

Economic and Environmental Benefits Of Electricity/Synfuel Coproduction From Coal + Biomass with CCS Under a C-Policy Constraint

Robert Williams

Princeton Environmental Institute, Princeton University, USA

Which Technologies to Diversify Transportation Fuels?

IFP Conference

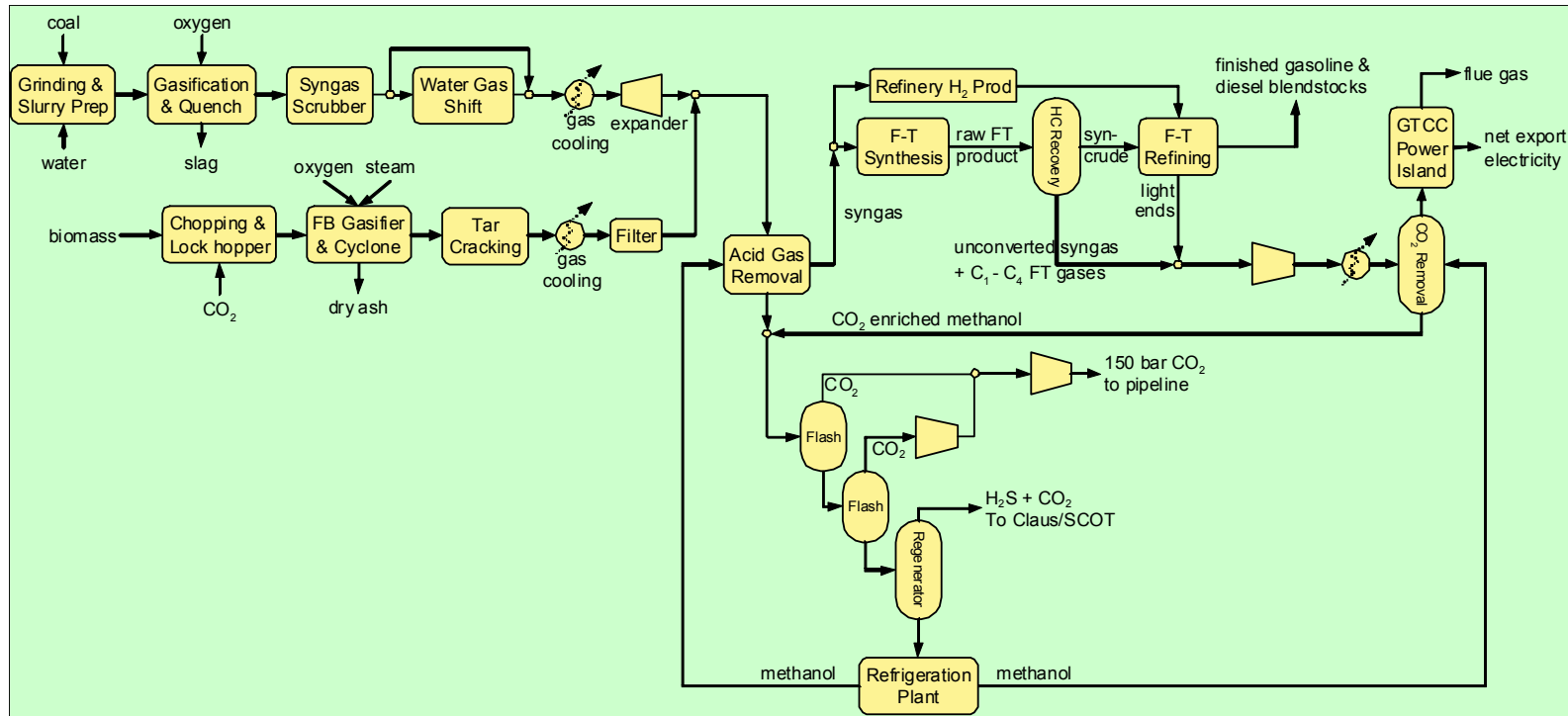
Rueil-Malmaison, France

9 December 2009

Making Synfuels + Electricity from Coal + Biomass with CCS Offers

- Approach for decarbonizing coal electricity at much lower incremental cost than any other strategy now actively being discussed
- Opportunity for coal to enable production of low-GHG emitting transport fuels at much lower cost than via biofuels strategies—giving coal major new role in C-constrained world
- Opportunity for synfuel producers to make synfuels at competitive costs with much lower levels of capital investment than via conventional synfuel production strategies
- Potential for producing much more low GHG-emitting liquid fuel using sustainably produced scarce biomass resources
- Realization of all above benefits using only commercial and near-commercial technologies that could be widely deployed, beginning in middle of the coming decade

CBTL-OT-CCS System for Making Electricity + Synfuels from Coal + Biomass



These systems can be viewed from perspective of either:

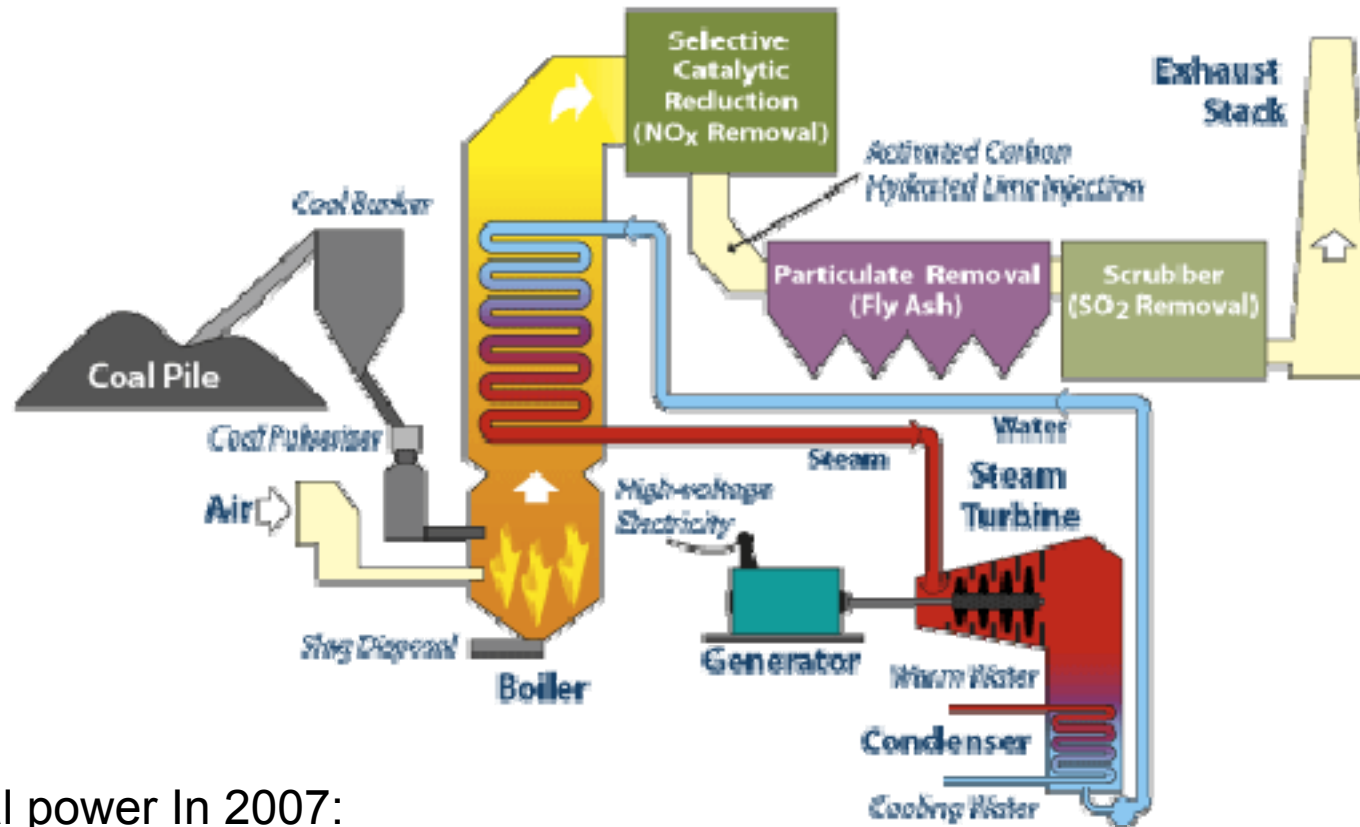
- A synfuel producer, or
- An electricity producer

