Clean Coal and Biomass to Electric Power and Liquid Fuels

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Objectives and Overview

Key Objectives:

- **Electricity: Reduce criteria emissions and CO_2 emissions**
- **Liquid fuels: Broaden sourcing and reduce transport sector CO_2 emissions**

Talk Overview:

1. **Clean coal power generation, plus geologic CO_2 storage**
2. **Coal and biomass to liquid fuels (CBTL)**
3. **Coal and biomass to power and fuels**
4. **Opportunities**

Evaluation Approach, and Bases

- Integrate and evaluate commercial technologies
- All process material and energy balances done with Aspen Plus
- One equipment-cost base; grounded in IGCC experience; in 2007$
- N^{th} Plant, where N is a small number (N = 5 to 7)
- 20 year levelized cost evaluation (capital charge rate 14.4%/y)
- Life-Cycle GHG emissions outside plant estimated with GREET
- Coal (Illinois #6) at $46/tonne ($1.7/GJ {HHV})
- Biomass at $94/dry tonne ($5.0/GJ{HHV}), 1 million dry tonnes/year/site
- Consistent, comparative economics, U.S. Gulf Coast

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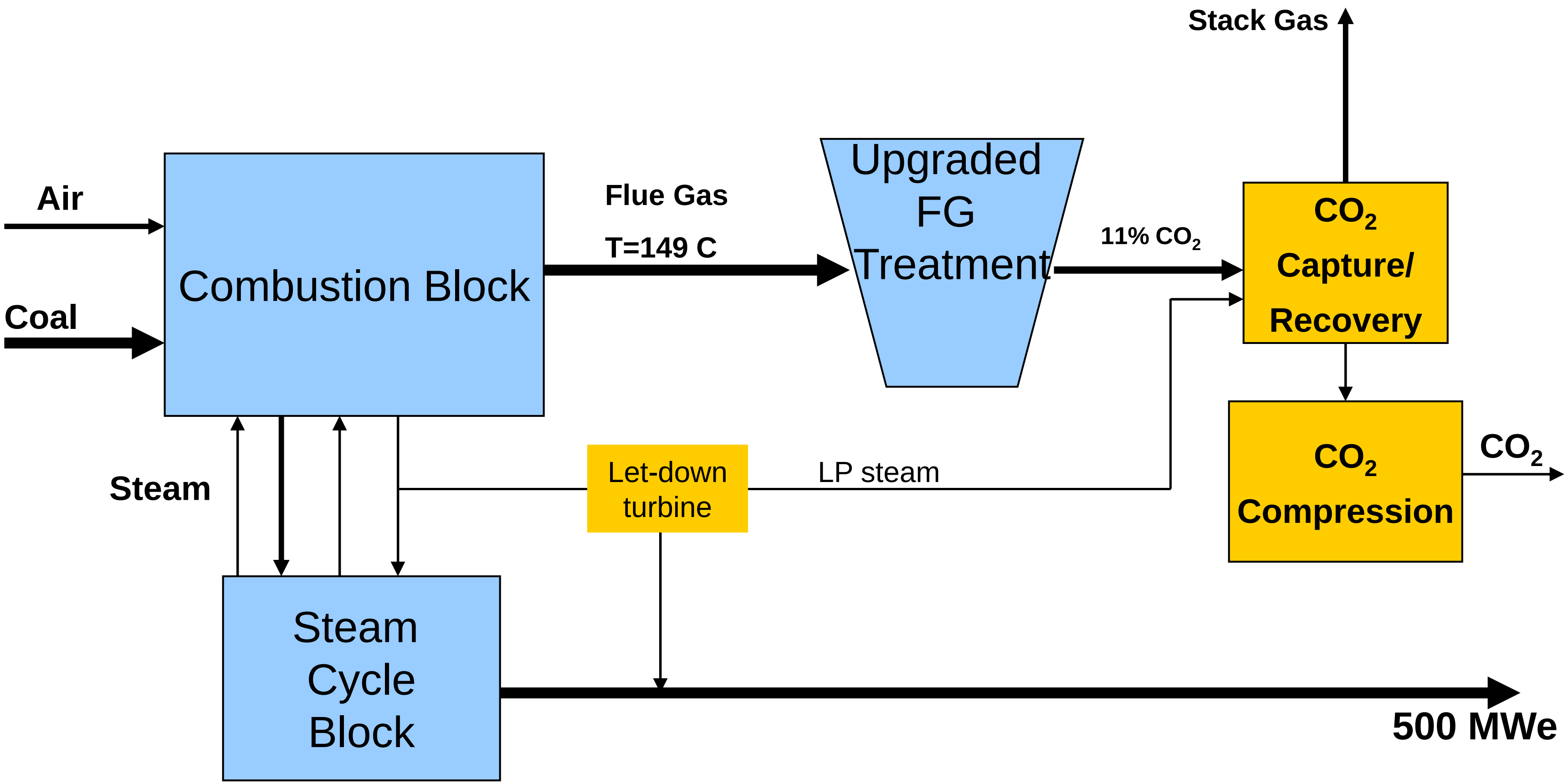
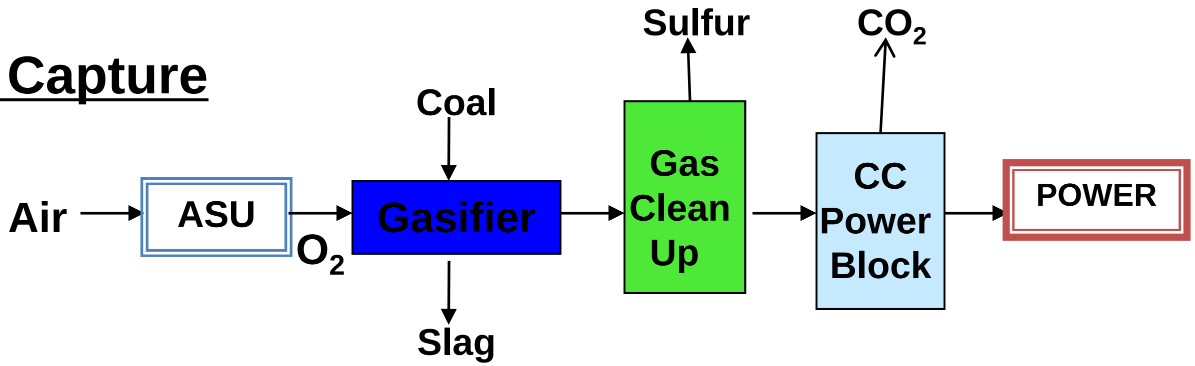
PC Plant with Amine-Based CO_2 Capture



