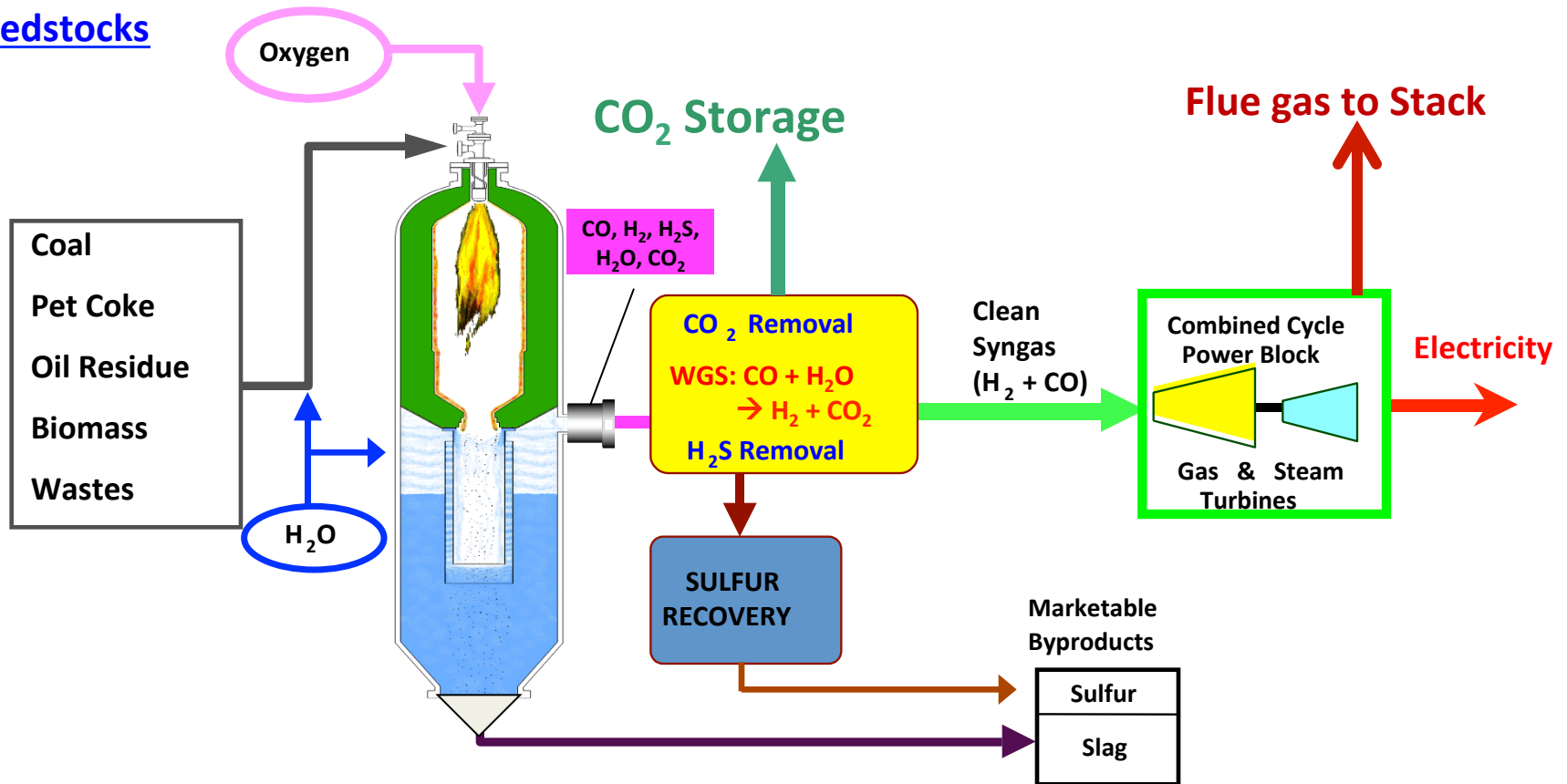
# Gasification-Based (IGCC) Electricity Production

Low-value feedstocks

Gasification

Gas Cleanup

Electricity Production



- IGCC has lower CCS energy penalty than for PC technology, ~ 6-7 percentage points
- Cost of CO<sub>2</sub> avoided is ~\$39/tonne, including transport and injection
- Cost of producing electricity is ~\$99/MW<sub>e</sub>h
- Ultra-low emissions (SO<sub>2</sub>, NO<sub>x</sub>, PM, Hg, other contaminants) at low incremental cost

# FutureGen Timeline

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**Objective: To demonstrate coal-based power generation with close-to-zero emissions, including CO<sub>2</sub> emissions**

- **FutureGen first announced by Bush 02/2003**
- **DOE awarded cooperative Project Agreement 12/2005**  
(Engineering design work not started, IGCC, 90% CO<sub>2</sub> capture)
- **FutureGen stopped 03/2008** (Construction had not begun)
- **FutureGen restarted 07/2009**
- **FutureGen Project canceled ~07/2010**
- **FutureGen redefined as oxy-fuel combustion, relocated, and restarted 07/2010**
- **Oxy-Fuel FutureGen2 construction-start estimated 2013**
- **Estimated construction finish 2016, 4 years operation for learning would give ~2020 demo finish**