Attractive approach for US is to regard them as repowering options for decarbonizing existing coal power plant sites

Toward Decarbonization of Coal Power

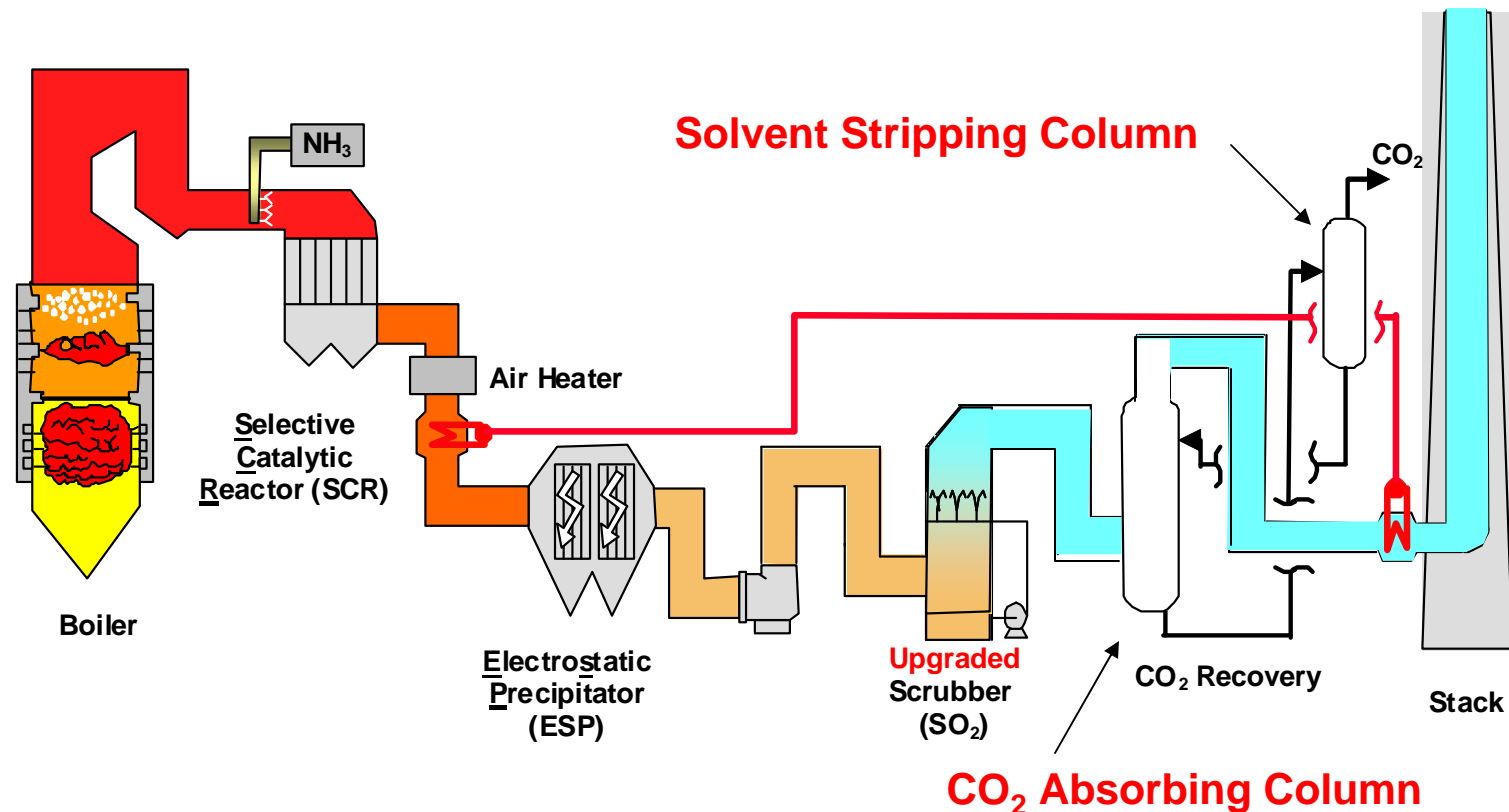
- Coal power accounts for $\frac{1}{2}$ of US electricity and $\frac{1}{3}$ of US CO₂ emissions from fossil fuel burning. What should be done?
- Existing plants warrant priority under serious C-mitigation policy
- Options to be discussed:
 - CCS retrofit for pulverized coal plant (PC-CCS retrofit)
 - Repowering with:
 - Coal integrated gasifier combined cycle with CCS (CIGCC-CCS)
 - Coal/biomass to fuels + electricity with CCS (CBTL-OT-CCS)
- Definitions:
 - Retrofit: retain plant but add equipment to “scrub” CO₂ from flue gases
 - Repower: bulldoze site and rebuild there—but retain all infrastructure
- Will show CBTL-OT-CCS repowering option preferable in C-mitigation /economic terms but faces institutional obstacles
- This option also help decarbonize transport fuels, which also account for $\frac{1}{3}$ of US CO₂ emissions from fossil fuel burning

Existing Pulverized Coal Steam Power Plant (PC-V)



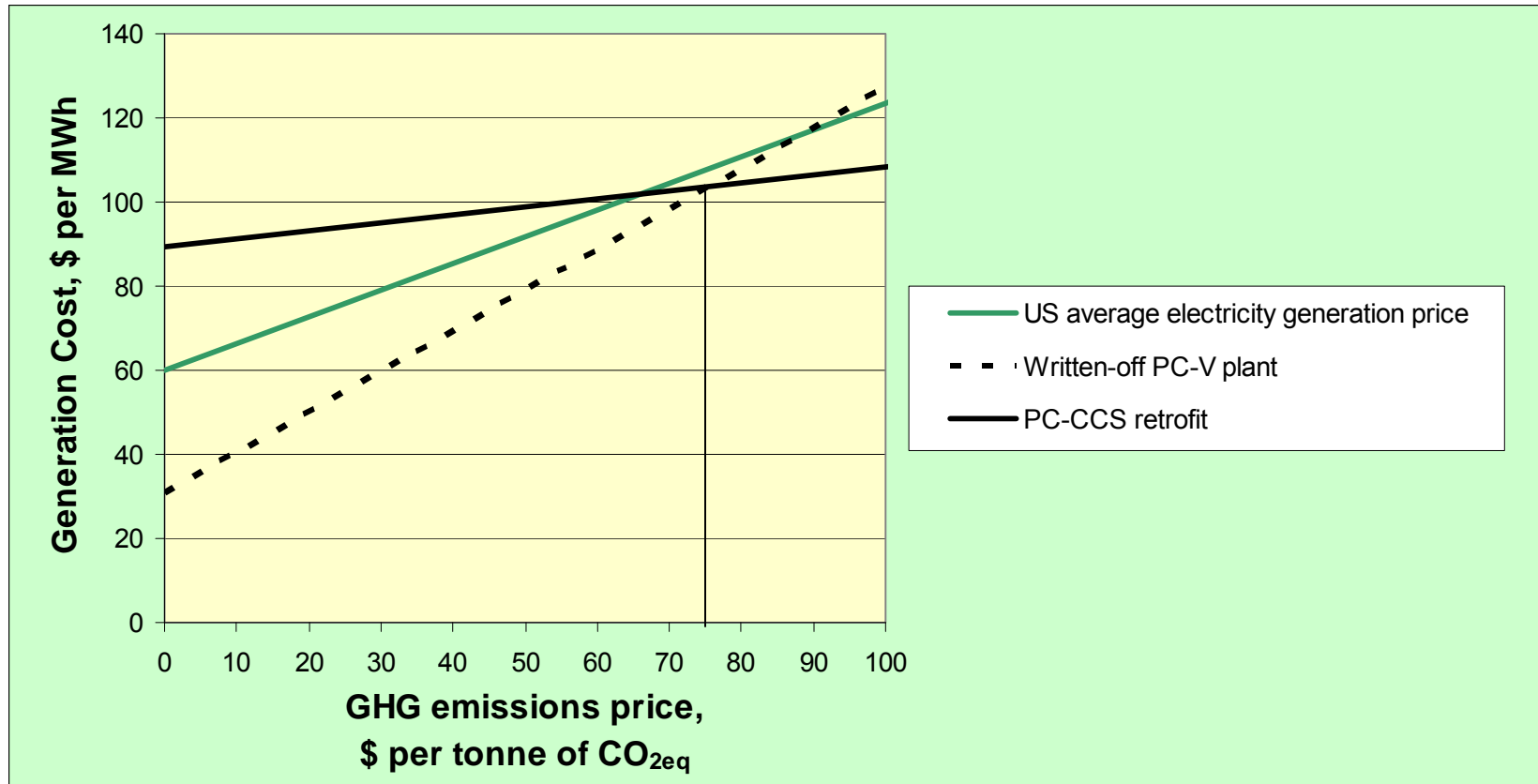
- US coal power In 2007:
 - 315 GW_e of coal electric capacity (32% of total)
 - Coal power generation = 49% of total
 - Average efficiency = 32.8%
- As of 2010:
 - 95% of existing capacity > 20-years old
 - 35% > 40-years old
- **Retrofit aged 543 MW_e 33.6%-efficient plant for post-combustion CO₂ capture**
- **Partial pressure of CO₂ in flue gases = 0.15 bar**

