

Low-GHG Liquid Fuels from Coal + Biomass

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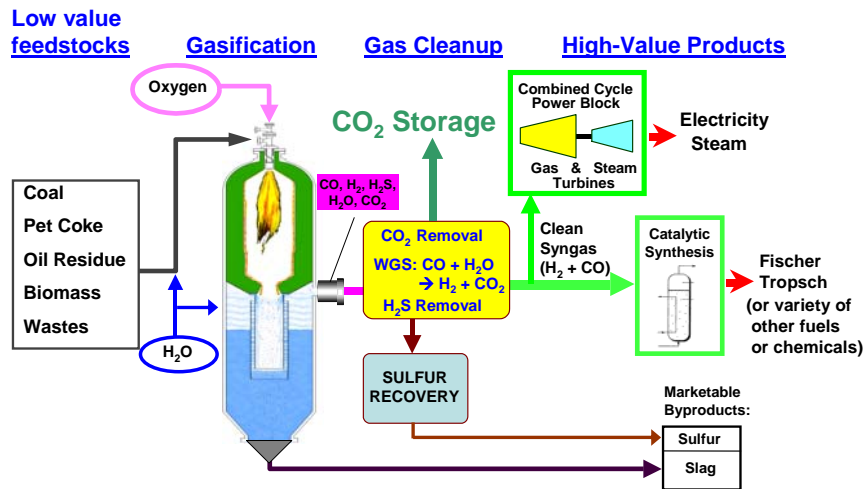
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Energy Systems Analysis Group

- ESAG has been a research unit at Princeton University since 1971.
- Problem-focused research aims to understand near-term technology options to facilitate long-term solutions to major energy-related problems of global climate change, urban air pollution, energy insecurity, rural poverty in developing countries, and others.
- “Hard-nosed” engineering-based analysis, but interacting with experts in many disciplines to help understand socio-economic contexts and to help shape solutions.

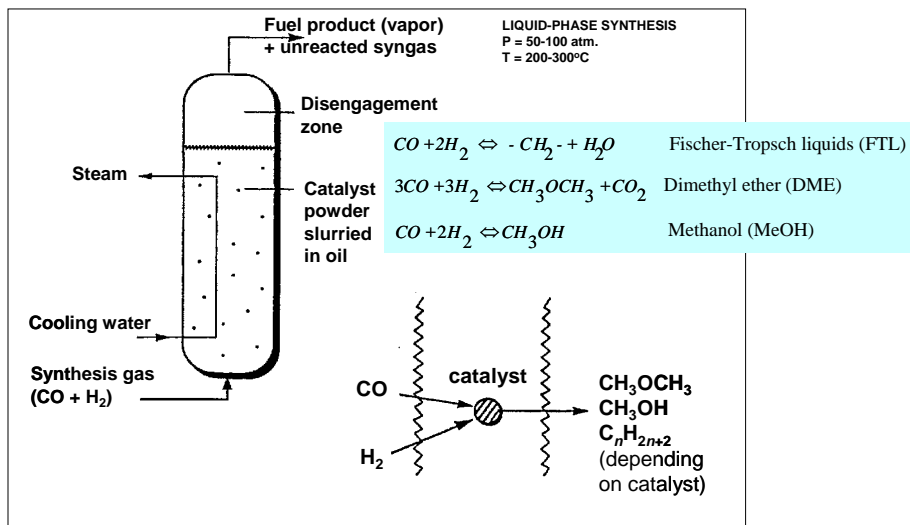
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Gasification-Based Fuels and/or Electricity Production



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Synthesis of Liquid Fuels from Syngas (CO+H₂)



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Fischer-Tropsch Fuels (straight-chain C_nH_{2n} , C_nH_{2n+2})

- F-T fuels of interest include
 - high-cetane, low-aromatic, no-sulfur diesel or jet fuel substitute
 - naphtha as chemical feedstock (upgradable to gasoline blendstock)
- F-T technology is commercially established
- F-T production from “stranded” natural gas:
 - Mossgas (South Africa) started 1992: 26k barrels per day
 - Shell Bintulu (Malaysia) started 1993: 13k barrels per day
 - Additional plants under construction or planned (Qatar > 300K bpd)
- Coal F-T projects:
 - Sasol II & III in South Africa, 150k barrels/day (bpd) total capacity
 - 20k bpd, Inner Mongolia (2007)
 - 2 x 80k bpd, Sasol/China feasibility study
 - 5k bpd demo, Gilberton, Pa (2008)
 - Several projects (10k-50k bpd proposed for U.S.)
- Biomass F-T development in Germany (Choren/Shell)