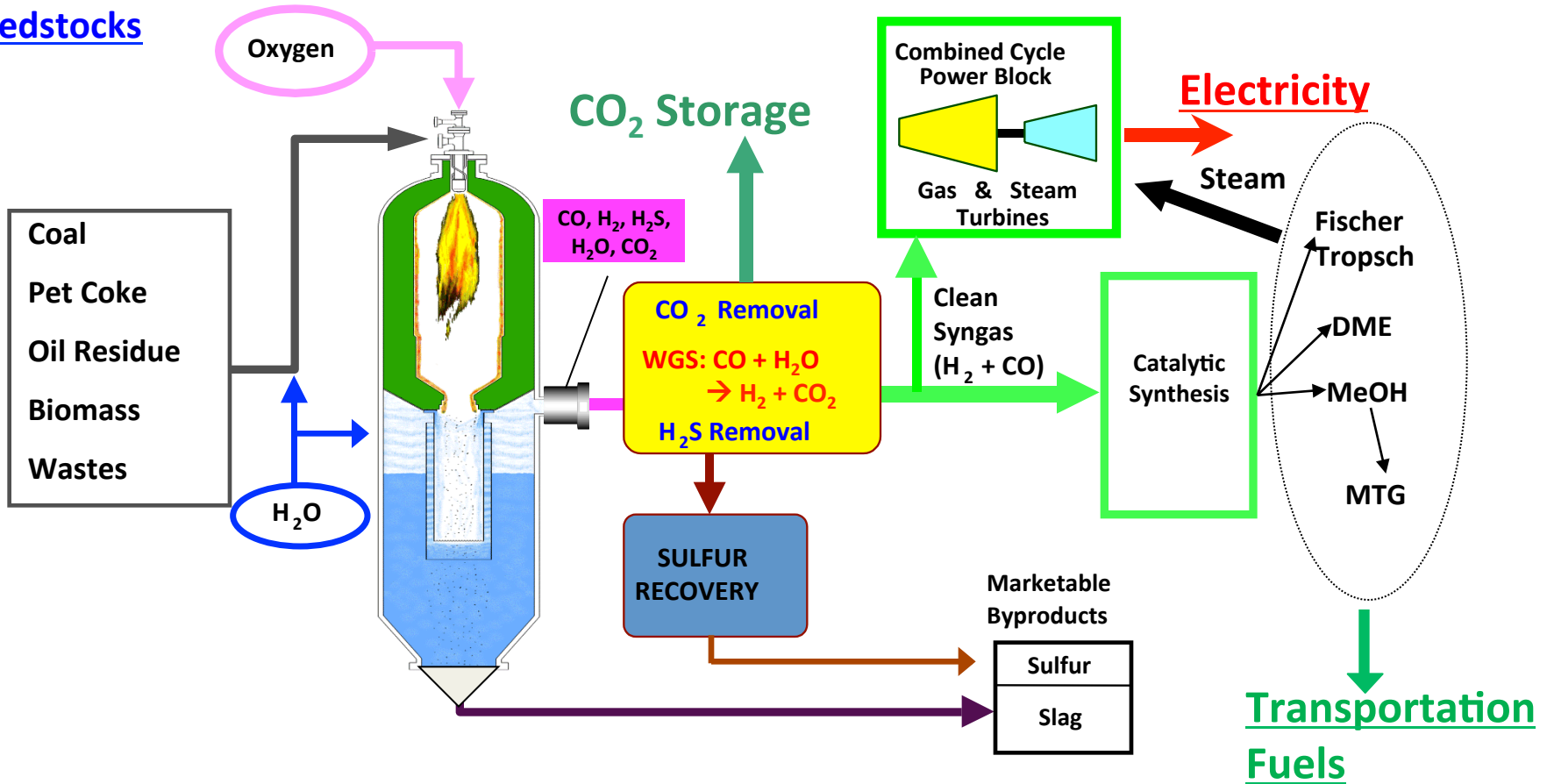
# Gasification-Based Energy Production

Low-value feedstocks

Gasification

Gas Cleanup

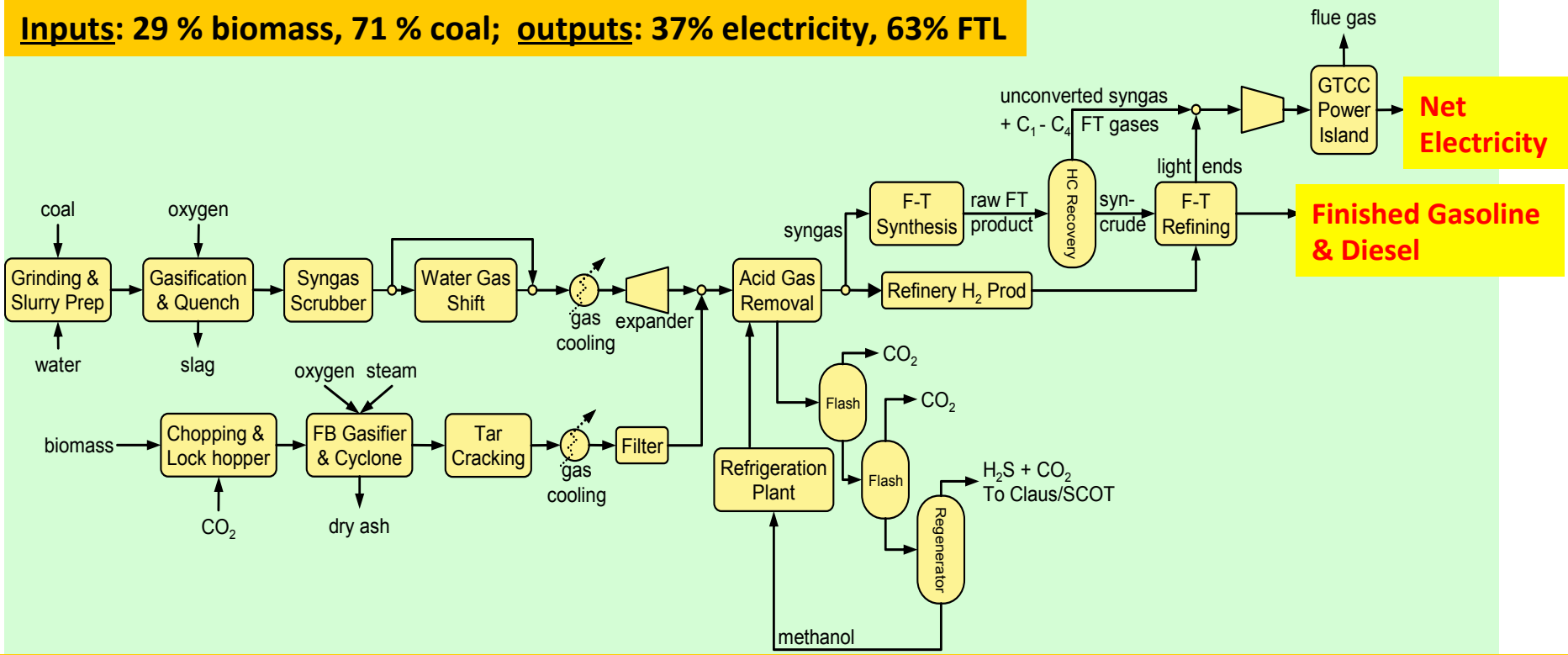
High-Value Energy Products



- Gasification-produced syn gas can be used to produce electricity and/or liquid fuels
- Technologies upstream of the synthesis/power blocks are the same
- Next we consider co-production of electricity and transport fuels