Post-Combustion Capture System for Pulverized Coal Steam Power Plant with CCS (PC-CCS retrofit)



- Strong **chemical** (amine) solvent used to extract CO₂ in **absorber** and bind it
- Much steam required to release CO₂ from solvent in **stripper**
- GHG emission rate reduced 80% from written-off coal steam plant level (90% capture)
- CAPEX = \$430 million for system with same coal input as original plant
- **36% energy penalty** (efficiency from 33.6% → 24.7%)
- Site water requirements up 33%

Economics of PC-CCS Retrofit



- 20-year levelized cost for CCS retrofit @ \$0/t CO_{2eq}
 - = 2.9 X (cost for written-off PC-V plant)
 - = 1.5 X (US average generation price)
- GHG emissions price of **\$76/t CO_{2eq}** needed to induce CCS by market forces
- **Generation cost includes cost of CO₂ compression to 150 atmospheres**
- **Assumed cost for CO₂ transport and geological storage = \$15 per tonne of CO₂**

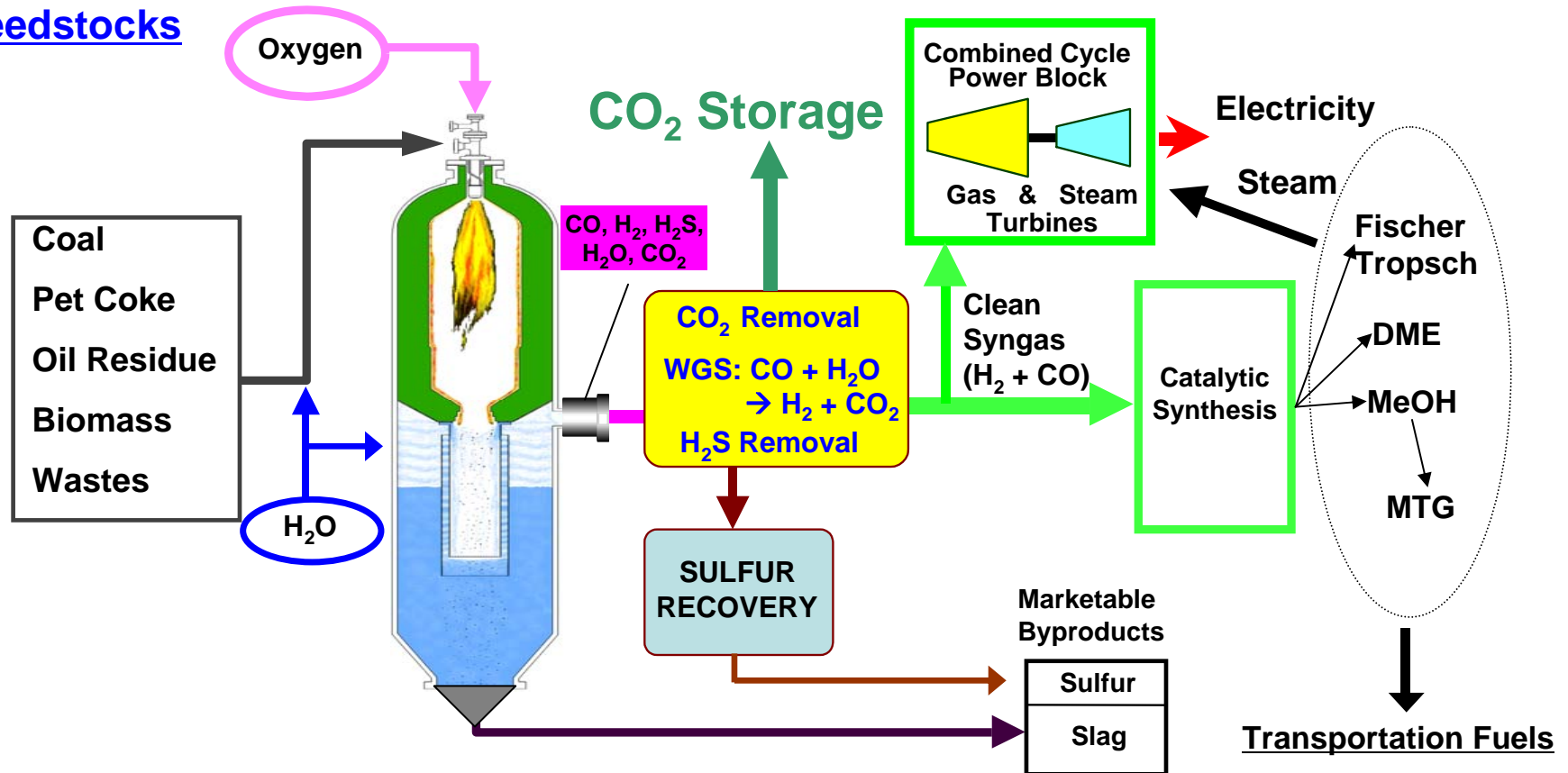
Gasification-Based Electricity and Fuels Production

