Alternative Fuels Seminar: Carbon to Liquids

Center for Strategic and International Studies

Toward Cost-Competitive Synfuels from Coal and Biomass with Near-Zero "Well-to-Wheels" GHG Emissions by Simultaneous Exploitation of Two Carbon Storage Mechanisms

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OUTLINE

- Biofuels dilemma
- 2-part photosynthetic C storage strategy to address dilemma
- Alternative coal & coal/biomass plants to make synfuels
- GHG emissions, other characteristics of alternative synfuels
- Tilman research on mixed grasses with soil/root C storage
- Implications of proposed coal/biomass synfuels strategy for biodiversity loss concerns
- Economic analysis of synfuel production exploiting two-part photosynthetic C storage opportunity
- Suggestions for public policy

Dilemma for Conventional Biofuels

- Advantages:
  - Carbon neutrality via photosynthetic CO_2 removal from atmosphere
  - Renewability
- Downside:
  - Limited availability of high-quality land for dedicated energy crops arising from low efficiency of photosynthesis (*competition with food production*) ➔ conventional biofuels can satisfy only part of liquid fuel demand even with improved conversion technologies
  - Biodiversity loss concerns about high levels of development of monoculture crops grown for energy

TWO PART C-STORAGE STRATEGY FOR ADDRESSING DILEMMA

- ***Shift biomass from C-neutral → C-negative*** via two-part C-storage strategy for biomass to help address land-use constraint posed by conventional biofuels:
  - *First part*, based on biomass conversion via gasification, involves separating out/storing underground (*in geological formations*) as CO_2 most C in biomass not needed in final energy products. This part of strategy is made economically feasible by coprocessing biomass with coal to make synfuels with CO_2 capture and storage (CCS) in large conversion plants. "Negative CO_2 emissions" from photosynthetic CO_2 storage offset coal CO_2 emissions from plant and from eventual release of CO_2 from coal as result of synfuel combustion.
  - *Second part,* growing biomass as *mixed grasses on C-depleted soils*, leads to substantial additional storage of photosynthetic CO_2 as soil C and root C.
- Second part of strategy also addresses effectively biodiversity challenge posed by conventional biofuels

Key Quantitative Aspects of Bio-C Storage Strategy

- Up to ~ 90% of C in biomass can be routinely stored underground as CO_2 at relatively low incremental cost along with CO_2 derived from coal if biomass is gasified to make synfuels and electricity

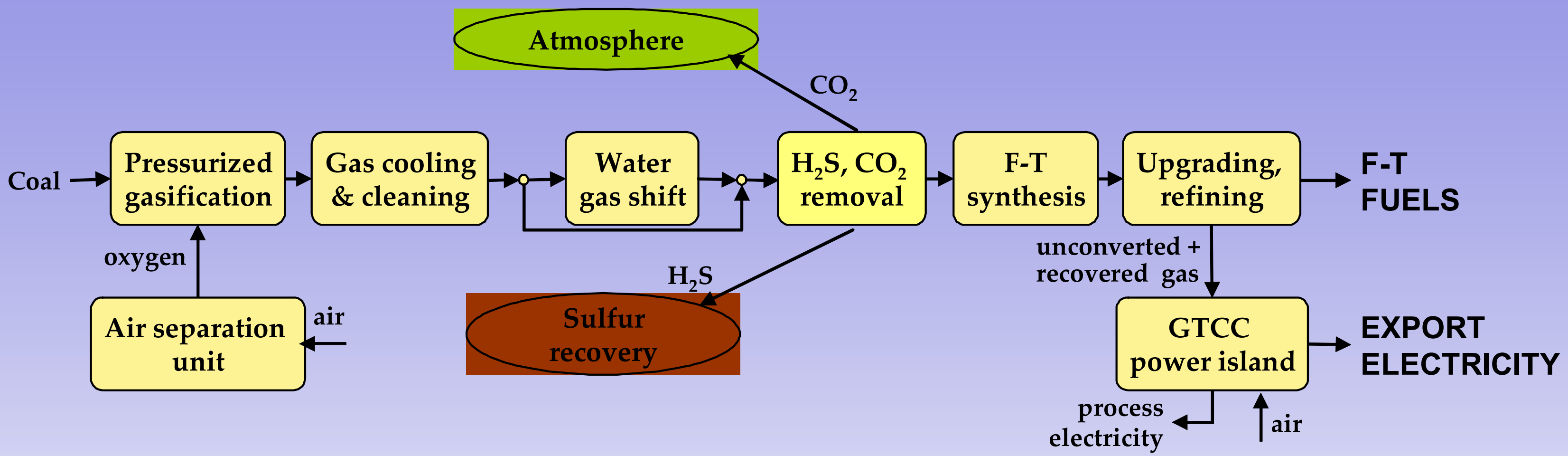
  R. Williams, E. Larson, and H. Jin, "Synthetic Fuels in a World with High Oil and Carbon Prices," *Proceedings of the 8th International Conference on Greenhouse Gas Control Technologies*, 19-22 June 2006 (*forthcoming*)