# Co-Production (Coal/Biomass w Venting: GHGI = 0.9)

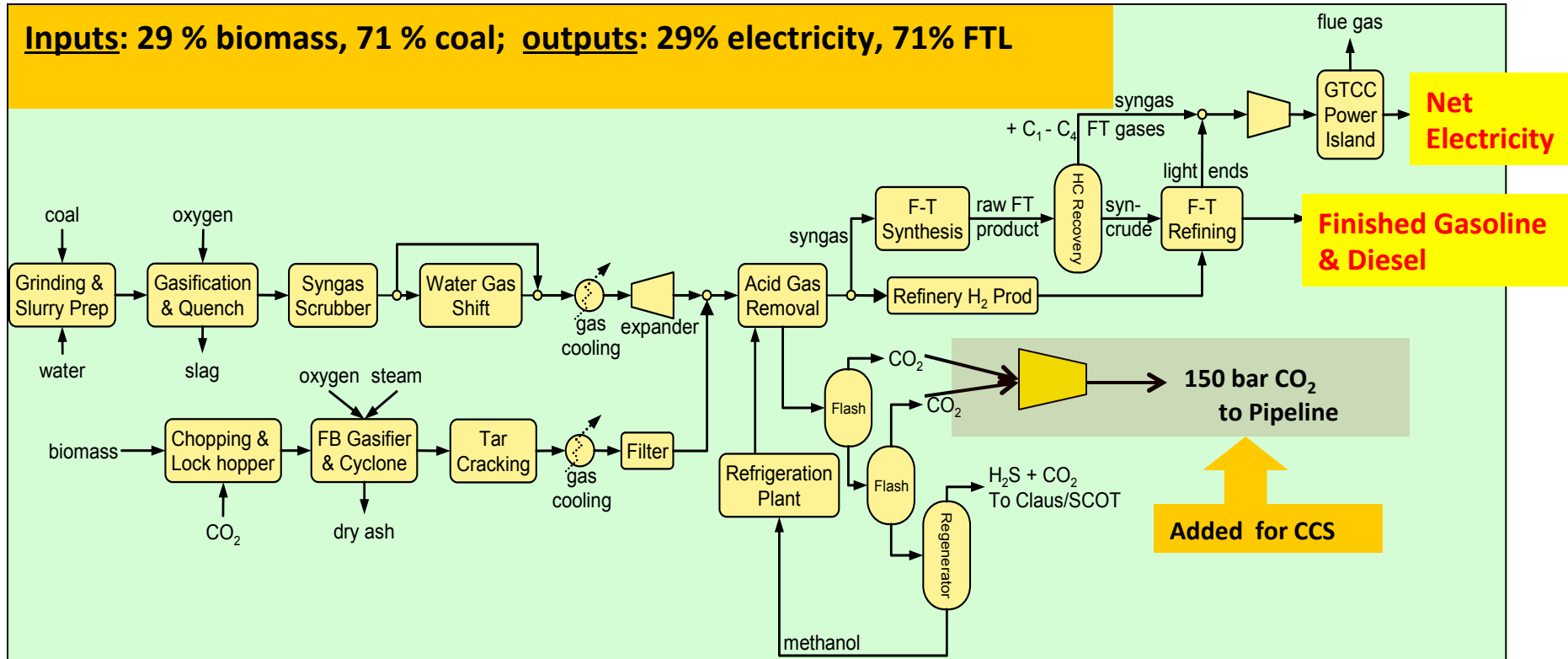
**Inputs:** 29 % biomass, 71 % coal; **outputs:** 37% electricity, 63% FTL



- CO<sub>2</sub> separation upstream of synthesis + venting of separated CO<sub>2</sub> is required part of synthesis process; separation cost included in synfuel production cost
- Fuel cost ~\$2.00/gge at \$60/MWh electricity sale price
- Add coal to biomass → lower average feedstock cost, scale economy gain—e.g., for:
  - CTL w venting: \$1.55/gge (same FTL output, GHGI = 1.3)
  - BTL w venting: \$2.20/gge (same bio input, GHGI = 0.96)

# Co-Production (Coal/Biomass w CCS: GHGI = 0.09)

**Inputs: 29 % biomass, 71 % coal; outputs: 29% electricity, 71% FTL**



- Can provide simultaneously near zero-C “drop-in” fuels & near zero-C electricity
- Cost of GHG emissions avoided: ~\$25/tonne CO<sub>2eq</sub>, including CO<sub>2</sub> transport and injection
- Fuel cost: \$2.60/gge at \$60/MWh electricity sale price

# Cost of GHG Emissions Avoided

## (Excluding Cost of CO<sub>2</sub> Transport and Injection)

Non-Capture to Capture Technology	CO <sub>2</sub> Capture Cost, \$/tonne
Old PC-V --→ New PC-CCS	85
New NGCC-V → New NGCC-CCS	72
New PC-V → New PC-CCS	65
Old PC-V → Old PC-CCS	48
Old PC-V → New NGCC-CCS	45
New IGCC-V → New IGCC-CCS	31
CBTL-OTA-V → CBTL-OTA-CCS	19

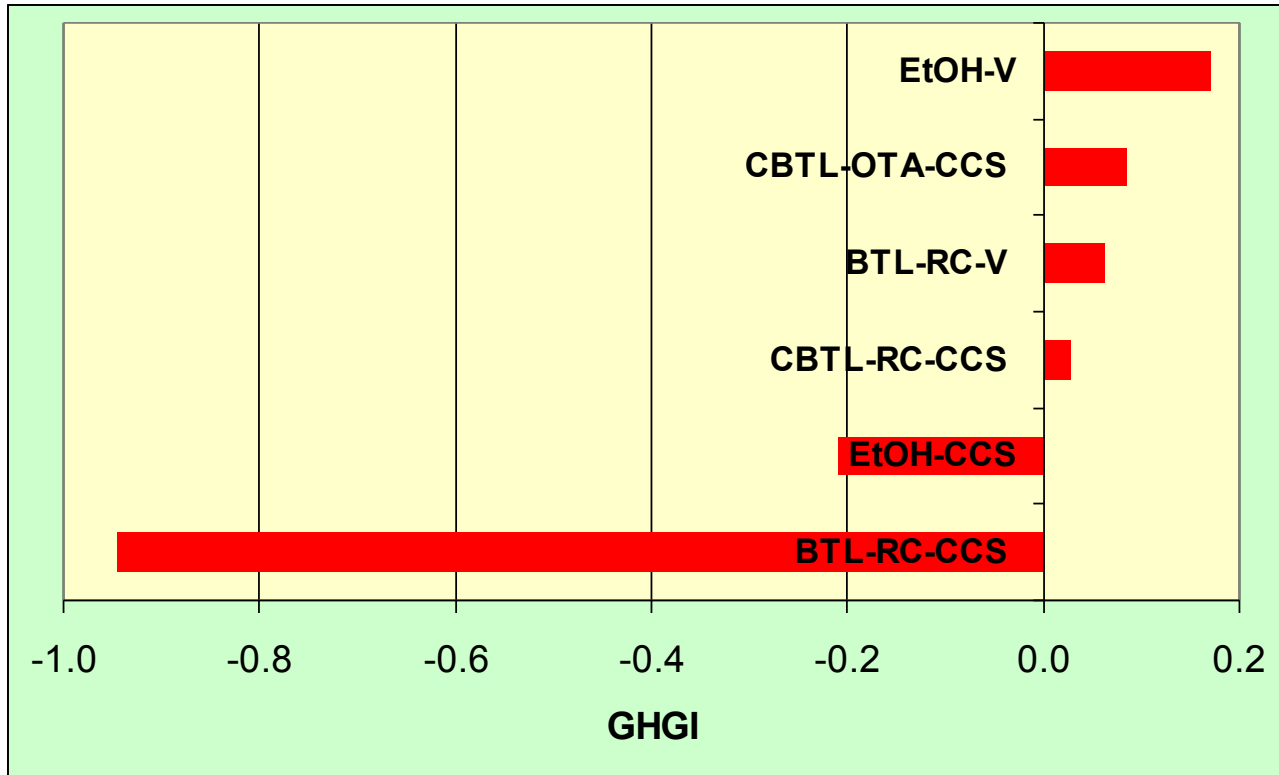
**Cost of GHG Emissions Avoided = [(Production cost with capture) – (Production cost with venting)] / ( GHG emissions avoided)**