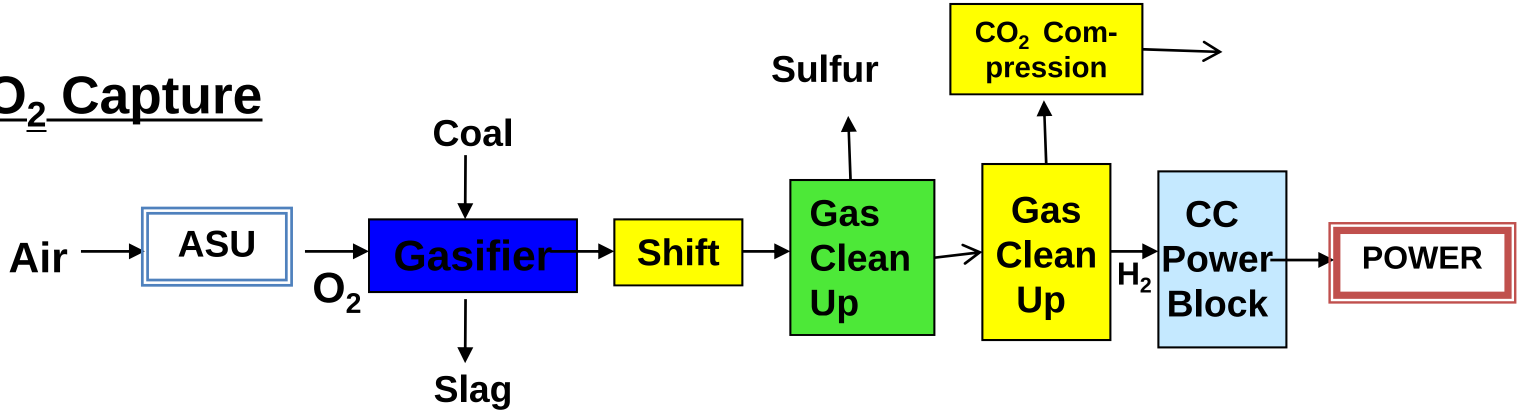
- Subcritical units have 33-36% (HHV) efficiency; generating efficiency is reduced to ~ 25 % (HHV) for new subcritical with CO_2-capture, requiring ~40% more coal for same electricity
- Ultra-supercritical units have 40-44% efficiency which is reduced to ~ 34 % (HHV) with CO_2-capture.

IGCC without and with CO_2 Capture

W/O CO_2 Capture



With CO_2 Capture



CO is converted to CO_2 & hydrogen via the shift reaction; the CO_2 is then removed and compressed for storage

Coal Power: Electricity Cost and CO_2 Emissions

	Electricity Cost, \$/MW_eh		CO_{2eq} Emissions, kg / MW_eh			
PC-Vent	58		831			
PC- CCS	106		170			
				\$73/tonne CO_{2eq} avoided		
IGCC-Vent	65		833			
IGCC-CCS	89		138			
				\$35/tonne CO_{2eq} avoided		

- IGCC-CCS can provide lowest cost decarbonized electricity from coal
- IGCC provides lowest cost CO_2 avoided
- Further, IGCC produces dense vitrified solids, no FGD sludge, requires significantly less water, and has very low emissions to air

Coal Power: Emissions Performance

Technology	Case	Particulates	SO_2	NO_x	Mercury
		lb / MM Btu	lb / MM Btu	lb / MM Btu	% removed
PC Plant					
	U. S. Typical	0.04	0.8	0.3	
	Best Commercial	0.015 (99.5%)	0.04 (99+%)	0.03 (90+%)	90
IGCC Plant					
	Best Commercial	0.001	0.015 (99.8%)	0.01	95

- IGCC emissions can be very low and should be similar to NGCC.
- IGCC has lowest emissions and with CCS they should be even lower
- Gasification (IGCC) should be key technology for the future, but not fully embraced by power industry

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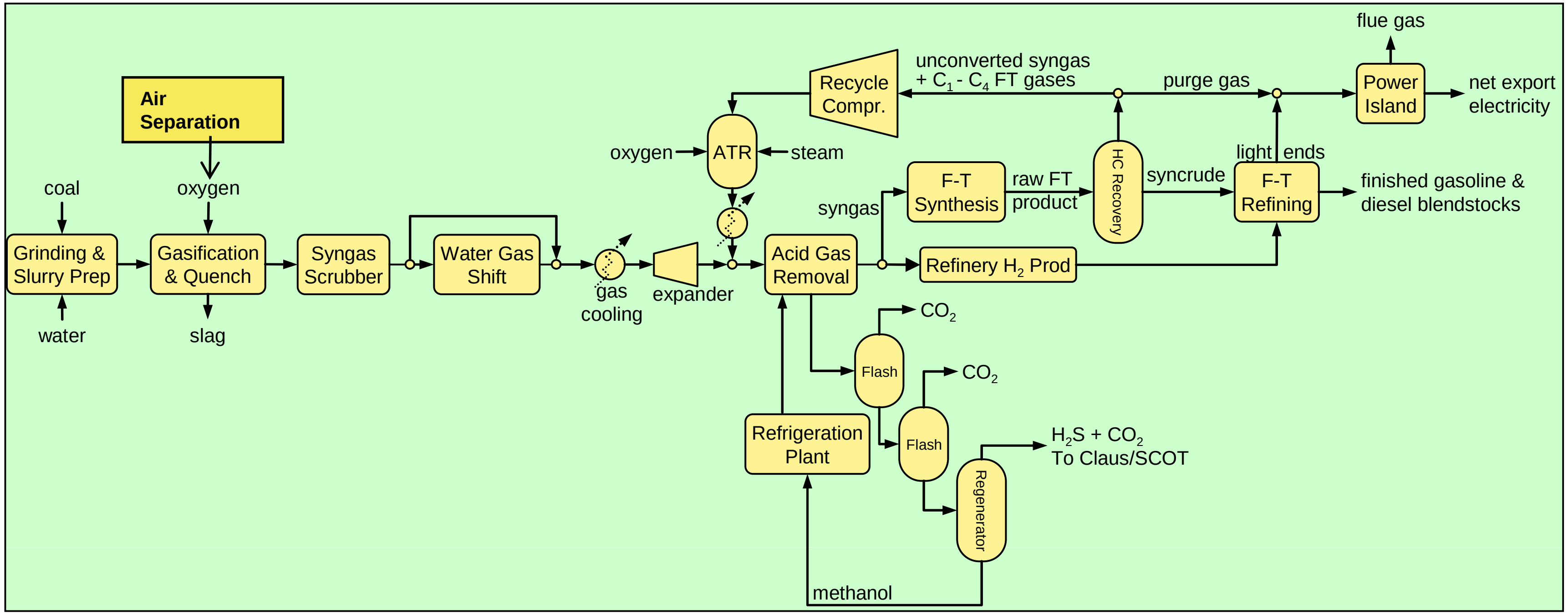
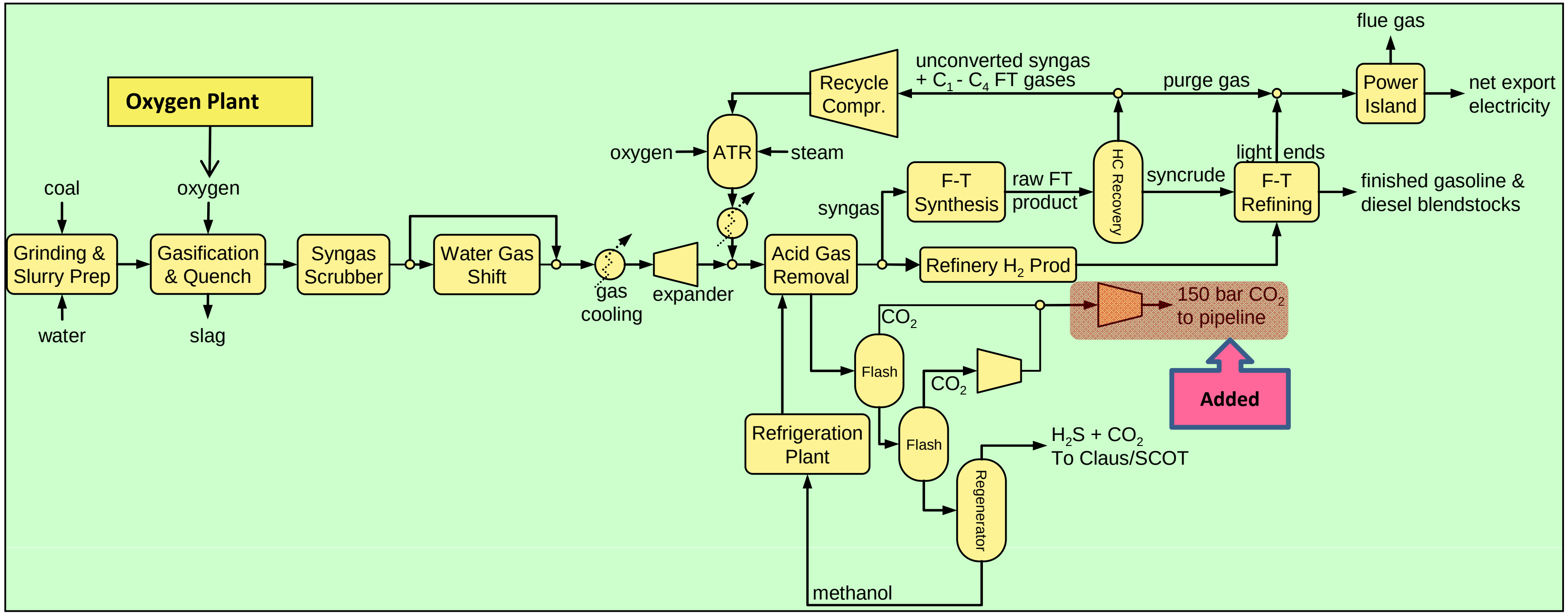
Coal to Liquid Fuels without CO_2 Storage [CTL-RC-V]