- If biomass is mixed prairie grasses grown on C-depleted soils, biomass growth would be accompanied by C-buildup in soils/roots at rate up to ~ 60% of C in harvested biomass

  D. Tilman, J. Hill, and C. Lehman, "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass," *Science*, **314**, 1598-1600, 8 December 2006

- ➔ total C storage rate up to 150% of C in harvested biomass
- Two-element C-storage strategy makes it feasible for biomass to play much greater role in mitigating climate change than with any conventional biofuel—and to do so without biodiversity loss concerns posed by conventional biofuels based on growing monocultures

F-T FUELS + ELECTRICITY FROM COAL w/CO_2 VENTED



- Technologies for making F-T fuels from coal are commercial
- Least-costly fuels will often be those from "polygeneration" plants that also make co-product electricity
- Using low-cost Western coals, such plants can provide fuels that can compete with diesel/gasoline from \$40-\$50/barrel crude oil
- If the relatively pure stream of CO_2 recovered upstream of synthesis is vented, GHG emission rate from plant + F-T combustion ~ 1.8 X GHG emission rate for crude-oil-derived diesel/gasoline

INTERGOVERNMENT PANEL ON CLIMATE CHANGE (2005) ON CO_2 STORAGE

- On geological storage capacity for CO_2:

  …worldwide, it is virtually certain that there is 200 Gt CO_2 of geological storage capacity and likely that there is at least about 2000 Gt CO_2…

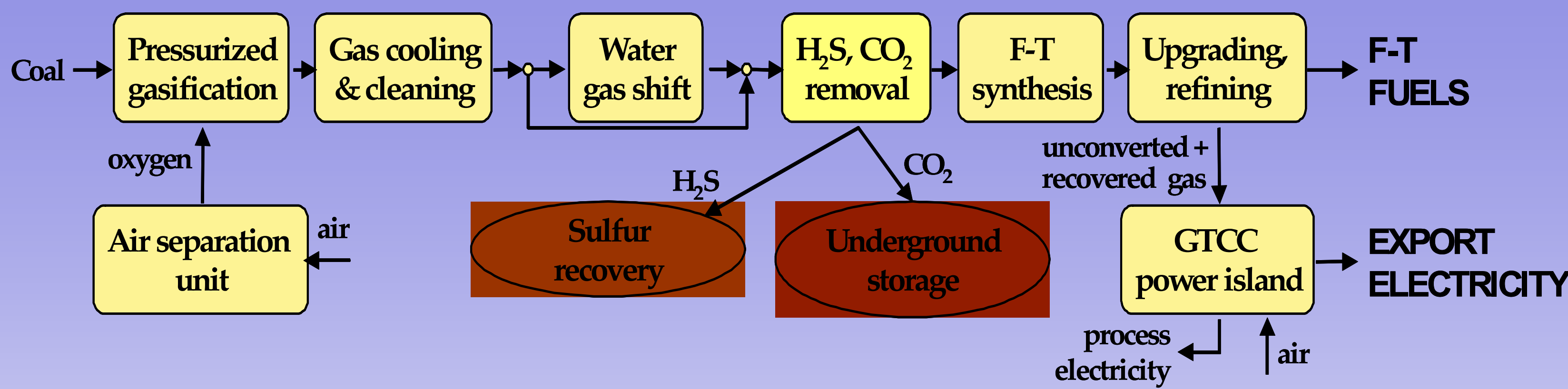
- On geography of sources and sinks for CO_2:

  …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 CO_2 storage:

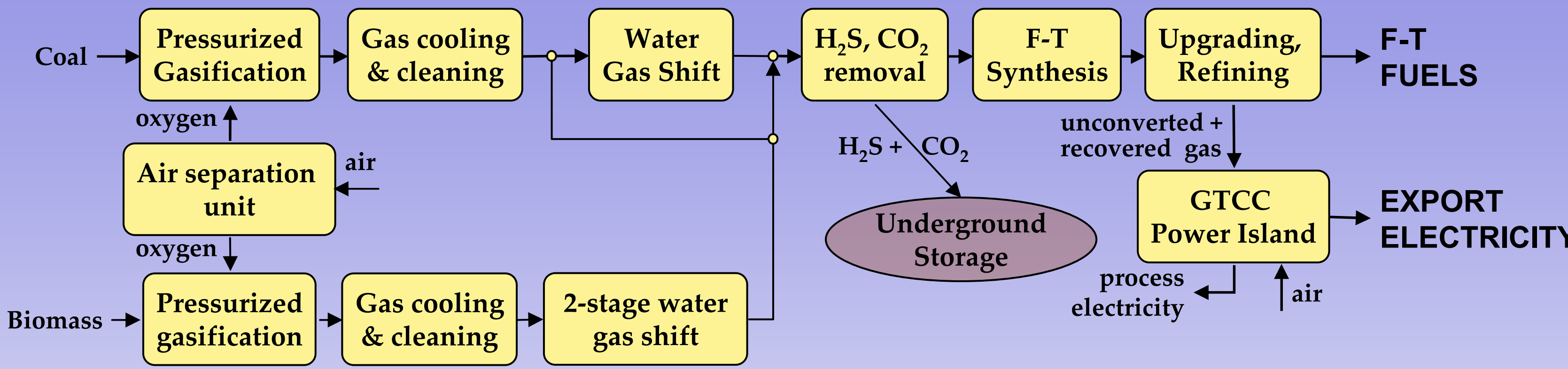
  …based on observations and analysis of current CO_2 storage sites, natural systems, engineering systems, and models, the fraction [*of injected CO2*] retained in appropriately selected and managed reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1000 years…

F-T FUELS + ELECTRICITY FROM COAL w/CCS



- CO_2 can be recovered upstream of the synthesis reactor so as to reduce CO_2 emissions associated with both F-T fuels & electricity
- With CCS, the GHG emission rate for:
  - Electricity ~ same as for a coal IGCC with CCS
  - F-T fuels ~ slightly higher than for crude oil-derived hydrocarbon fuels
- No synfuel plant should ever be built w/o CCS—incremental cost of CCS is less than for adding CCS to any coal plant making electricity
- In a climate-constrained world, liquid fuels characterized by near-zero GHG emissions ➔ must do better than CCS for coal F-T fuels