# Co-Production of Electricity and Liquid Transport Fuels

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- U.S. has over 150 GW<sub>e</sub> of old sub-critical coal units which will need to be upgraded or replaced soon
- Conventional approaches (e.g., PC-CCS )are costly but will work
- Unconventional approaches are needed to seriously address the cost & CO<sub>2</sub> problems
- Co-production of fuels and electricity offers significant potential to achieve desired goals

# GHG Emissions Index (GHGI) for Alternative Energy Systems

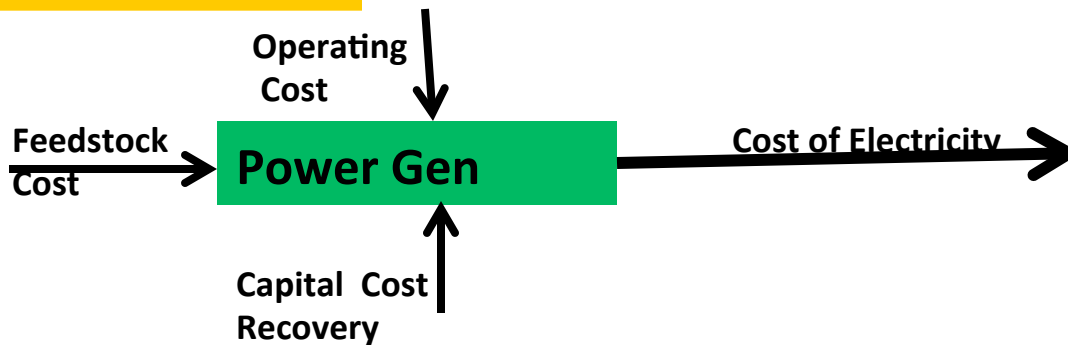


$$GHGI \equiv \frac{(\text{total GHG emissions for energy production \& consumption})}{(\text{total GHG emissions for fossil energy displaced})}$$

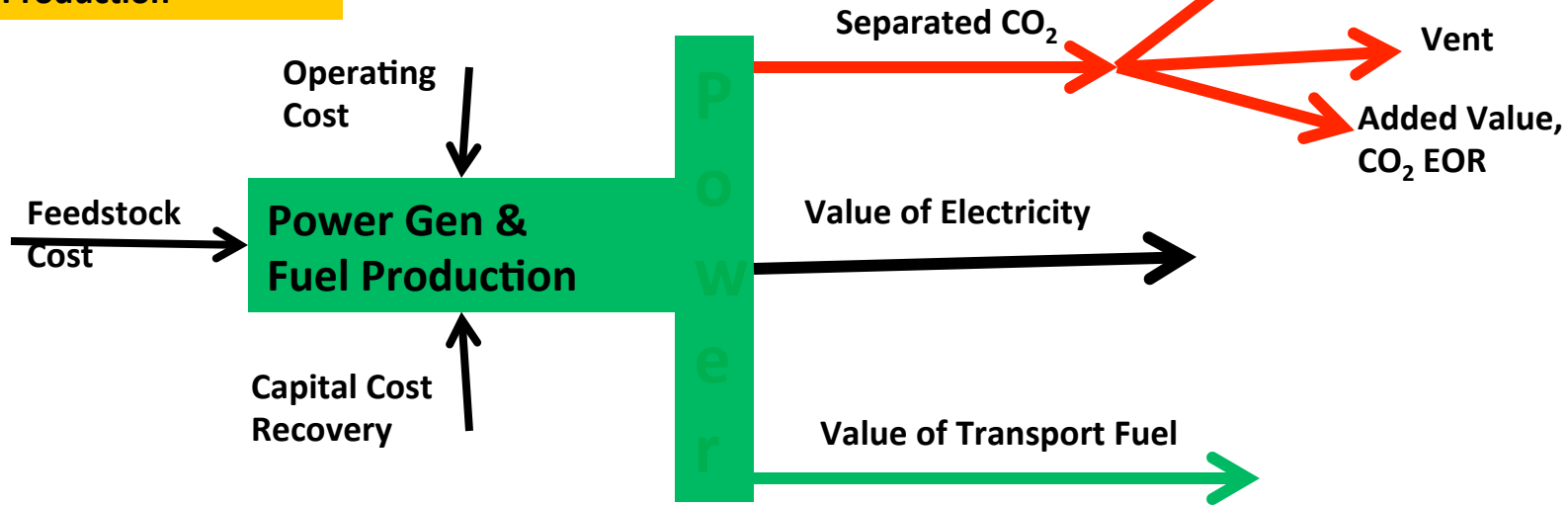
Fossil energy displaced = (equivalent crude-oil-derived products)  
+ (electricity from a new supercritical PC electric plant venting CO<sub>2</sub>).