Low value feedstocks

Gasification

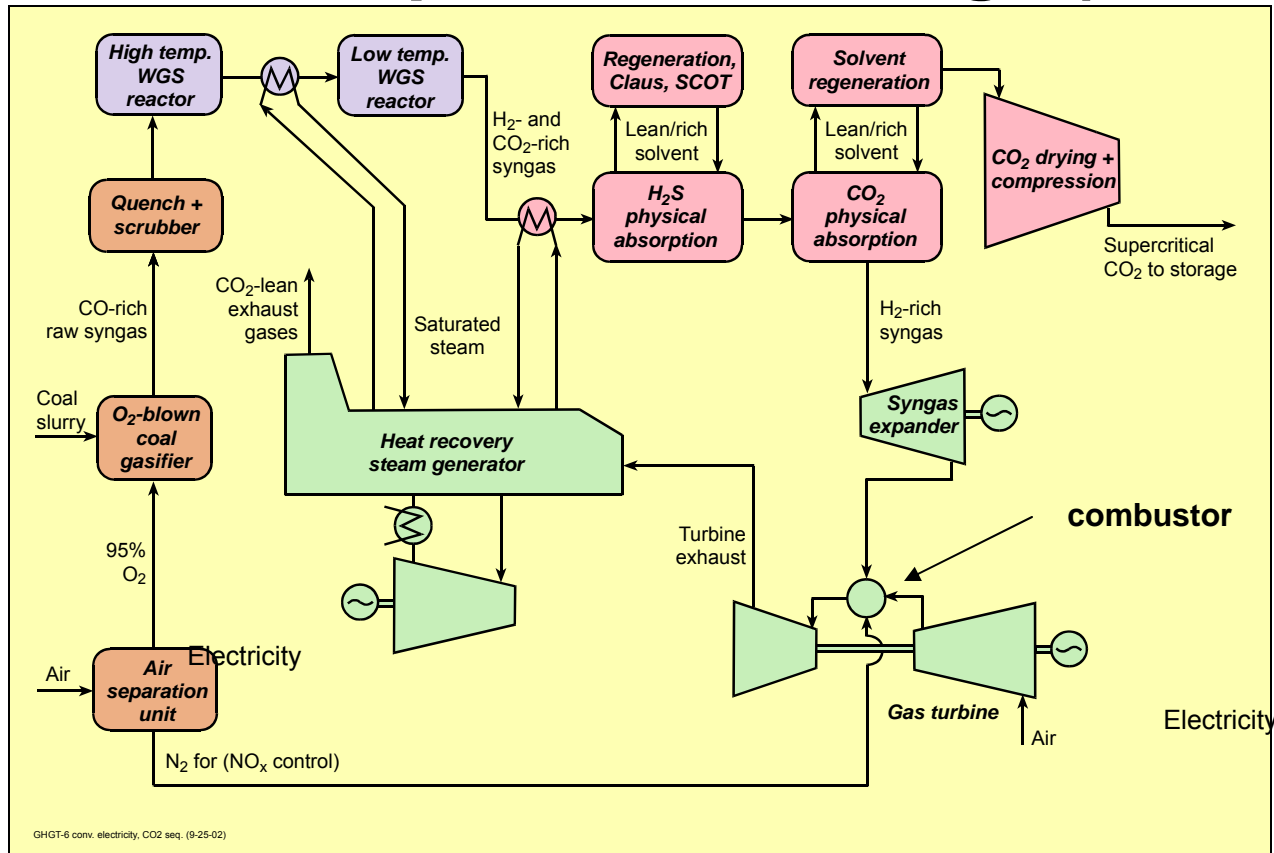
Gas Cleanup

High-Value Energy Products



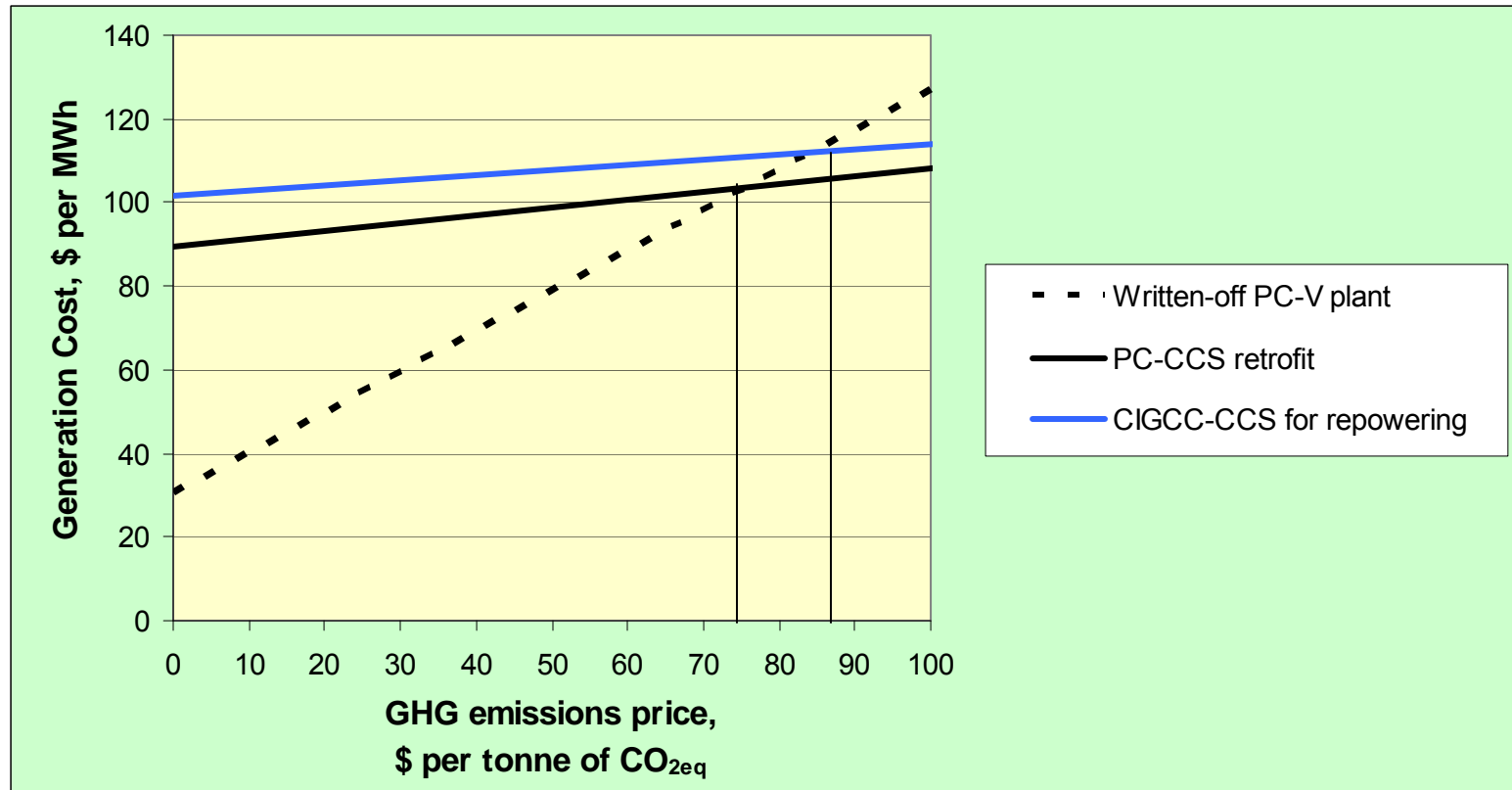
- Pre-combustion capture → lower energy penalty than for post-combustion
- Ultra-low emissions of SO₂, NO_x, PM, Hg at low incremental cost
- Reduced H₂O requirements
- Reduced solid waste management problems
- Flexibility: Can make electricity, fuels, or **combinations** thereof

Repowering via Coal Integrated Gasifier Combined Cycle, Carbon Capture and Storage (CIGCC-CCS)



- **Pre-combustion capture** at high CO₂ partial pressure (11 atmospheres) → can use less energy-intensive **physical** solvents
- GHG emission rate reduced 87% from written-off coal steam plant level (90% capture)
- Capture 0.86 t CO₂/MWh vs 1.2 t CO₂/MWh for coal steam retrofit
- **19% energy penalty**; 0.93 X water requirement for coal power plant displaced

Economics of Repowering: CIGCC-CCS



- For “greenfield” projects CIGCC-CCS provides less costly electricity than PC-CCS
- But CIGCC-CCS repowering < economically attractive than PC-CCS retrofit
- Reason: CAPEX for CIGCC-CCS repowering ~ 3X CAPEX for PC-CCS retrofit when energy input levels are same for both

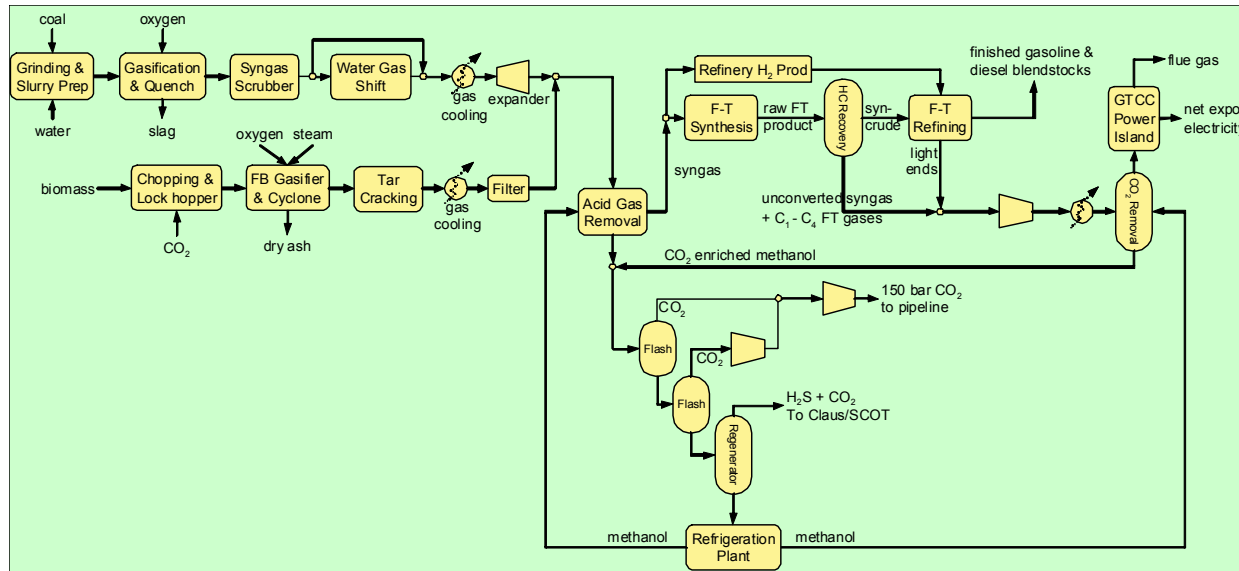
Feedstock Assumptions

Feedstock	Type	Delivered price, \$/GJ _{HHV}
Coal	Bituminous, Illinois #6	1.7
Biomass	Switchgrass	5.0