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Coal-to-Liquids (CTL) Technology

- CTL = F-T liquids from coal.
- Intense commercial interest in CTL, esp. in U.S. and China.
- CTL can be made with existing technologies, in large quantities, for a long time, and at competitive costs when oil is ~\$50/barrel or higher ⇒ ☺ energy security.
- CTL greenhouse gas (GHG) emissions are about twice the emissions per unit of energy as with petroleum-derived fuels ⇒ ☹ global warming.
- With CO_2 capture and storage (CCS), GHG emissions can be reduced to same level as for petroleum fuels ⇒ ☹ not good enough (especially for U.S.) to stabilize atmospheric CO_2 concentration.

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Making FT Liquids Using Biomass

- F-T liquids from biomass (*BTL*) with CO₂ vented.
- F-T liquids from biomass with CCS (*BTL w/CCS*)
 - The F-T process generates a pure CO₂ stream accounting for ~ ½ of the carbon in the feedstock
 - Low incremental cost for CCS (*CO₂ compression + transport + storage*).
 - Biomass goes from being “carbon neutral” to “carbon-negative” (due to underground storage of photosynthetic CO₂).
- F-T liquids from biomass + coal w/CCS (*CBTL w/CCS*) offers same benefits as *BTL w/CCS* and in addition:
 - Economies of scale of coal conversion to be exploited for biomass without massive quantities of biomass. (*F-T technology costs are scale sensitive.*)
 - Relatively high cost biomass can be used, since much of the feedstock input would be low-cost coal.
 - Prospectively large climate-friendly role for coal and more effective use of biomass than conventional biofuels (like ethanol).
 - Is *CBTL w/CCS* feasible?

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Carbon Capture and Storage (CCS)

- Coal has no significant future without CCS in a carbon-constrained world
 - If CCS works for coal, it will also work for biomass
- IPCC Special Report on CCS*:
 - IPCC is positive on geological storage, not so positive on ocean storage or mineralization (carbonate rocks)
 - Assigns “*high*” probability (66-90%) that worldwide geological storage capacity is at least 2000 Gt CO₂.
 - Fossil fuel emissions were 24 Gt CO₂ in 2002.
 - Regarding security of geological storage:
 - “*Very high*” probability (90-99%) that > 99% retained over 100 years
 - “*High*” probability (66-90%) that > 99% retained over 1000 years
 - CO₂ pipeline risks are comparable to, or less than, risks with hydrocarbon pipelines operating today

* Intergovernmental Panel on Climate Change, *Special Report on Carbon Dioxide Capture and Storage*, 2005.

Baard Energy CBTL Project

- 50,000 barrels/day CBTL plant at Wellsville, Ohio on Ohio River
- Builds on Buggenum C/B co-gasification experience:
 - Shell gasifier
 - Up to 30% biomass planned
 - CCS planned...CO₂ for EOR (*nearby oil field*) or stored in deep saline formation
- GHG emission rate for FTL ~ ½ rate for crude oil-derived products displaced...*IF fired with 30% biomass and 85% of C not contained in products is captured as CO₂*
- How “real” is this project?
 - Ongoing \$50 million FEED study (*Amec Paragon with Uhde/Black & Veatch*)...expected to be finished mid-2008
 - Some long-term biomass supply contracts secured
 - Seeking federal incentives...but intend to proceed even if not received
 - Ohio Air Quality Development Authority has authorized raising state tax-exempt bonds for debt financing
 - Plant start-up targeted for 2011-2012