F-T FUELS + ELECTRICITY FROM COAL + BIOMASS w/CCS

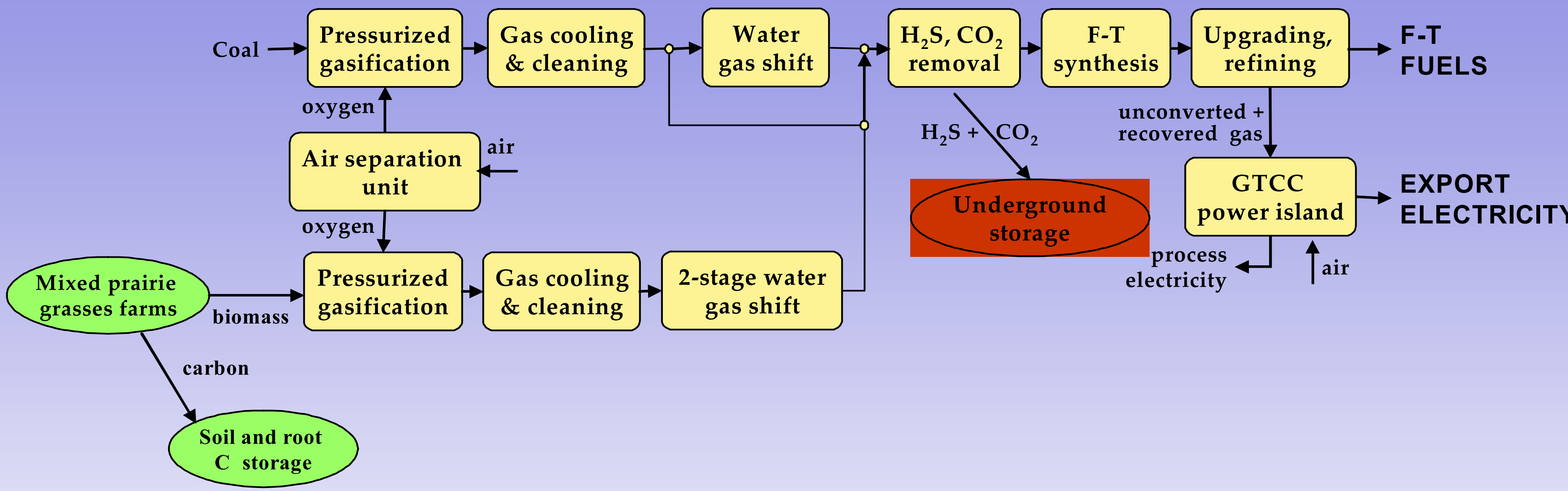


- Adding biomass (*residues or dedicated energy crops*) to system with CCS ➔ can exploit negative CO_2 emissions potential of storing photosynthetic CO_2 in geological formations to offset coal CO_2 emissions from plant and from eventual F-T fuel combustion

- Co-processing coal/biomass ➔ low emissions @ low cost exploiting:
  --scale economies of coal conversion, low cost of coal
  --negative emissions potential of biomass