Acronyms Relating to FTL

CTL	Coal to finished Fischer-Tropsch Liquid (FTL) fuels and electricity
BTL	Biomass to finished FTL fuels and electricity
CBTL	Coal + biomass to finished FTL fuels and electricity
RC	FTL synthesis with recycle (RC) of unconverted syngas for maximum FTL output ...small amount of coproduct power is generated in steam turbine power plant from purge gases
OT	FTL synthesis with once through (OT) synthesis; unconverted syngas used to make large amount of coproduct power in a gas turbine/steam turbine combined cycle
V	Coproduct CO ₂ is vented
CCS	Coproduct CO ₂ is captured and piped to underground storage site

CBTL-OT-CCS System for Making Electricity + Synfuels from Coal + Biomass

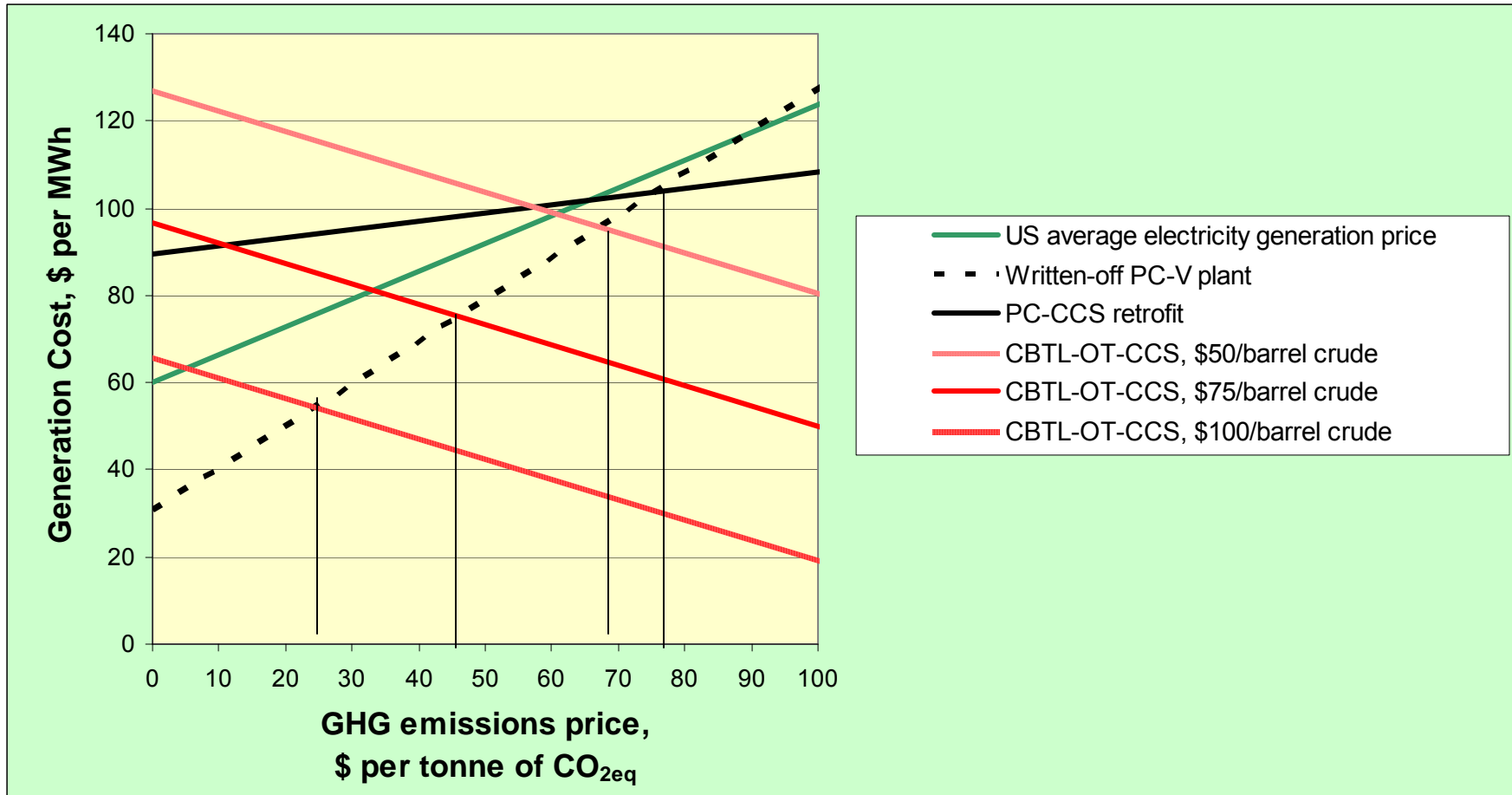


- System designed to make FTL (~ 2/3 of energy output as synthetic diesel/gasoline) and electricity (~ 1/3 of energy output from combined cycle)
- ~ 1/2 of C in feedstock captured as CO₂ and stored in geological media
- GHG emission rate declines as biomass % of energy input increases
- Consider configuration in which biomass accounts for 38% of input energy (10⁶ t/year of dry biomass) → GHG emissions are reduced 92% relative to energy displaced (existing coal power + equivalent crude oil-derived products)
- **7% energy penalty**; 0.81 X water requirement for coal power plant displaced
- CAPEX ~ 3 X CAPEX of CCS retrofit for system with same energy input rate

When Evaluating Costs for Coproduction Units As Power Generators

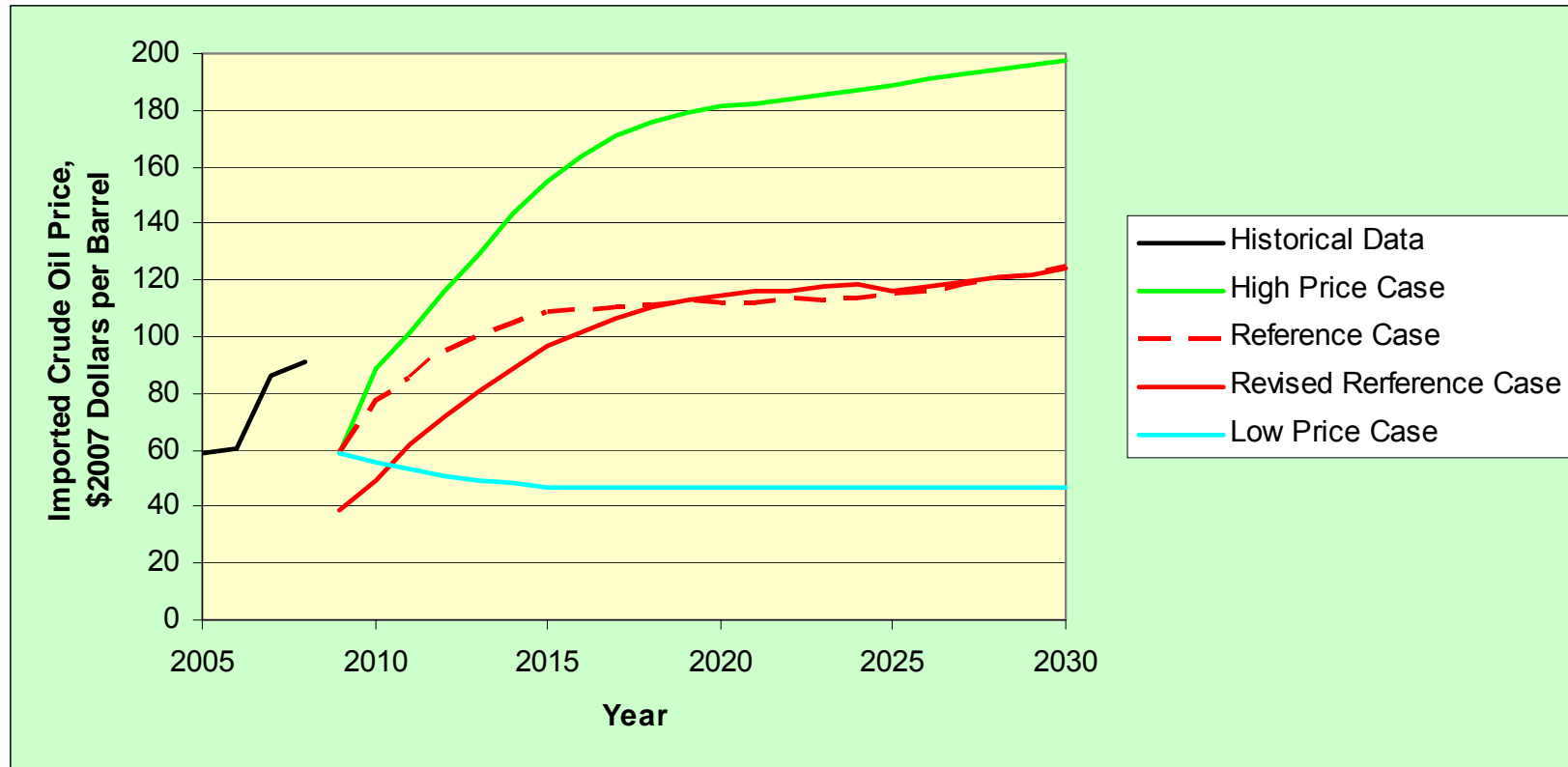
- Economic worth of synfuel products = refinery-gate prices of crude oil-derived products displaced
 - Thus, levelized generation cost (\$ per MWh of electricity)
- = [Levelized system cost (\$/year) – levelized economic worth of synfuel products (\$/year)]/[levelized generation rate (MWh/year)]
- **Generation Cost is Sensitive Function of Oil Price!!**