# Co-Production Economics

## Conventional Production

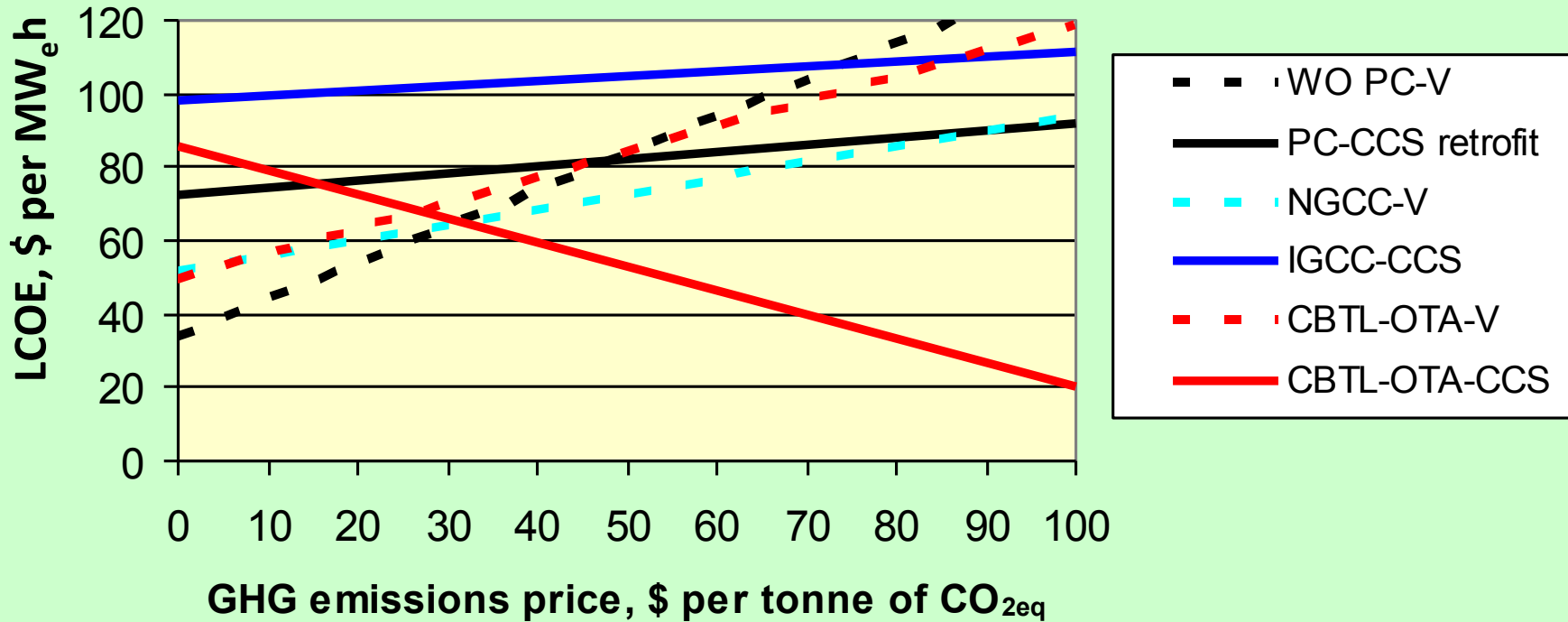


## Co-Production



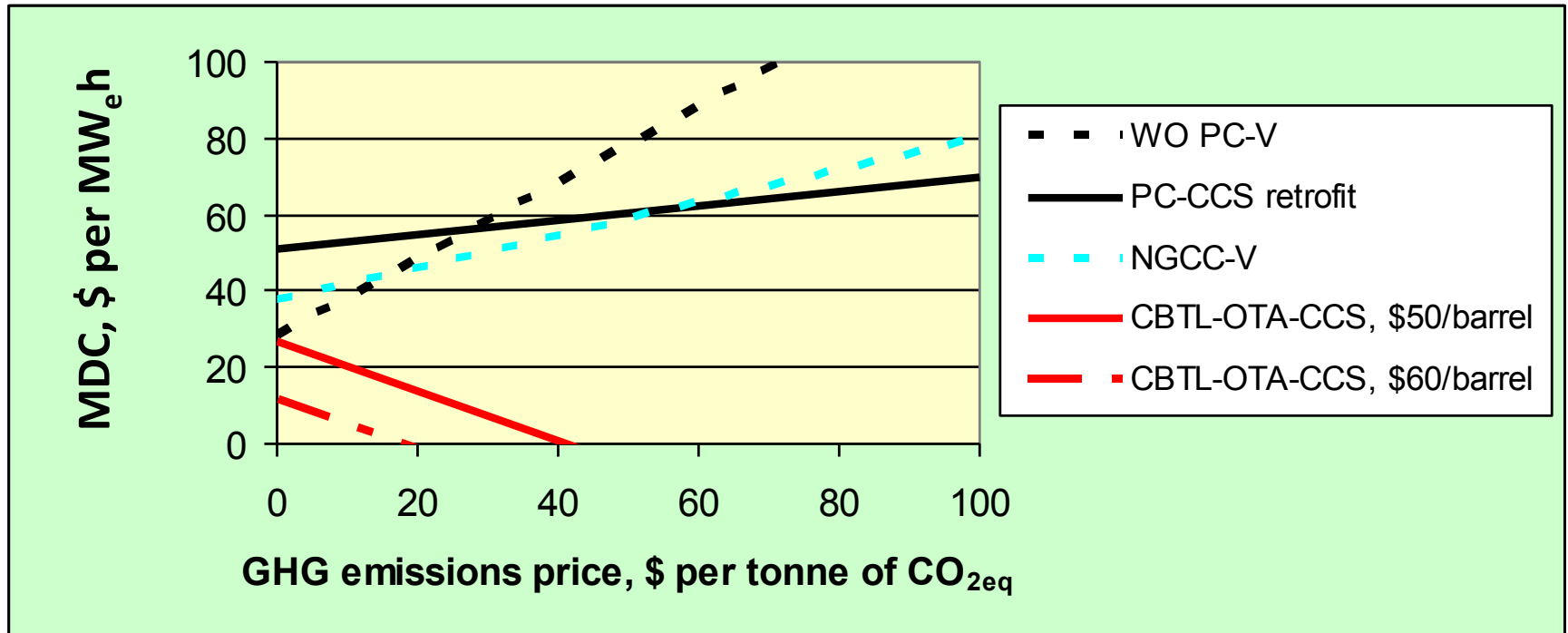
# Levelized Cost of Electricity

(\$90 a Barrel Crude Oil Price, aquifer storage of CO<sub>2</sub>)



- Each biomass-using system consumes 1.0 million dry tonnes per year.
- CO<sub>2</sub> is stored in an aquifer 2.5 km underground, 100 km from conversion plant.