Fischer-Tropsch conversion technology used; methanol-to-gasoline also applicable; 50,000 bpd

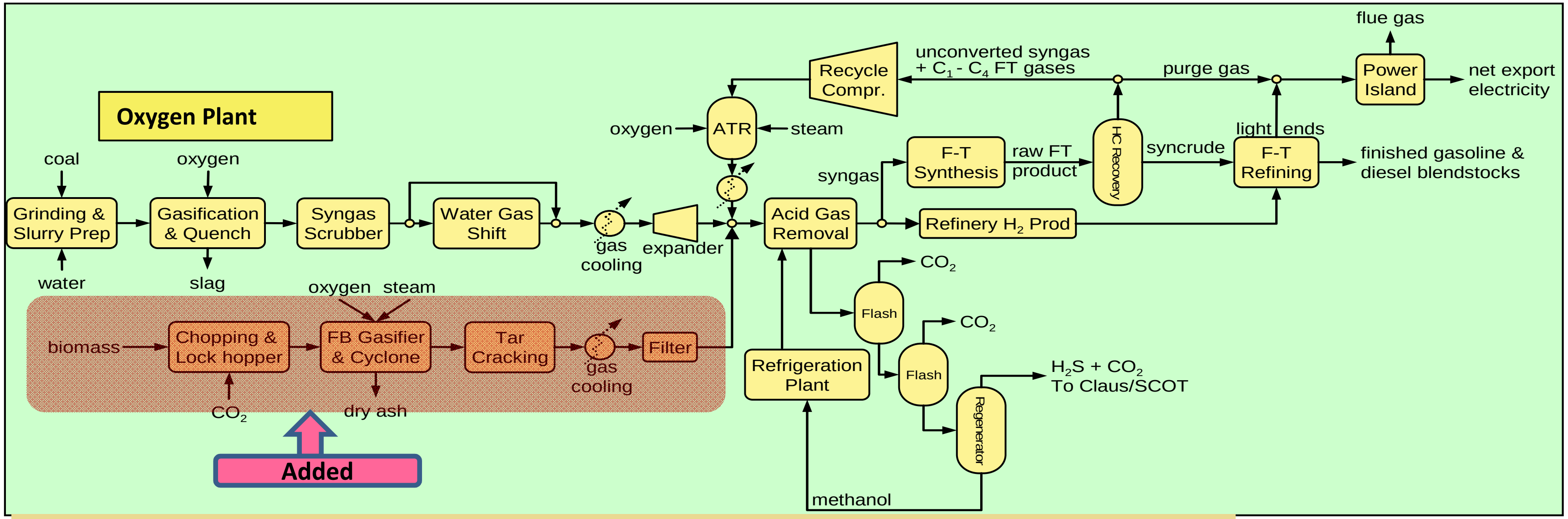
- **Liquid transportation fuels produced are economically viable for $60/ bbl crude oil**
- **Life-cycle CO_2 emissions almost twice those for crude oil-based fuels**
- **CO_2 separation required as part of liquids synthesis process**
- **Electricity to grid is about 12% of product sold on an energy basis**

Coal to Liquid Fuels with CO_2 Storage [CTL-RC-CCS]



- For CCS, require adding only CO_2 compression and storage
- Cost of CO_2 avoided is less than $15/tonne
- CCS adds marginally to fuel cost