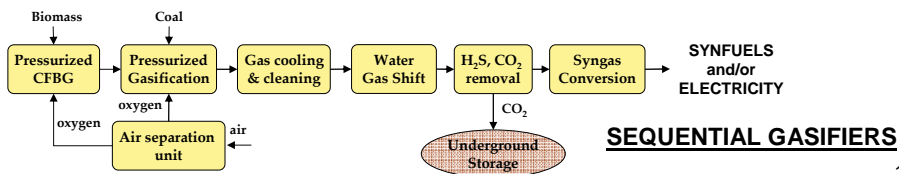
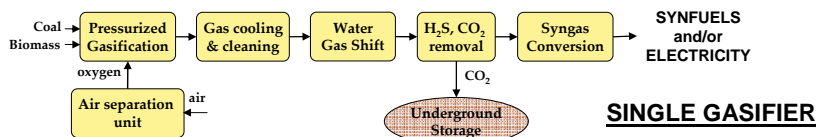
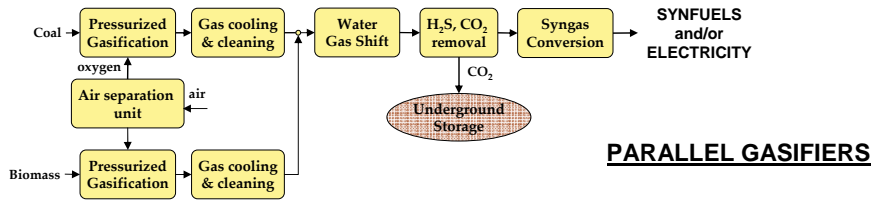
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Twin River CBTL Project, Wiscasset

- 9,000 b/d FTL + 700 MW electricity capacity
- Bituminous coal is bulk of the feedstock.
- Eventually 5% to 15% of input feedstock is woody biomass.
- Dry-feed gasifier (Shell?) simultaneously gasifying the two feedstocks
- CCS ?

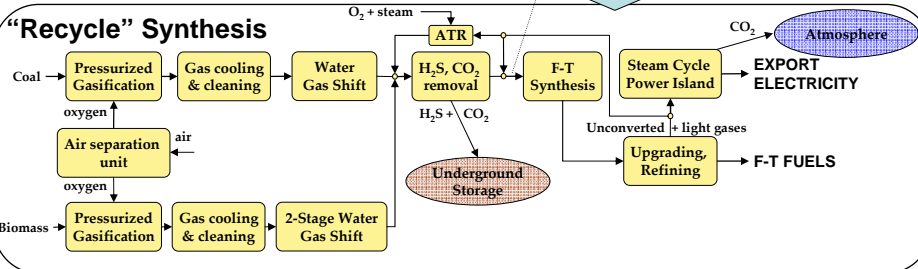
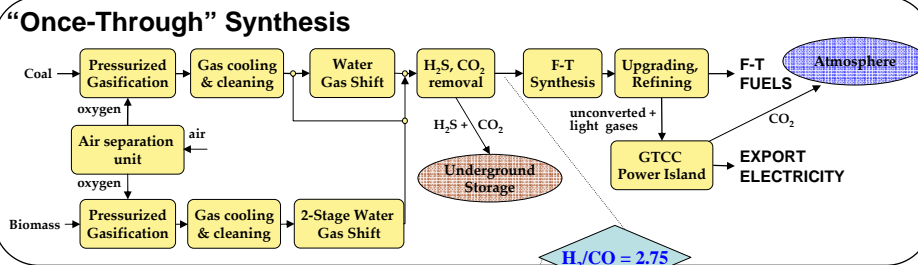
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CBTL w/CCS Process Configurations



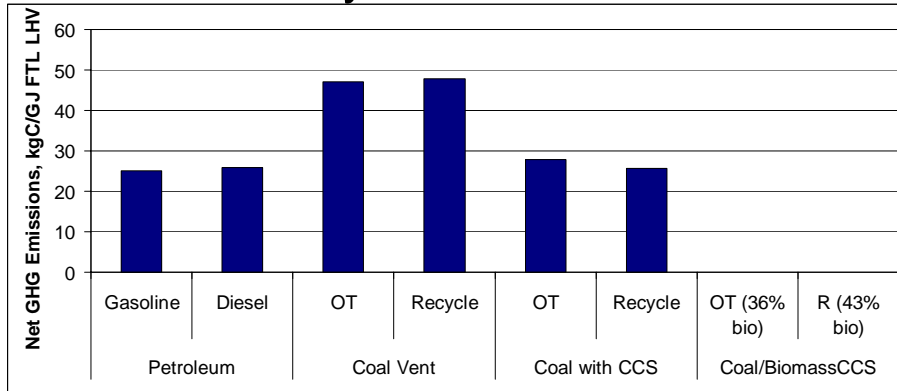
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Two CBTL Options with Parallel Gasifiers