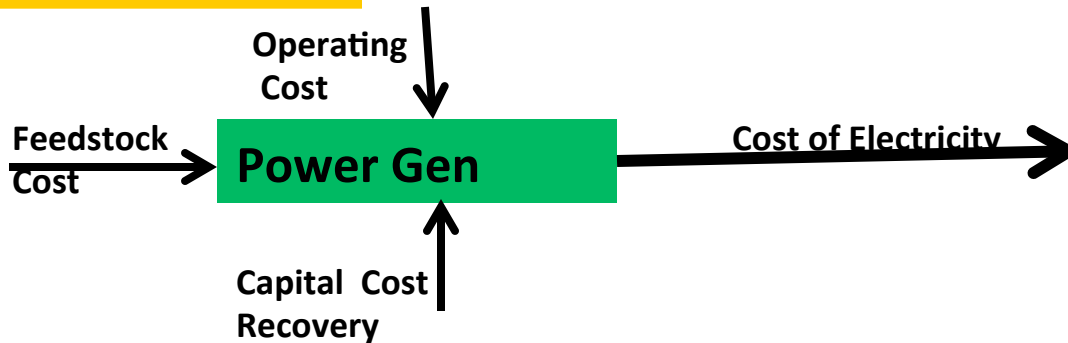
# Minimum Dispatch Cost (MDC) (Aquifer Storage of CO<sub>2</sub>)



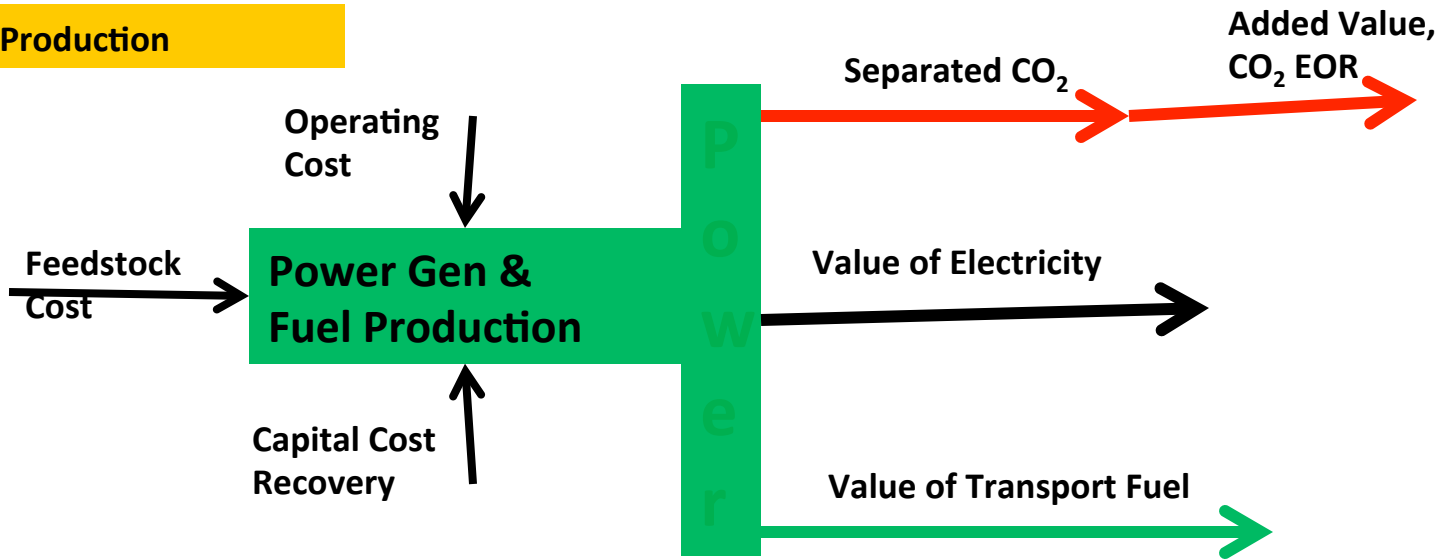
- MDC = \$0/MWh for CBTL-OTA-CCS at \$0/t GHG emissions price when crude oil price = \$67/barrel
- In economic dispatch competition, these plants could defend high design capacity factors & force down capacity factors of competing technologies