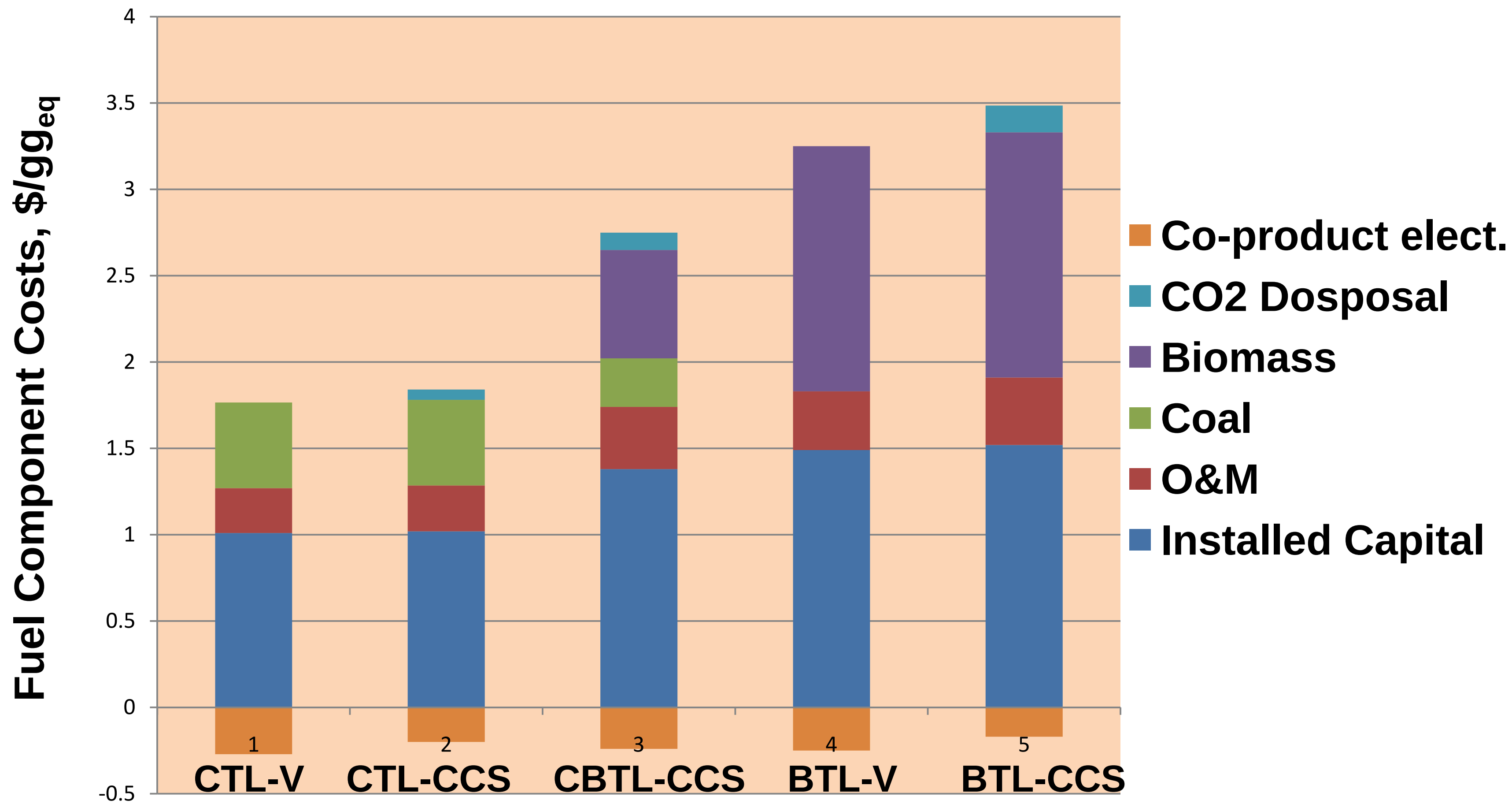
Coal plus Biomass to Liquid Fuels [CBTL]



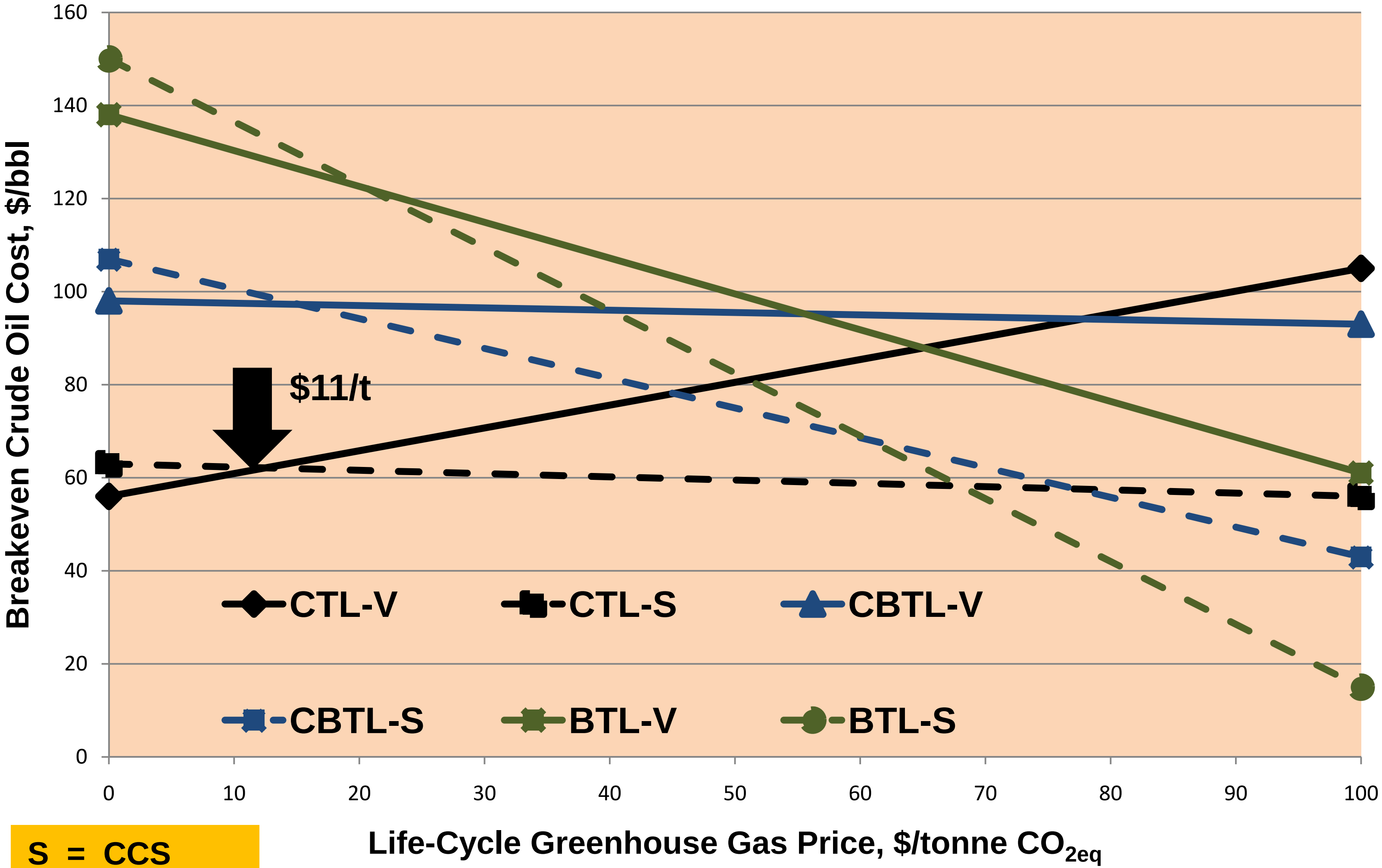
Biomass limited, 1 million dry tonnes/year; ~10,000 bbl/day liquid fuels

- **Used fluid-bed gasifier for biomass gasification alone and in combination with coal**
- **Biomass is scarce resource; gain economies of scale by combining with coal**
- **Coal to biomass input ratio (energy basis) an important parameter**

Coal/Biomass to Fuel Costs



Effect of Life-Cycle GHG Price on Liquids Production Breakeven Crude Oil Cost



S = CCS

Life-Cycle Green House Gas Performance Characterized by Greenhouse Gas Emissions Index (GHGI)