Economics of Repowering: CBTL-OT-CCS



- Over wide oil price range CBTL-OT-CCS economics better than for PC-CCS retrofit
- Strong carbon mitigation policy protects investors in this low GHG emissions option against risk of oil price collapse...**without government guarantee of floor price on oil**

Prospective Prices for Imported Crude Oil



Projections of the Energy Information Administration. The Low Price, Reference Case, and High Price projections are from *Annual Energy Outlook 2009* (March 2009). Subsequently (April 2009) the EIA revised its Reference Case projection to reflect the expectation that the world recession would last longer than expected in *AEO 2009*.

Why Does CBTL-OT-CCS Perform So Well?

CBTL-OT-CCS exploits simultaneously

- Low cost of CO₂ capture for synfuels manufacture,
- High marginal efficiency/low incremental capital cost of power
- Large credit for FTL coproducts at high crude oil prices
- Negative GHG emissions benefit of photosynthetic CO₂ storage

So why not pursue CCS for **pure bioenergy systems** instead?
Better economics realizable via CBTL-OT-CCS because of:

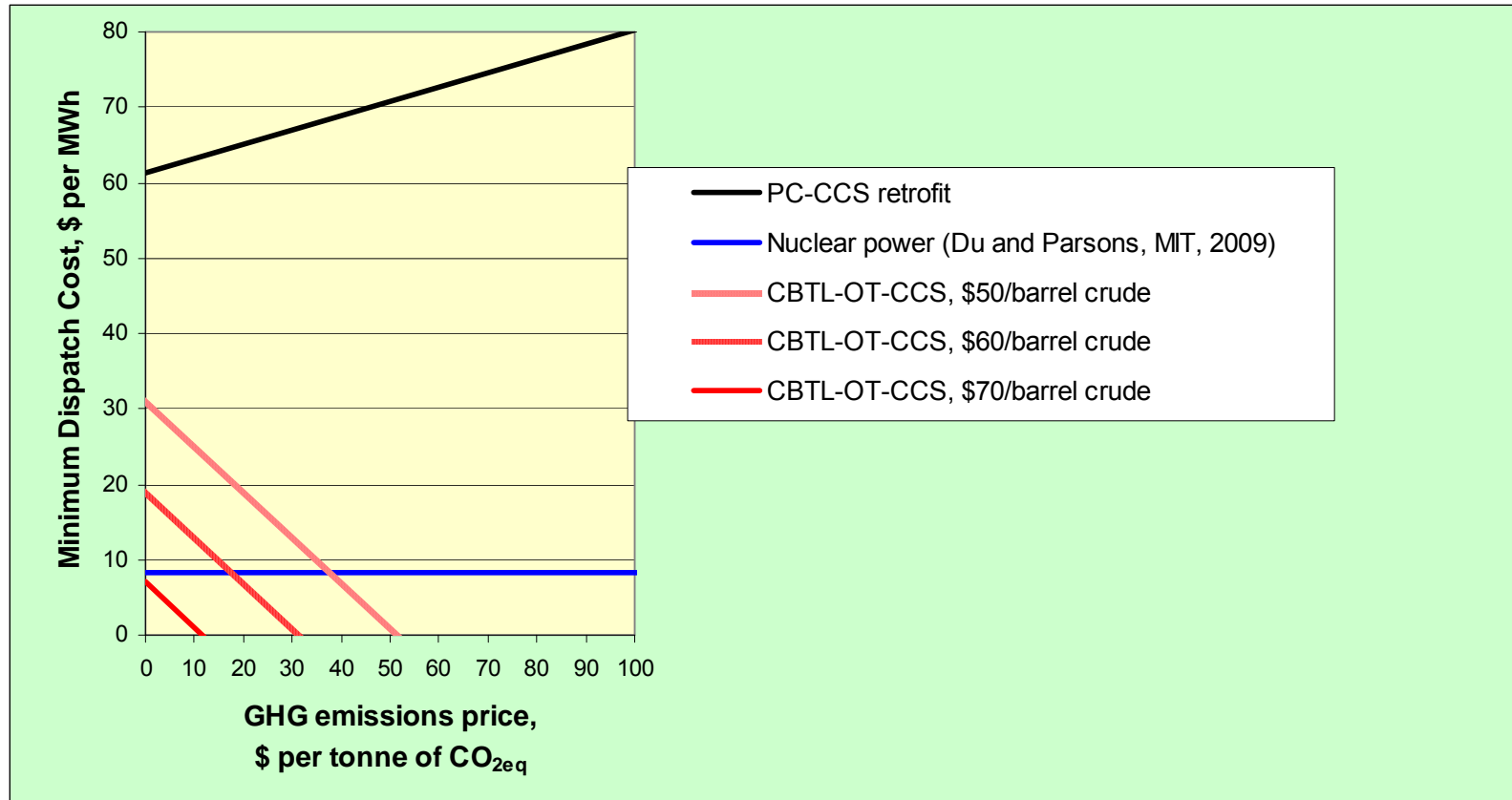
- Scale economy of coal energy conversion
- Low cost of coal as feedstock

Economic Dispatch Competition on Electric Grids

- Market determination of which plant on power grid gets dispatched first and relative capacity factors depends only on short run marginal cost (*SRMC*)...CAPEX is sunk cost that does not come into play
- Power plant operators will bid to provide power in economic dispatch at electricity prices down to minimum dispatch cost (*MDC*), determined by Revenues = *SRMC*
- Coproduction units have two revenue streams:
 - One from power sales;
 - One from synfuel sales

→ At sufficiently high oil prices coproduction system operators will be able to defend high capacity factors and drive down capacity factors of competing technologies (e.g., **PC-CCS**)