# Co-Production with EOR

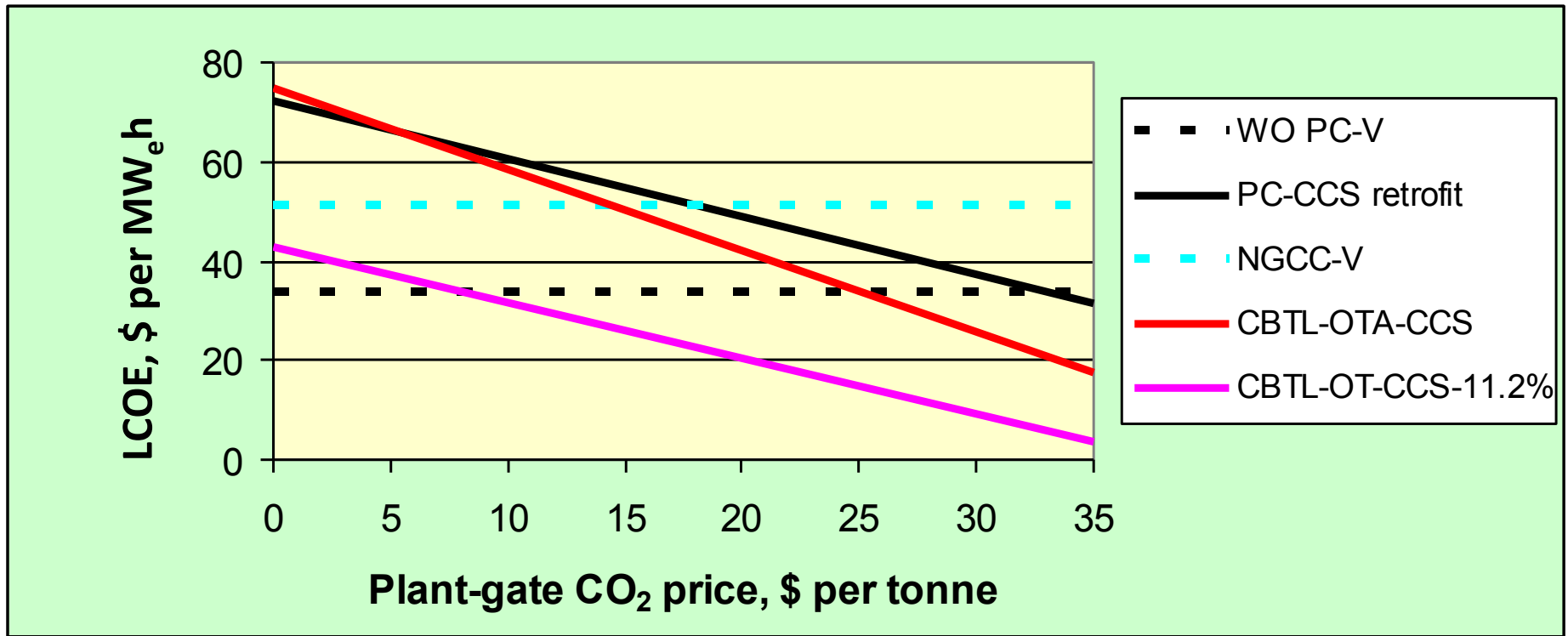
## Conventional Production



## Co-Production



# Levelized Cost of Electricity with CO<sub>2</sub> EOR Applications



- \$90/Barrel Crude Oil Price; \$0/t CO<sub>2eq</sub> GHG emissions price : **No Government Subsidies**
- For 1-2 decades, CCS will be via CO<sub>2</sub> EOR (proven CO<sub>2</sub> storage option).
- 1<sup>st</sup> mover coproduction technology assumed for this CO<sub>2</sub> EOR analysis is fired with 11.2% biomass (enough to reduce GHG emission rate for synfuels to ½ rate for crude oil products displaced when GHG emissions rate assigned to power = NGCC-V rate)
- Current CO<sub>2</sub> EOR market price = \$25 to \$40 a tonne at EOR site

# Achieving Major Mid-Century CO<sub>2</sub> Emissions Reductions via Co-Production

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**Thought-Experiment:** Use co-production technology (CBTL-OTA-CCS), 1 million tonnes of biomass/site/year (+70 % coal) to replace old PC plants when economically attractive; natural gas makes up the electricity deficit when needed; start using CO<sub>2</sub>-EOR, switch to saline aquifer storage when necessary and safe.

- **Transportation Sector: GHG emissions reduced 75% from 2005 to 2050 while liquid fuels use is reduced 18 % due to transport efficiency improvements**
- **Coal power generation: GHG emissions reduced by 93 % while coal-based power reduced by 7%**
- **GHG emissions for the two sectors reduced by 83% in 2050 vs. 2005**

# Conclusions and Observations

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- **Co-production of electricity and transport fuels addresses both power and transport sector emissions, and oil imports**
- **Although all technology discussed is commercial, first-mover applications will require assistance; beyond that co-production technologies can be economically viable without government subsidies**
- **Co-processing options with ~ 10% biomass are ready for deployment in this decade**
- **Geologic CO<sub>2</sub> storage is critical to meeting desired GHG emissions reductions**
- **CO<sub>2</sub> EOR is commercially used & proven, improves economics, increases domestic oil production, and offers important transition to saline aquifer storage**
- **If this is so attractive, why are we not doing it today?**
  - **Components are moving forward today separately/not in integrated system**
  - **Is hindered by lack of forward policy certainty**
  - **Lacks a clear champion {power company?; fuel company?; production company/}**
- **Need to move forward more rapidly than we are now**

# Thank You- Questions ??

Much of this is based on work done by Bob Williams at PEI, Princeton University, Bob has lead in the development of CBTL and the developed the analysis and numbers in Co-processing. His work is greatly appreciated.

For example see:

Guangjian LIU, Eric. D. Larson, Robert H. Williams, Thomas. G. Kreutz and Xiangbo GUO, 2011: “Making Fischer-Tropsch Fuels and Electricity from Coal and Biomass: Performance and Cost Analysis,” *Energy and Fuels* **25**, 415-437, DOI:10.1021/ef101184e (published online: 6 December 2010)

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Williams, Robert H., “Coproducton Strategy to Realize by Midcentury An 83 % Reduction in GHG Emissions for Transportation Fuels and Coal Power,” presented at NREL, August 24, 2011.

# Coal-Power Emissions Performance

Technology	Case	Particulates	SO <sub>2</sub>	NO <sub>x</sub>	Mercury
		g/kW <sub>e</sub> h	g/kW <sub>e</sub> h	g/kW <sub>e</sub> h	% Removed
<u>PC Plant</u>	U. S. Average	0.18	3.7	1.7	
	Best Commercial (US)	0.066 (99.5+%)	0.18 (99+%)	0.13 (90+%)	90%
<u>IGCC Plant</u>	Best Commercial (Japan)	0.004	0.066 (99.8%)	0.044	95%

- IGCC can have the lowest air emissions, similar to NGCC
- Gasification (IGCC) with CCS should be key technology for the future
- Gasification (coal and biomass) is a key platform for the future power, fuels, & chemicals production

# 2009 U. S. GreenHouse Gas Emissions

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- **Total U. S. GHG Emissions:**
  - 6,600 million tonnes CO<sub>2eq</sub>
  - 5,500 million tonnes CO<sub>2</sub>
- **Electricity Generation:**
  - 2,200 million tonnes CO<sub>2</sub>
  - 40 % of total
  - 83 % is coal based
- **Transportation Sector:**
  - 1,700 million tonnes CO<sub>2</sub>
  - 31 % of total