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Net Fuel-Cycle GHG Emissions

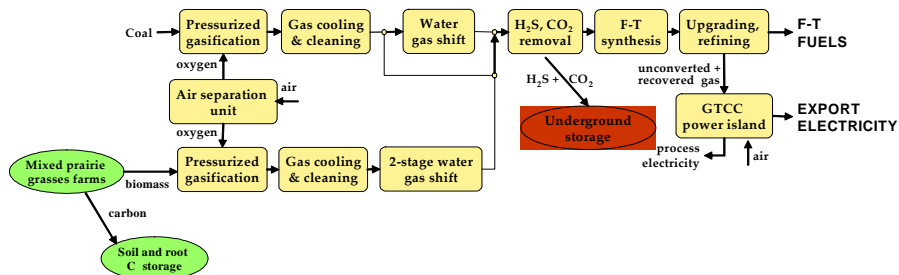


For C/B systems w/CCS using switchgrass biomass, zero net GHG emissions when biomass fraction of input is 36 - 43%.

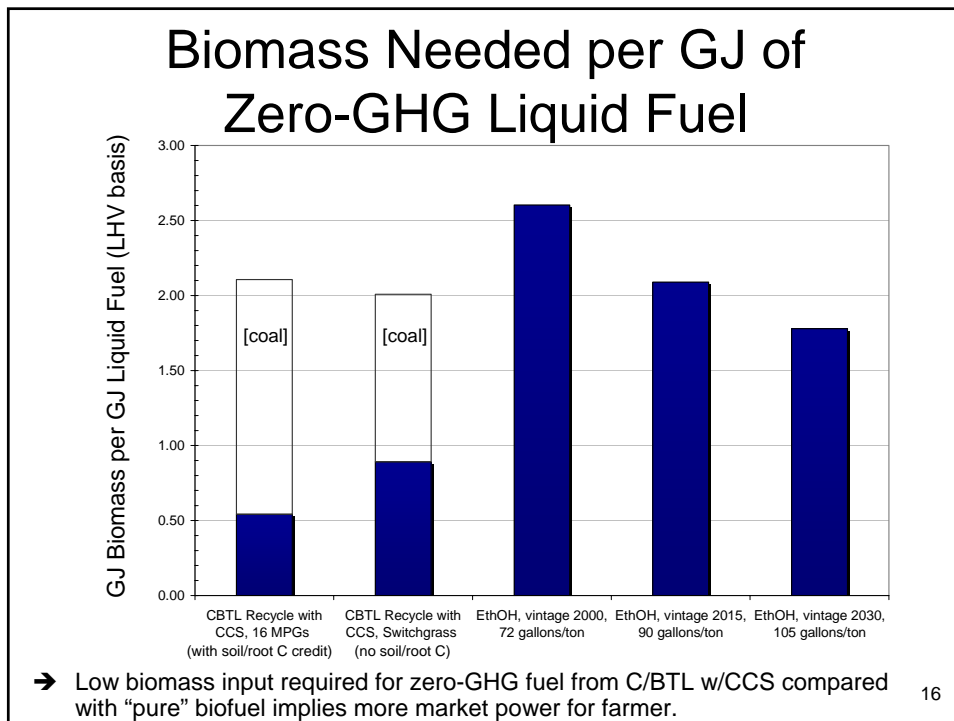
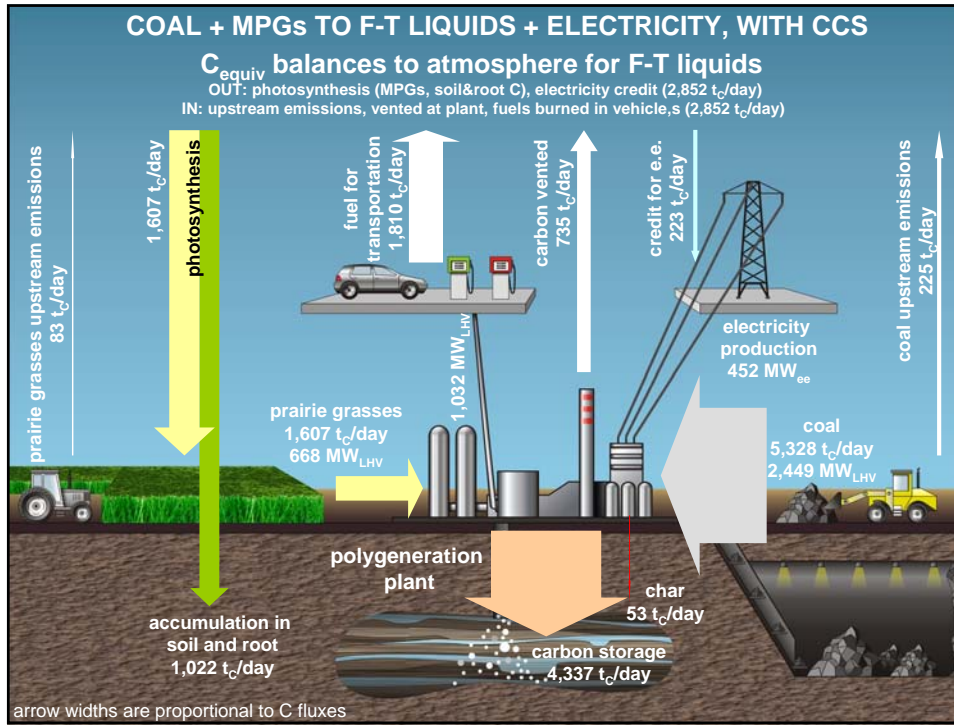
Net GHG emissions charged to FTL include:

- all upstream emissions associated with coal and biomass production
- + emissions at the FTL production facility
- + emissions from combustion of the FTL when used as fuel
- credit for emissions associated with electricity. [Per kWh credit equal to emissions from stand-alone coal-IGCC w/o CCS (Coal-Vent cases) and stand-alone coal-IGCC w/CCS (all CCS cases).]

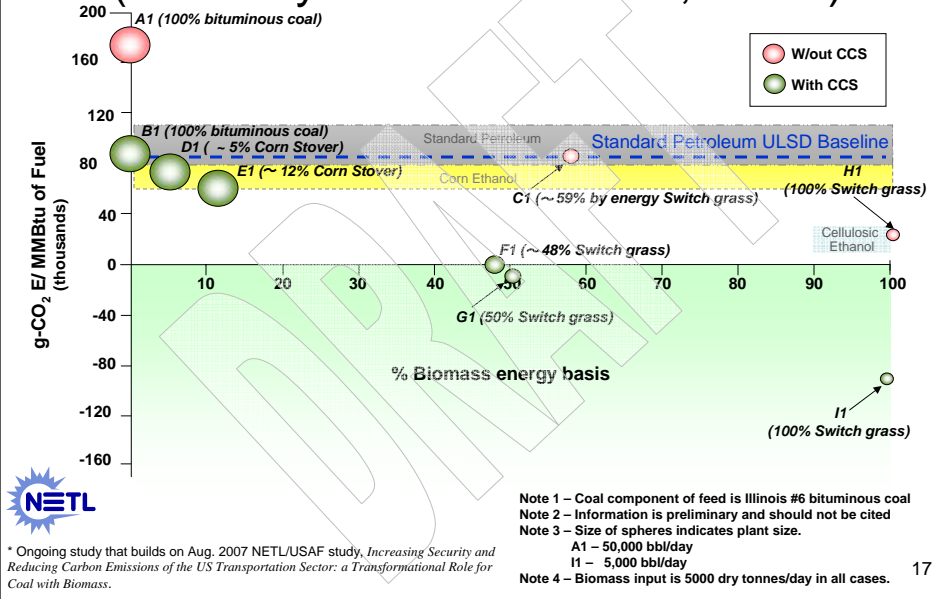
CBTL for Coal + Mixed Prairie Grasses and Two Carbon Storage Mechanisms