Minimum Dispatch Cost for Alternative Electric Power Options

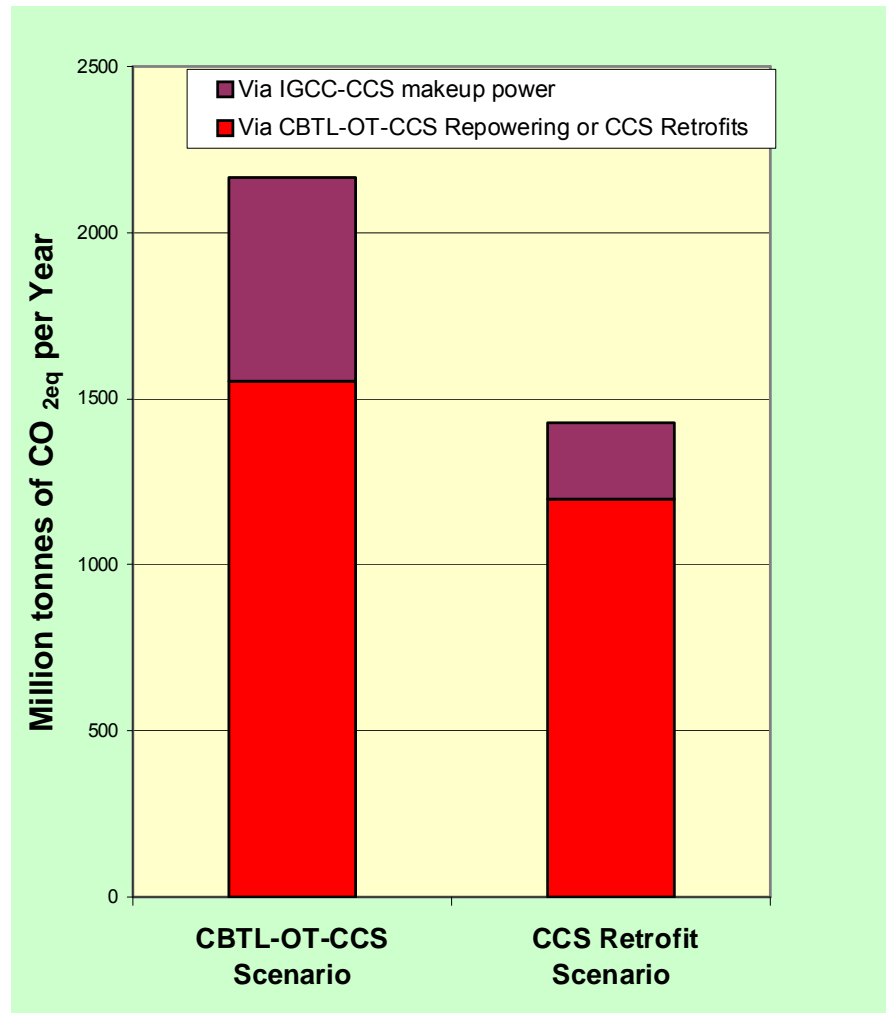


- It will be difficult for PC-CCS retrofit option to defend high CF if CBTL-OT-CCS systems are available in substantial capacity on the electric grid
- At current oil/GHG emissions prices, CBTL-OT-CCS systems would be dispatched before nuclear power if economic dispatch competition determines merit order

Thought Experiment

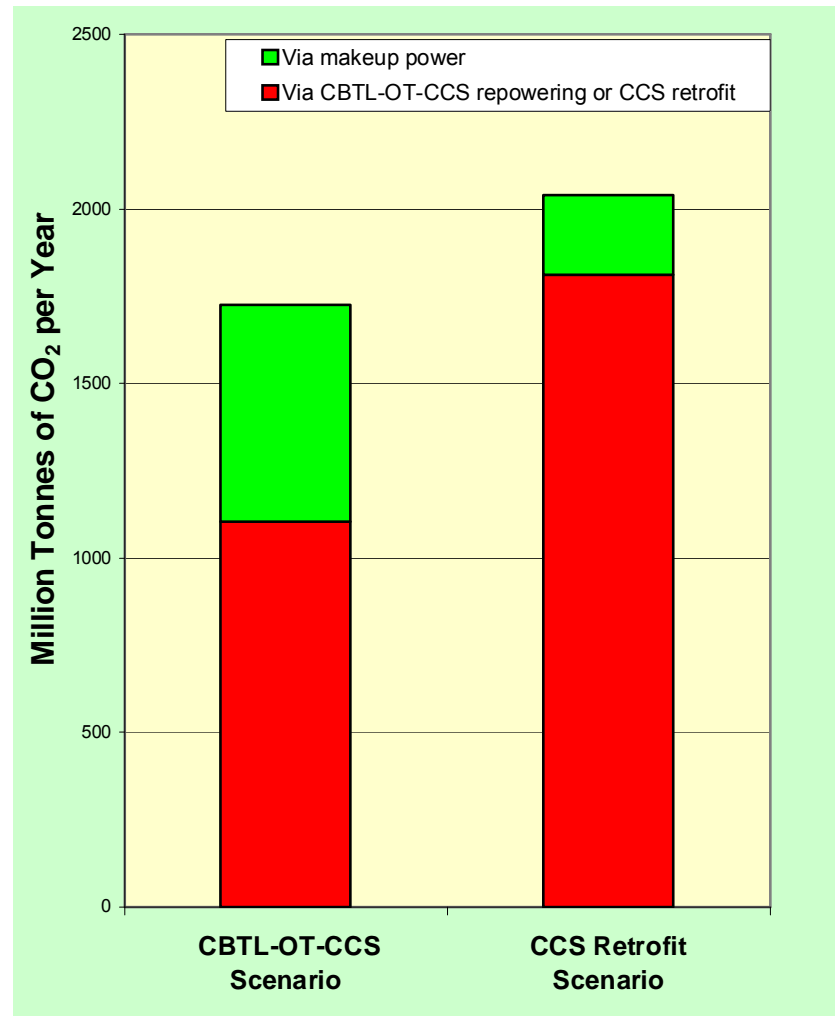
- Imagine that by midcentury CBTL-OT-CCS systems will have displaced US written-off coal capacity to extent of 100% of prospective US biomass supplies exclusive of dedicated energy crops grown on cropland (*~ 0.5 billion tonnes/year*)
- Consequences:
 - 90% of current coal capacity replaced
 - Decarbonized electricity= 60% of current generation from coal
 - 3.9×10^6 barrels/day of low GHG-emitting synfuels...enough for:
 - 100% of fuel future needs of US fleet of fuel-efficient light-duty vehicles [if 2030 version of Prius (76 mpg) eventually becomes norm]
 - more than 1/3 of future fuel needs for air transportation
- Compare to decarbonizing same coal capacity via CCS retrofits
- Assume 100% of makeup power via CIGCC-CCS—both cases

GHG Mitigation Benefits of Alternative CCS Strategies at Existing Coal Power Plant Sites



Both strategies provide 1800×10^6 MWh/y of low-C electricity but CBTL-OT-CCS also provides 3.9×10^6 barrels/day (gasoline equivalent) of low-C syngas

CO₂ Storage Requirements for Alternative CCS Strategies at Existing Coal Power Plant Sites