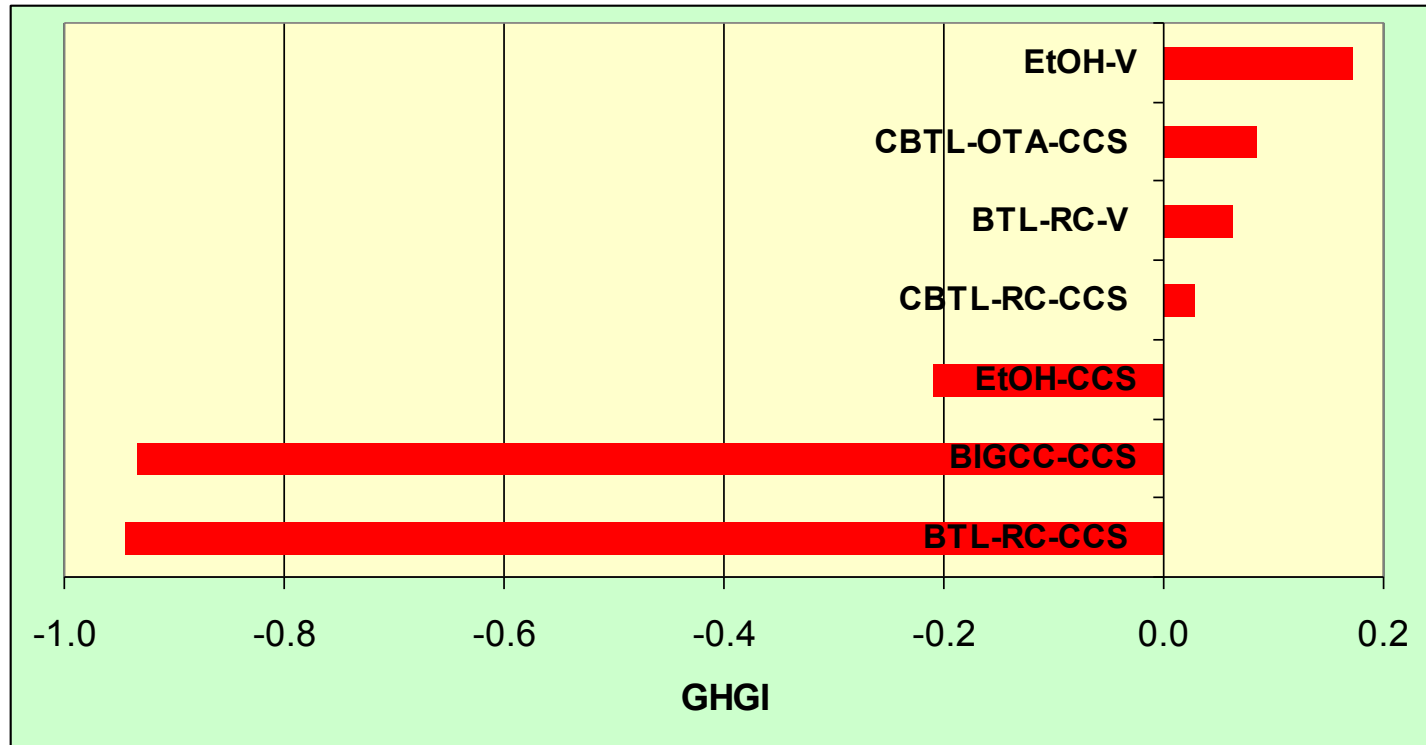
# CO<sub>2</sub> Capture Cost Summary

## (Excluding Cost of CO<sub>2</sub> Transport and Injection)

Non-Capture to Capture Technology	CO <sub>2</sub> Capture Cost, \$/tonne
Old PC-V → New NGCC-CCS	105
Old PC-V --→ New PC-CCS	69
New NGCC-V → New NGCC-CCS	59
New PC-V → New PC-CCS	42
Old PC-V → Old PC-CCS	33
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**Cost of CO<sub>2</sub> Capture = [(Production cost with capture) – (Production cost with venting)] / (CO<sub>2</sub> captured)**

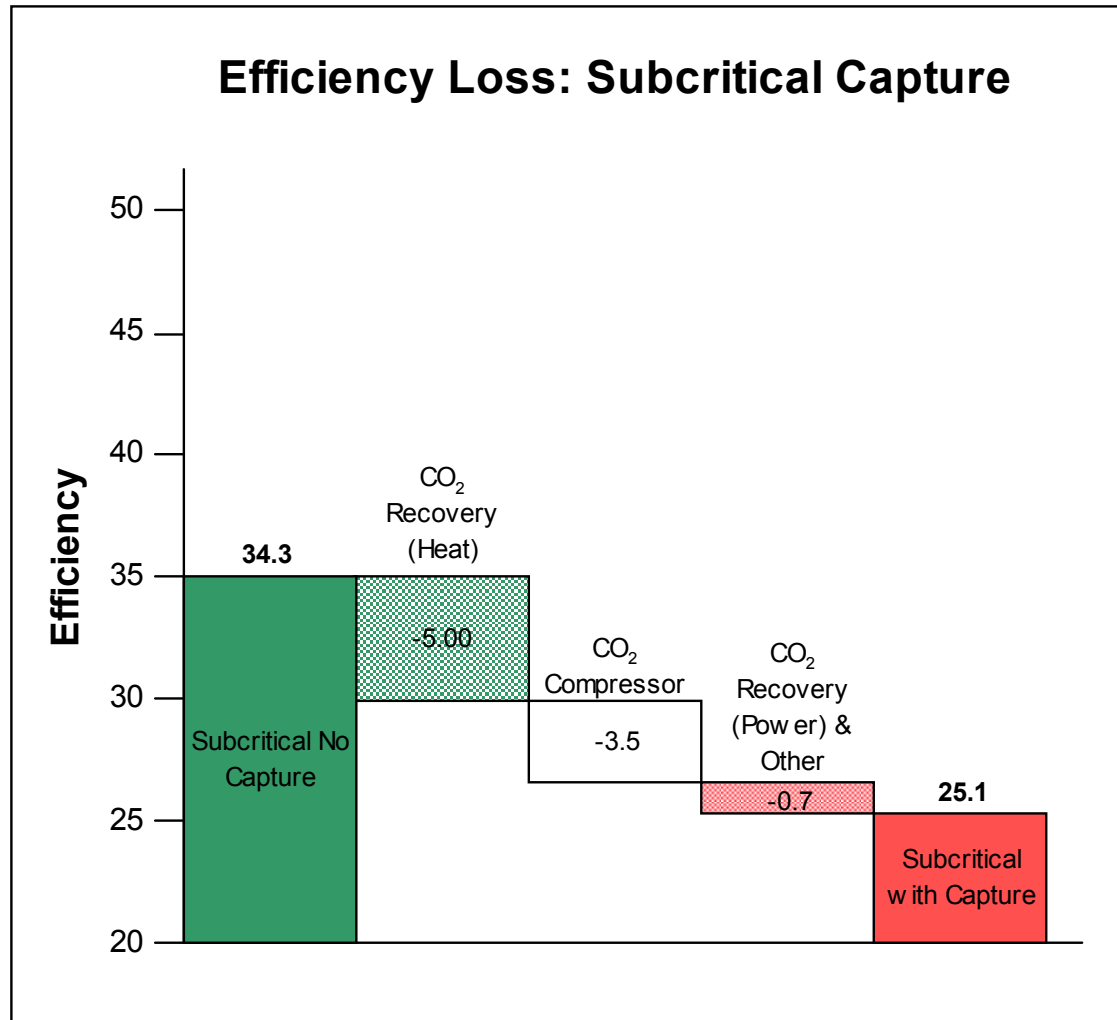
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Fossil energy displaced = (equivalent crude-oil-derived products)  
+ (electricity from a new supercritical PC electric plant venting CO<sub>2</sub>).

# Parasitic Energy Losses for CO<sub>2</sub> Capture on Subcritical PC



- Generating efficiency reduced by 9 to 12 percentage points by CCS