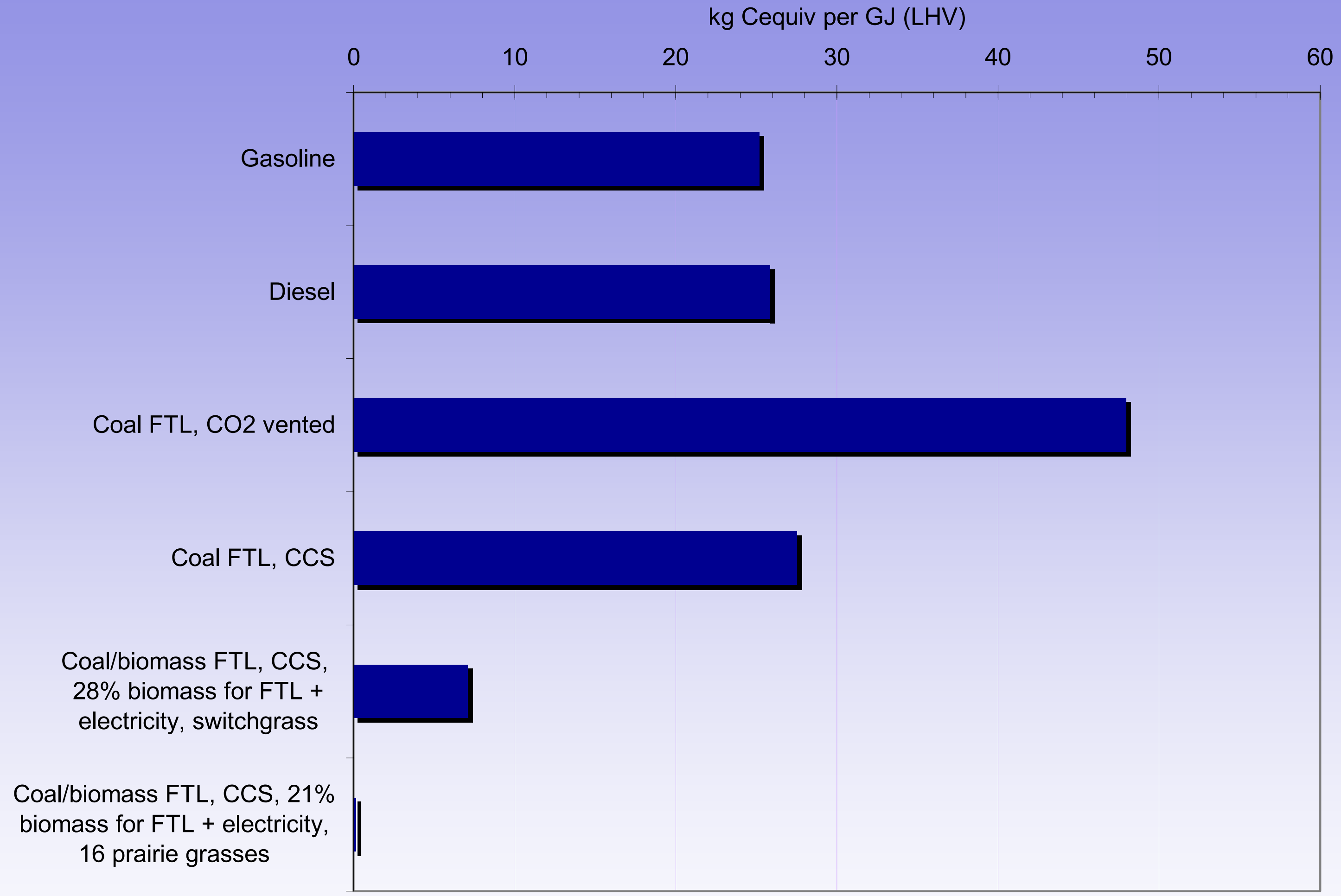
- No commercial large-scale biomass gasifier…but such could become commercial in 5-10 years if there were sufficient market interest

F-T FUELS + ELECTRICITY FROM COAL + PRAIRIE GRASSES WITH TWO C-STORAGE MECHANISMS



- Growing mixed prairie grasses on C-depleted soils ➔ substantial build-up of C in roots/soils
- Exploiting CCS + soil/root C buildup ➔ realization of near-zero GHG emissions for F-T fuels with modest biomass inputs
- Two-C-storage strategy ➔ much larger role for biomass in mitigating climate change than is feasible with any conventional biofuel strategy