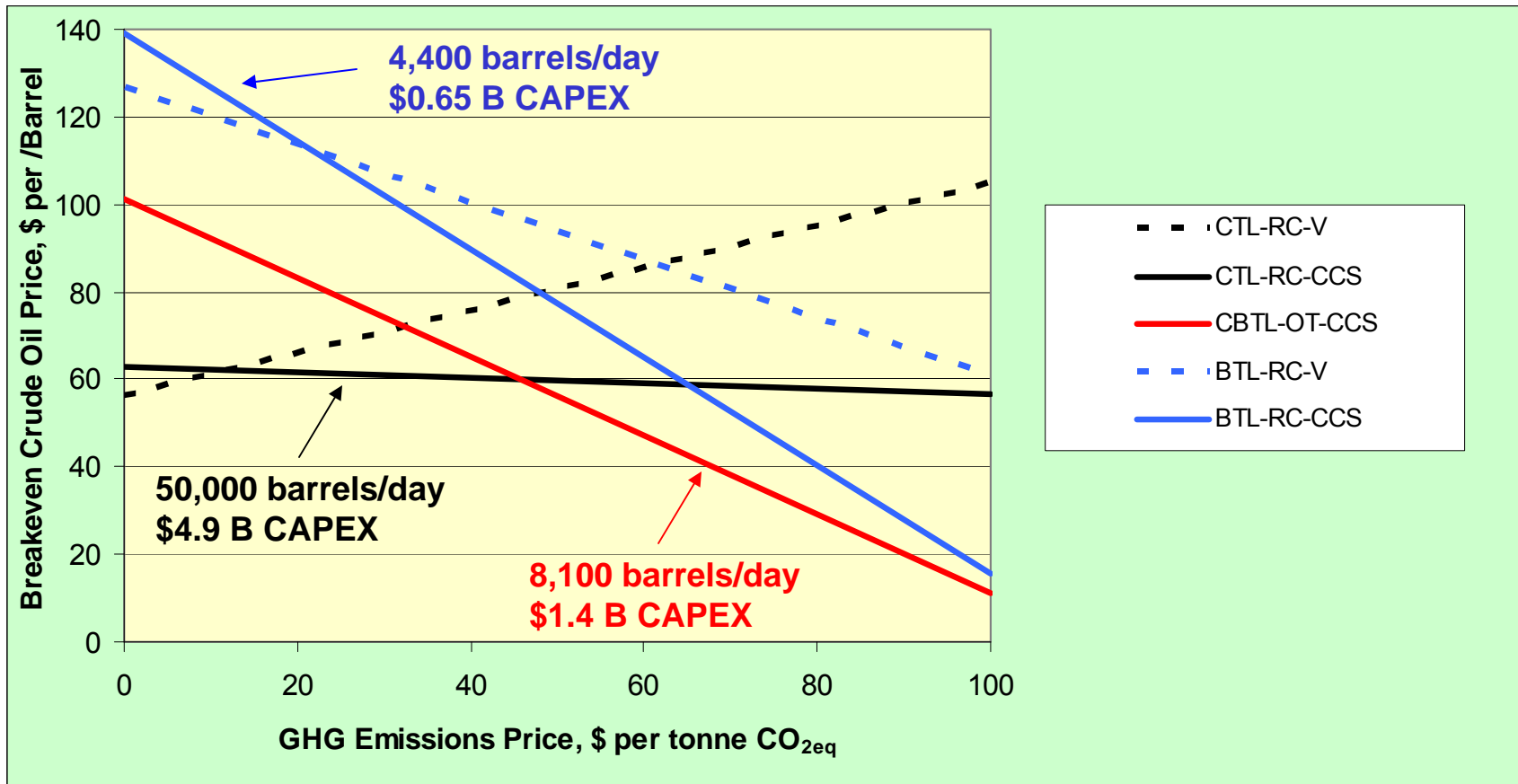


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Biomass Use for CBTL-OT-CCS vs Alternative Uses

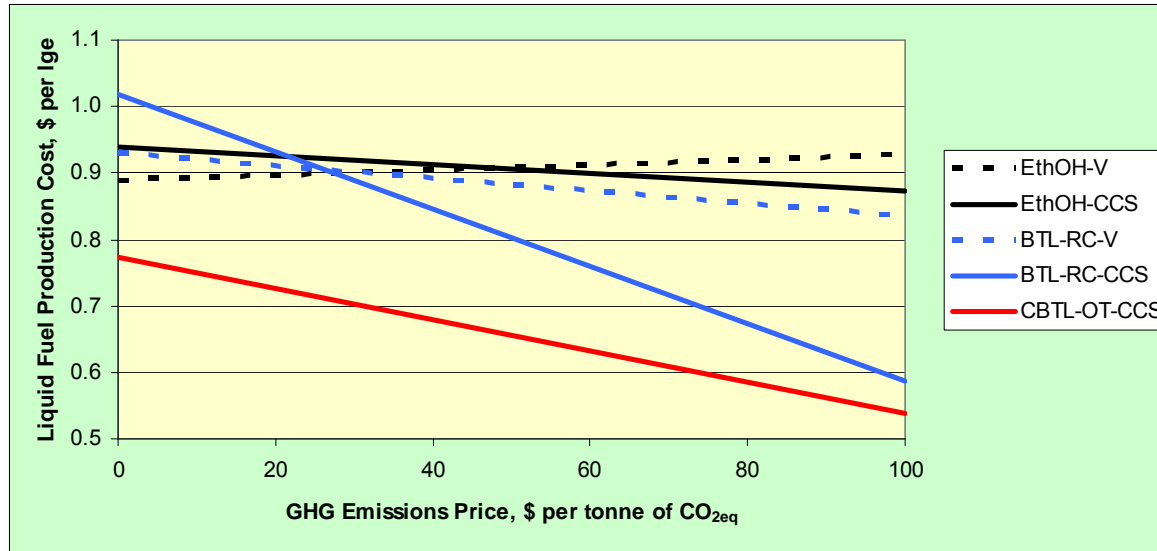
- It was assumed in Thought Experiment that all available biomass would be used in CBTL-OT-CCS systems
- How would these systems fare in competing for scarce biomass supplies with biofuel options?

Under C-Policy FTL from CBTL-OT-CCS Is Less Costly Than FTL From CTL and BTL Units Designed to Maximize Synfuels Output (*RC options*)



BTL-RC-CCS plants not competitive for GHG emissions prices < \$100/t

Economic Comparison of Cellulosic EthOH & FTL Options for Ligno-Cellulosic Biomass



lge \equiv liters of gasoline equivalent

Cost estimates are for **greenfield** sites

- All options evaluated for plants processing 0.5 million dry tonnes/year of ligno-cellulosic biomass— $\frac{1}{2}$ biomass processing rate assumed in earlier slides
- EthOH-V based on performance (*future yield of 334 liters/dry short ton*) and capital cost (*\$1.03 per liter/year*) as estimated in NRC, *America's Energy Future* (2009).
- EthOH-CCS based on calculations by author, assuming 1 mol pure CO₂ generated in fermenter per mol of ethanol (C₂H₅OH) produced.

CBTL-OT-CCS also outperforms future cellulosic ethanol technology

Institutional Challenges & a Way Forward

- First-generation (~ 10% biomass input) commercial-scale demos of CBTFE-CCS could be deployed during next decade
- Formidable institutional challenges to CBTL-OT-CCS in:
 - Managing 3 commodity products simultaneously
 - Managing 2 different feedstocks simultaneously
- New strategic alliances needed to overcome obstacles
 - In private sector:
 - power/oil industry partnerships?
 - Or should coal industry own and operate?
 - In federal government: DoD/DoE partnership?
- Needed facilitating policies:
 - Broad C-mitigation policy
 - CCS early action policy (*e.g., use Australian Global CCS Institute to implement G-8 Global CCS Initiative to sponsor 20 commercial-scale integrated CCS demonstration projects worldwide during 2010-2020*)
 - Incentives for commercial-scale demos (2010-2020) of CBTL-OT-CCS
 - More federal RD&D on thermochemical bioenergy conversion,
 - Policies to facilitate logistics development for biomass supplies

EXTRA SLIDES

FTL Analytical Framework

- Consistent and detailed analytical framework applied to compare 16 FTL process designs using coal and/or biomass as feedstocks.
- Aspen Plus for estimating mass/energy/carbon balances and then using these to estimate CAPEX, component by component.
- “Nth” plant ($N \approx 5$) performance/cost estimates (*all costs in mid-2007\$*)
- Key technology components:
 - GE quench gasifier for coal
 - GTI fluid-bed gasifier + tar cracking for biomass
 - Rectisol for acid gas removal
 - low-temperature slurry-phase FT reactor (*Fe catalyst*)
 - Onsite FT refining to **finished diesel/jet fuel and high-octane gasoline**
 - power island with:
 - steam turbine power for FT recycle cases that maximize FTL production
 - combined cycle power with “F” class gas turbines for FTL once-through cases
- GREET model in estimating fuel-cycle-wide GHG emissions

Thrust of FTL Analysis

- Emphasis on OT systems because of their superior economic prospects compared to RC systems
- Economics of OT systems considered:
 - First from perspective of synfuels producer
 - Then from perspective of electric power generator
 - As repowering alternatives to CCS retrofits at existing coal power plant sites
 - Then as greenfield units
- Particular attention is given to CBTL-OT options
- Merits of biomass use in CBTL-OT systems compared to other uses of biomass for making liquid fuels

INTERGOVERNMENT PANEL ON CLIMATE CHANGE (2005) ON CO₂ STORAGE

- On geological storage capacity for CO₂:
 - ...worldwide, it is virtually certain that there is 200 Gt CO₂ of geological storage capacity and likely that there is at least about 2000 Gt CO₂...
- On geography of sources and sinks for CO₂:
 - ...there is potentially good correlation between major sources and prospective sedimentary basins, with many sources lying either directly above, or within reasonable distances (*less than 300 km*) from areas with potential for geological storage...
- On security of CO₂ storage:
 - ...based on observations and analysis of current CO₂ storage sites, natural systems, engineering systems, and models, the fraction [*of injected CO₂*] retained in appropriately selected and managed reservoirs is **very likely** to exceed 99% over 100 years and is **likely** to exceed 99% over 1000 years...