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

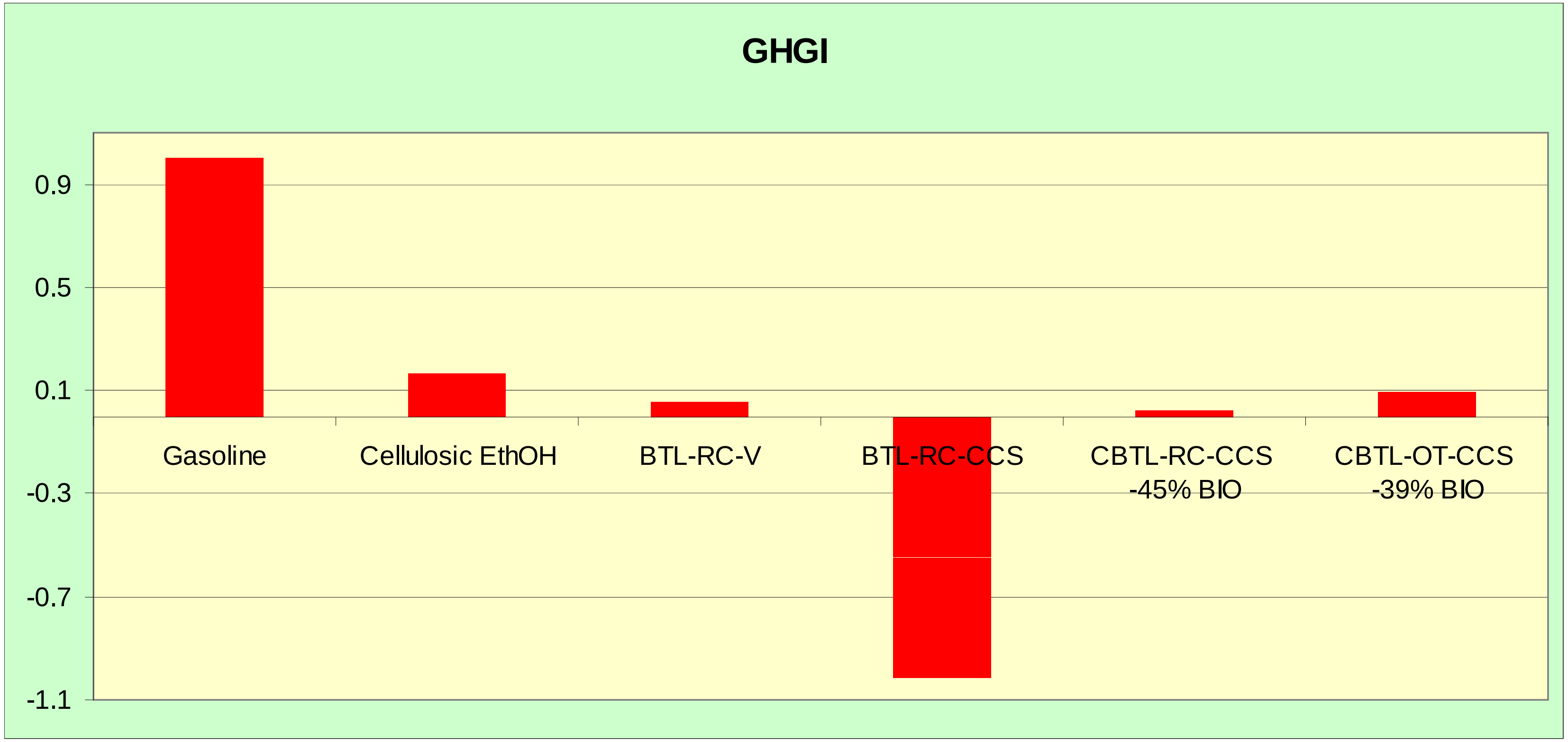
<u>Assumption</u>:

Fossil energy displaced is:

(equivalent crude-oil-derived products) +

(electricity from new supercritical pulverized coal plants venting CO_2)

Life-Cycle GHGI Values for Fuels Options Involving Biomass



Near-zero life-cycle GHG emissions can be achieved with coal being more than ½ of the fuel input