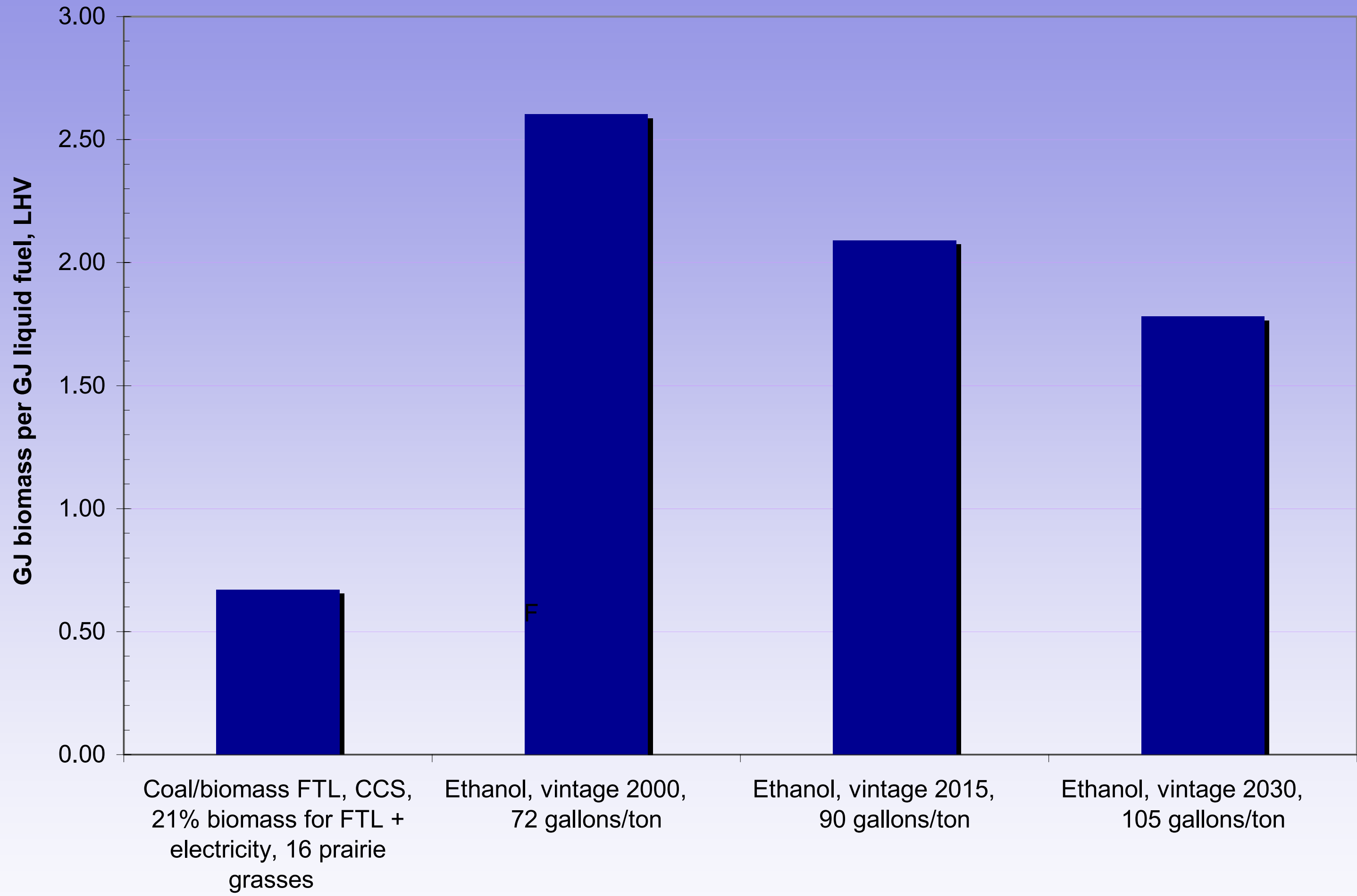
GHG Emission Rates for Fuel Production and Use



Penultimate case based on switchgrass (*28% of emission rate for gasoline*) exploits negative CO_2 emissions potential of photosynthetic CO_2 storage in geological reservoirs

Final case shows what can be realized by exploiting both CO_2 storage and soil/root C storage by growing mixed grasses on C-depleted (*formerly cultivated*) soils