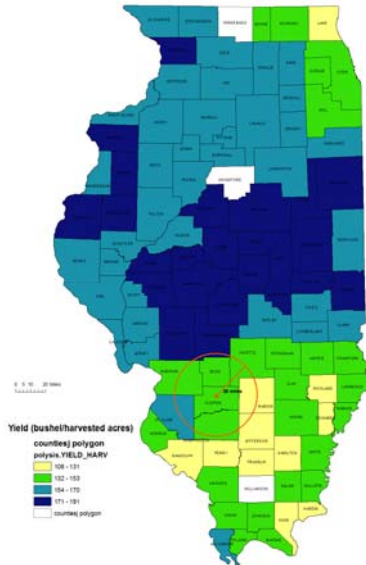
- Biomass input to realize zero net GHG emissions for FTL could be reduced further if biomass is grown on carbon-depleted soils.
- Additional C storage if biomass is grown on C-depleted soils
 - Up to 0.6 tC stored in soils/roots per tC in harvested mixed-native prairie grasses over 30 year period in Minnesota (Tilman et al, *Science*, 314:1598-1600, 2006).
 - Once mixed prairie grasses (MPGs) have been established, only modest additional inputs (e.g., gasifier ash) needed with annual harvesting.
 - Local biodiversity gain (vs. net biodiversity loss for monocultures).



Preliminary findings of NETL CBTL study* (Courtesy of Michael Reed, NETL)



Illinois Case Study for Coal/MPG Facility

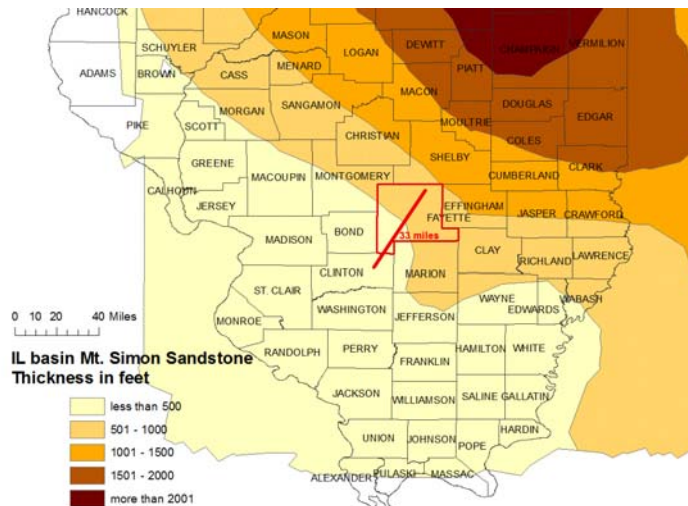


Minemouth facility in Clinton County

- Would use high sulfur bituminous coal and MPGs from land now growing corn.
- Co-produces FT fuel and electricity.
- MPG fraction of input is set to give zero net lifecycle GHG emission liquid fuel.
- One million t/yr MPGs needed; assuming 10.4 dt/ha/yr yield* and 15% of land around plant grows MPGs, average transport from harvest is 27 miles.
- CO₂ captured/piped 33 miles to injection site in Fayette Co. (Mt. Simon aquifer).

* Clarence Lehman, U. of Minnesota (private communication, April 2007), estimates that MPG yield on average cropland would be 1.5 X hay yield on lower-grade local land growing hay, based on correlation of actual hays and general productivity models.

POSSIBLE AQUIFER STORAGE SITE



Suggested region for aquifer CO₂ storage near proposed CBTL plant offered by Hannes Leetaru, and map of Mt Simon Sandstone features provided by Chris Korose —both of the Illinois State Geological Survey, private communication April 2007

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Prospective Farmer Economics

- Consider first a CTL plant with CCS
 - Site: coal mine-mouth plant in Southern Illinois (*corn country*)
 - CO₂ storage: 7500 ft underground, Mt. Simon aquifer (*33 miles away*)
 - Feedstock: high-S bituminous coal
 - Assume GHG emissions price = \$100/tC. This is minimum needed to make CCS economical for coal power. (\$100/tC applied to gasoline is 25¢/gallon.)
 - ➔ Breakeven crude oil price is in the range \$50 to \$60 barrel
- Next consider coal/MPG CBTL plant w/CCS with MPG input level to give net zero GHG emission rate for FTL & assume:
 - Estimated MPG yields for lands now growing corn there
 - Same outputs/product prices as for coal-only plant with CCS
 - ➔ determines “willingness” of synfuel producer to pay for MPG
- **What is income to farmer if MPG displaces corn compared to income from corn?**
 - Income/ha/yr comparable to that for corn at mid-2007 corn prices
 - Farmer income falls more than 40% if 0 credit for soil C/root C buildup⁹⁰

Q & A.

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