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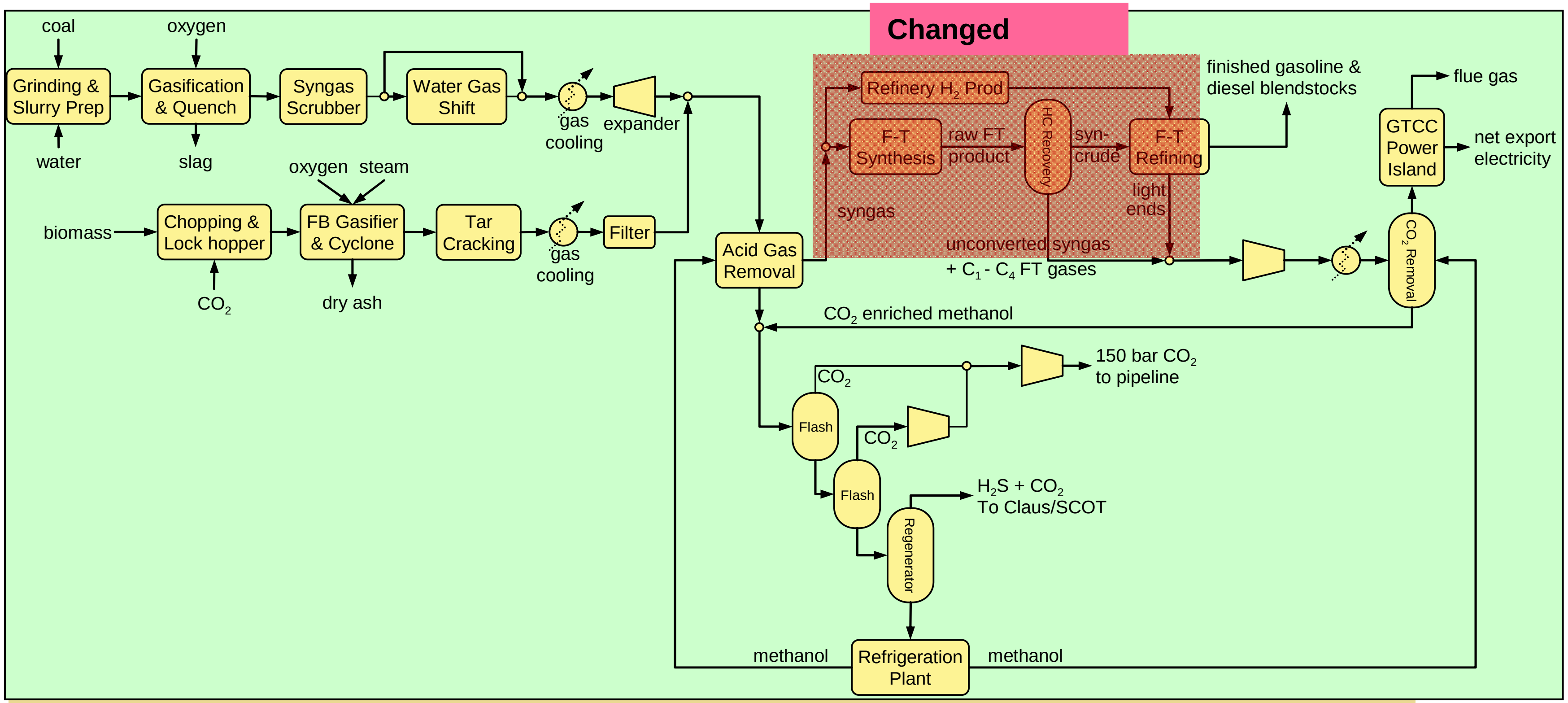
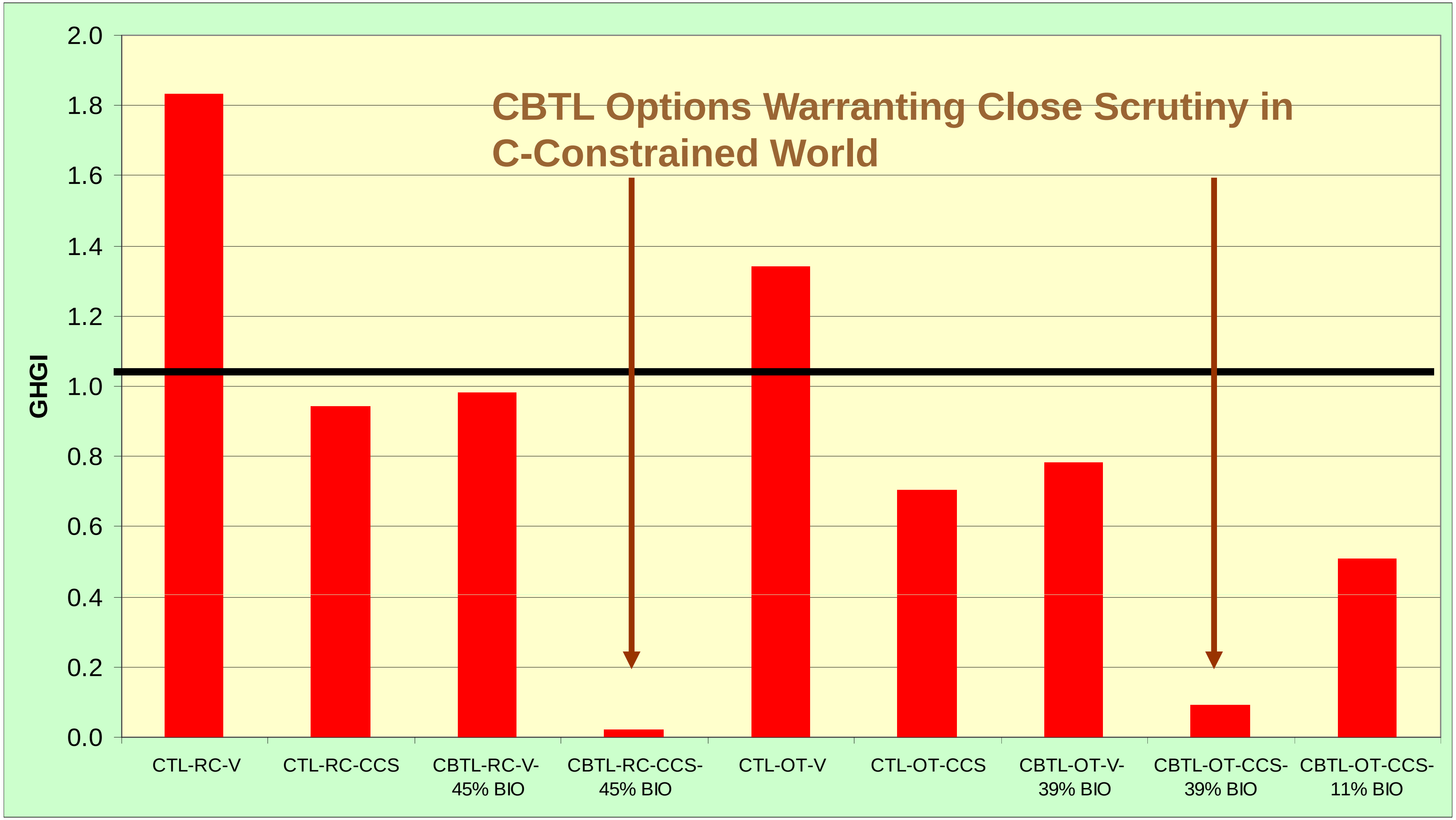
Once-Through (OT) For Liquid Fuels and Increased Electricity Production [CBTL-OT]



1 million dry tonnes/year biomass, ~10,000 bpd liquid fuels, ~275 MW_e electric power

- **Eliminate recycle and its costs; unconverted gases go directly to power island**
- **Electricity produced is about 40% of total output on an energy basis**
- **Cost of CO_{2eq} avoided is \$20/tonne**
- **At fixed electricity price, fuels are 7-10% cheaper for once-through plant**

Life-Cycle GHGI for Some CTL & CBTL Options



- **CBTL with CCS can simultaneously produce zero-carbon electricity and zero-carbon liquid fuels**

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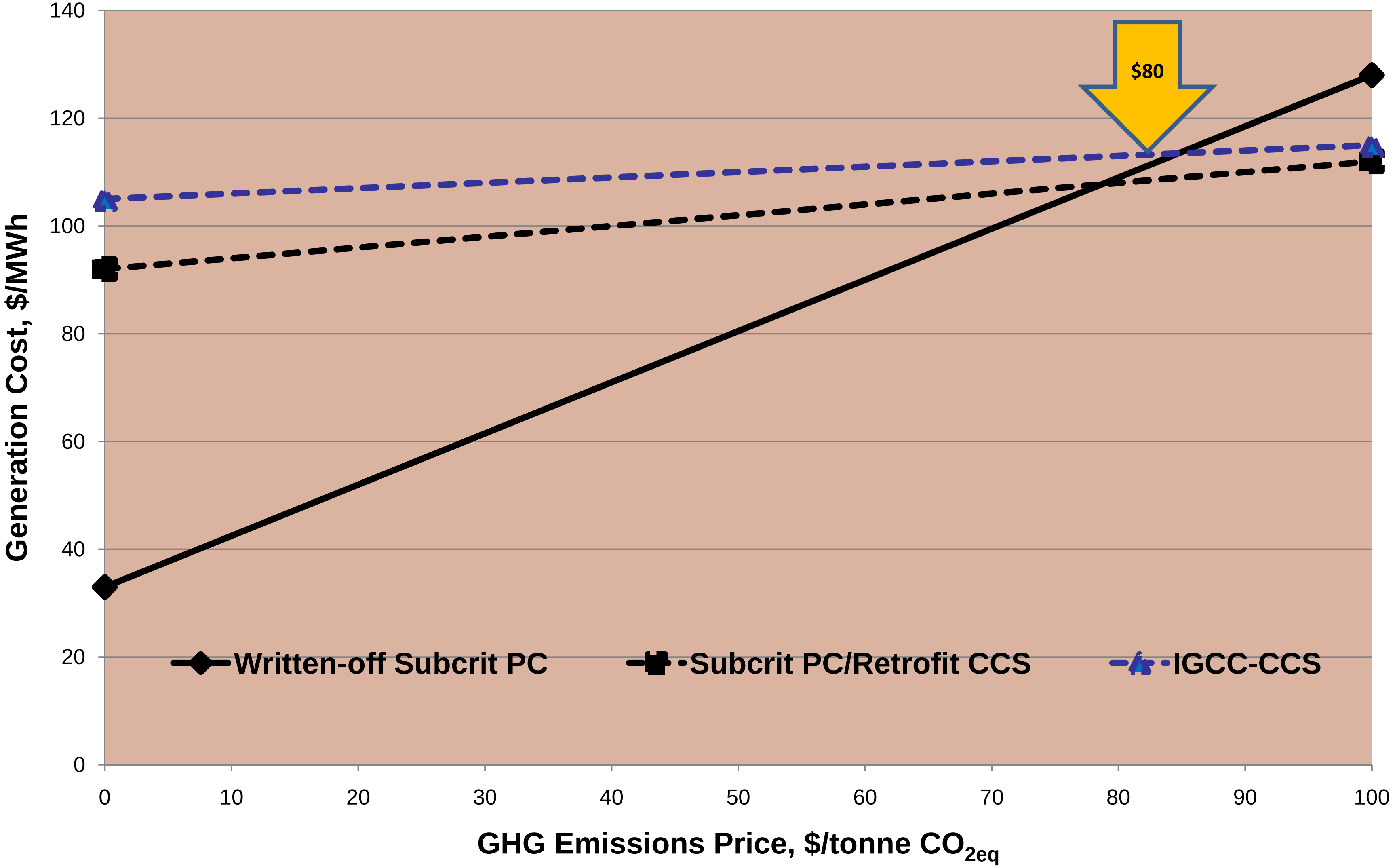
Reducing CO_2 From Existing Subcritical PCs

U.S. has ~314 GW of PC capacity; most units are subcritical; Japan has 11 GW of subcritical units of which 6 GW are utility based

- **Options:**
  - Retrofit with amine capture on flue gas train
  - Rebuild with IGCC with CCS
  - Rebuild with supercritical or ultra-supercritical PC with CCS
  - Rebuild with power & transport fuel co-production (CBTL)
  - Shut down
- **COE from paid-off unit is ~$33/$MW_e$h**
- **COE for amine retrofit at ~$90*/$MW_e$h is least costly retrofit**
- **COE for IGCC-CCS at ~$105*/$MW_e$h is least costly repowering option**

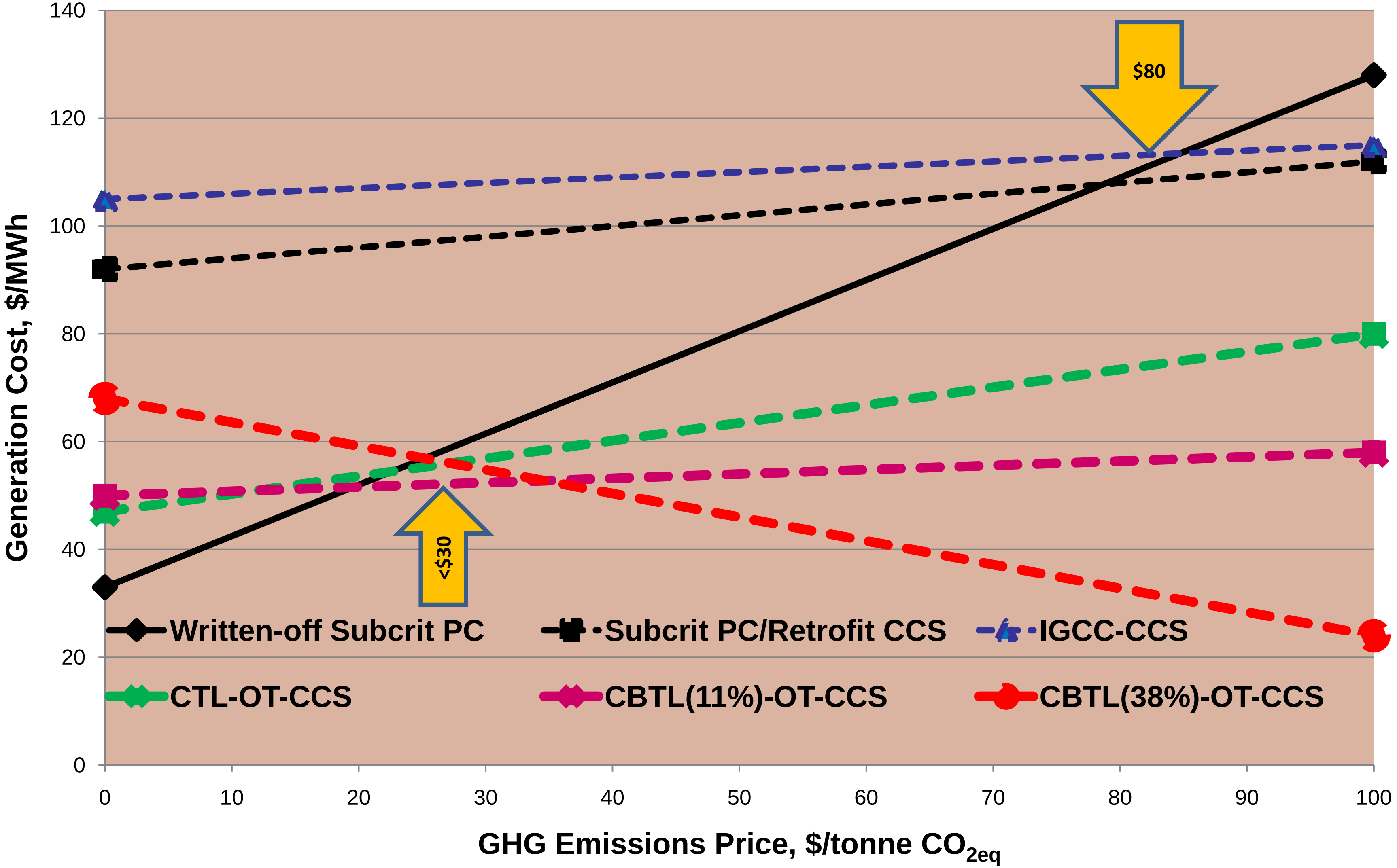
* Estimates from Dale Simbeck, MIT PC Retrofit Conference, 2009: In agreement with Williams et al.

Electricity Cost: CO_2 Price Impact



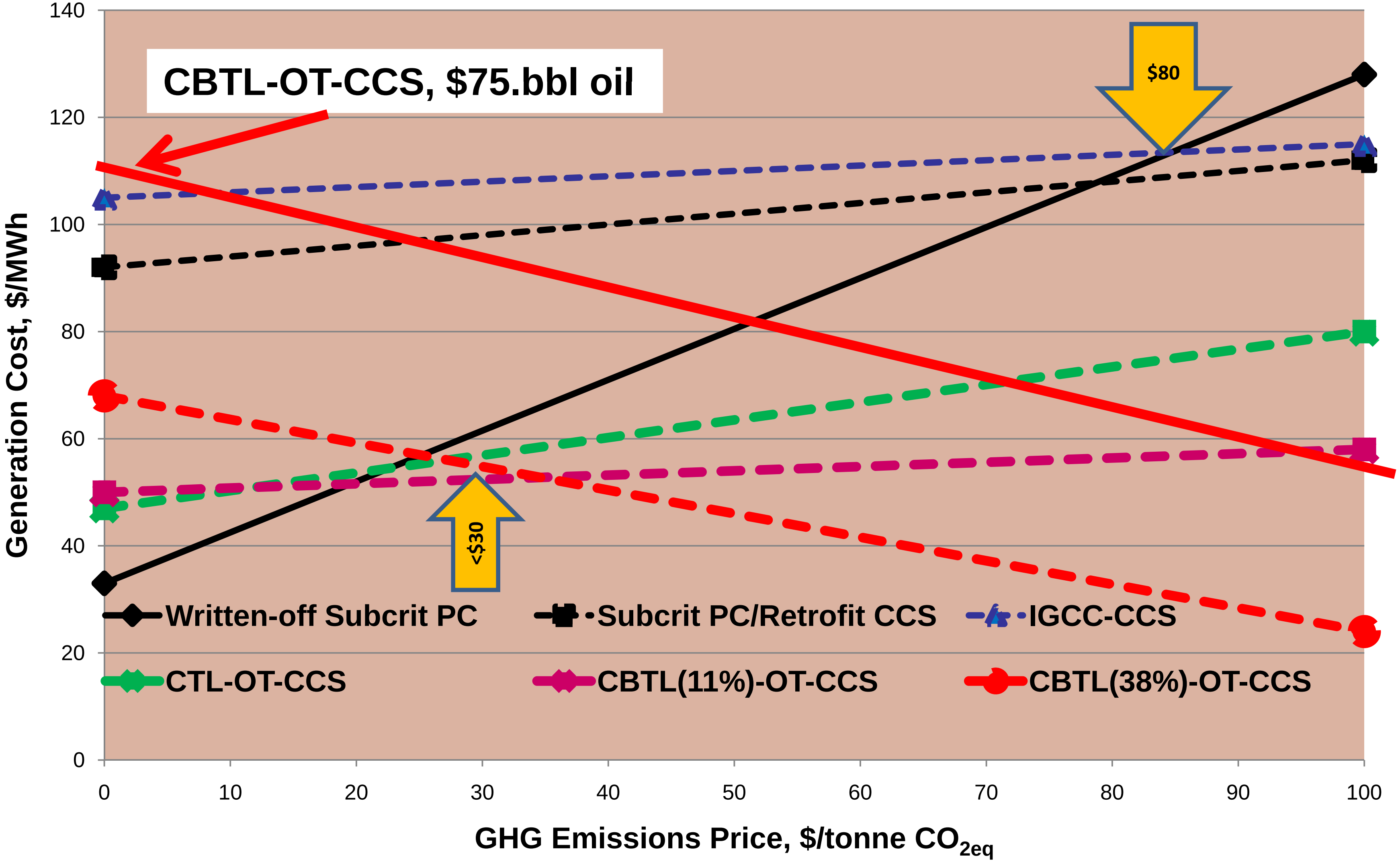
Coal at $46/tonne; Biomass at $94/dry tonne

Electricity Cost: CO_2 Price Impact for $100/bbl Oil



Coal at $46/tonne; Biomass at $94/dry tonne; Transport Fuels sold into a $100/bbl oil market

Electricity Cost: CO_2 Price Impact for $75/bbl Oil



Coal at $46/tonne; Biomass at $94/dry tonne; Transport Fuels sold into a $75/bbl oil market

Observations: Overview

- Geologic CO_2 storage (CCS) is critical
- Coal-based power can be very "clean," and IGCC can lead
- Gasification is a key platform technology to clean power and liquid fuels and can be deployed near-term
- Cost per tonne of CO_{2eq} avoided should be key technology-ranking parameter
- Co-production utilizing coal + biomass with CCS can address multiple energy challenges
  - Climate change
  - Security of supply
  - Diversity of supply
  - Air quality
- Commercial biomass supply chain needs to be developed and biomass gasification needs to mature commercially

Observations: Coal plus Biomass

- Biomass is renewable , but is a limited resource; SE Asia has ~40% of global biomass
- CBTL-CCS can produce simultaneously zero-carbon fuels and zero-carbon electricity
- CBTL production costs are attractive today and will be economically competitive in a carbon-constrained world
- Cost of CO_{2eq} avoided for co-production systems is less than $25/tonne, much lower than for stand-alone power systems
- CBTL, once-through with CCS, is an attractive option for replacing old, subcritical PC units or for greenfield projects to produce decarbonized electricity and carbon-free fuels
- Dealing with two very different products (electricity and liquid fuels) is a major obstacle

Co-Production of Fuels and Power, Japan

- Consider technology to replace old, low-efficiency PC plants, where sufficient biomass could be supplied
- Build new greenfield CBTL–OT plants where coal, biomass, and CCS are available
- Build CBTL plants off-shore where coal, biomass, and CCS are accessible
  - Import zero carbon transportation fuel to Japan
  - Receive credit (CDM) for the decarbonized electricity produced for local consumption

Co-Production of Fuels and Power, Estimated U.S. Impact

- U.S.* could produce about 500** million dry tonnes/year of biomass by 2035
- Using 250 million dry tonnes biomass/yr by 2035
  - CBTL-OT-CCS could produce 1.9 million bbl/day fuels and 65 GW power, both at attractive cost and carbon-free
  - This could reduce CO_2 by 300 million tonnes/yr from transportation and about 550 million tonnes/yr from power generation
- Sustainability advantages of combining coal with biomass:
  - utilizating gasification can have very low emissions
  - increases biomass' impact (more liquid fuel/tonne biomass)
  - extends the life-time for available coal
  - reduces cost of power and fuel produced

* The US consumes about 12 million bbl/day of transportation fuels

** From recent National Research Council Study

Thank You

I want to acknowledge, and greatly appreciate working with and input from Robert Williams and his group at Princeton

For more information see:

Thomas Kreutz, Eric Larson, Guangjian Liu, and Robert Williams, Princeton Environmental Institute, ***25th Annual International Pittsburgh Coal Conference, 2008, &*** http://www.princeton.edu/pei/energy/publications/texts/#2008

And

E. Larson, G. Fiorese, G. Liu, R. Williams, T. Kreutz, and S. Consonni, 2009: Coproduction of decarbonized synfuels and electricity from coal + biomass with CO_2 capture and storage: an Illinois case study*, Energy and Environmental Science* (in press)

J. Katzer, Executive Editor, "The Future of Coal," MIT, 2007, http://web.mit.edu/coal/

NRC Report: "Liquid Transportation Fuels From Coal and Biomass," 2009.

Advanced PC Power Plant