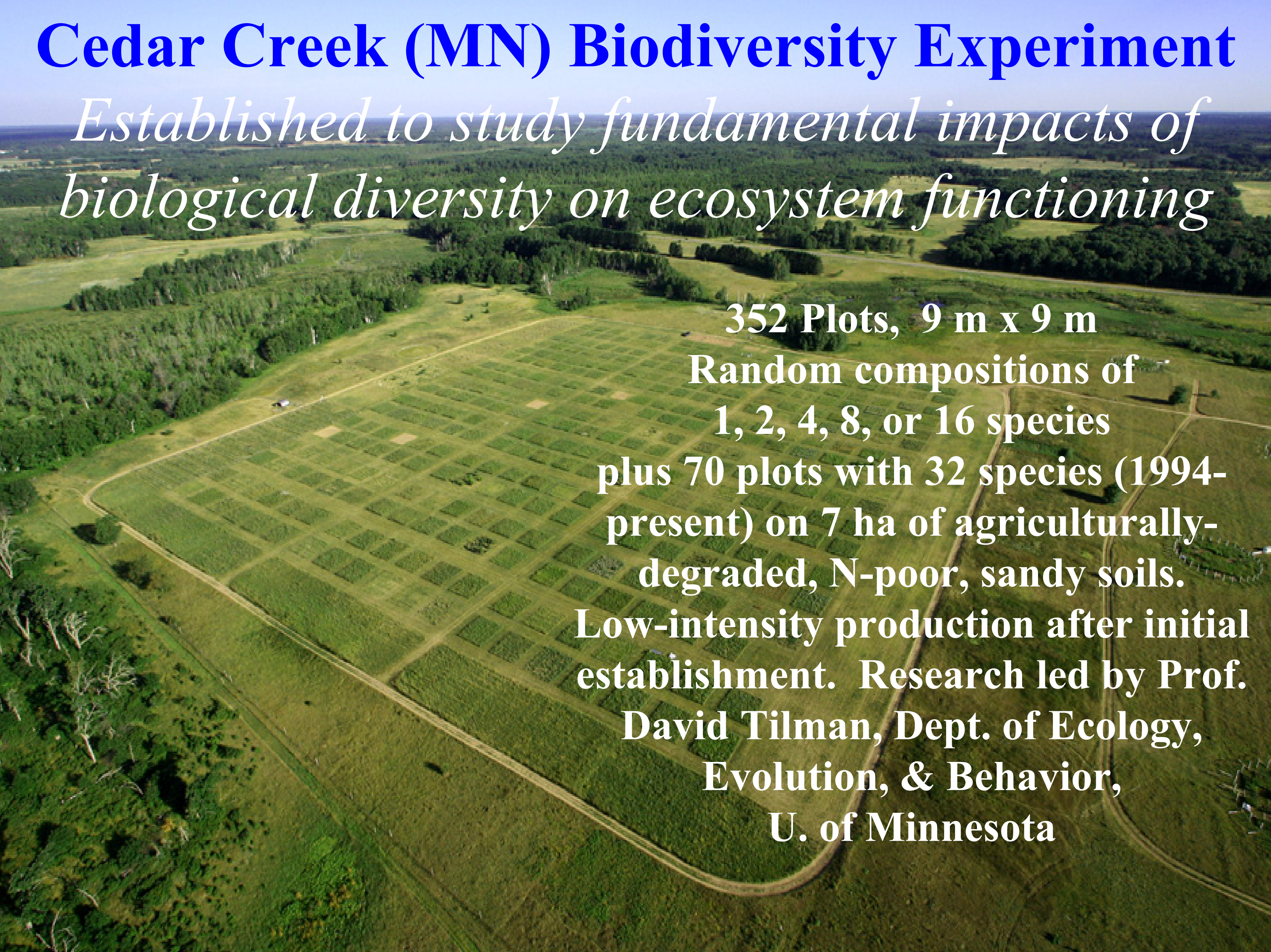
Biomass Required to Make 1 GJ of Liquid Fuel



The ethanol options involve alternative levels of technology for cellulosic ethanol—present technology (*vintage 2000*), near-term technology (*vintage 2015*) and hoped-for long-term (*vintage 2030*) technology)

Cedar Creek (MN) Biodiversity Experiment

Established to study fundamental impacts of biological diversity on ecosystem functioning



352 Plots, 9 m x 9 m
Random compositions of
1, 2, 4, 8, or 16 species
plus 70 plots with 32 species (1994-present) on 7 ha of agriculturally-degraded, N-poor, sandy soils.
Low-intensity production after initial establishment. Research led by Prof. David Tilman, Dept. of Ecology, Evolution, & Behavior, U. of Minnesota

Major Findings of Research by Tilman's Group

- Higher yields than with monocultures for same level of inputs
- Steady build-up of soil fertility vs little or no change for monocultures
- Much higher ecosystem stability than for monocultures
- Less leaching loss of nitrate/nitrite than for monocultures
- Lower incidence of foliar fungal diseases
- Greater soil microbial diversity
- Lower weed invasion
- High (energy output)/(energy input) for low-intensity production
- High sustained rate of soil C + root C buildup
  ➔ huge climate change mitigation benefit
- Local biodiversity gain vs. net biodiversity loss for monocultures

IMPLICATIONS OF "POLYCULTURE MANDATE" TO ADDRESS BIODIVERSITY LOSS CONCERNS

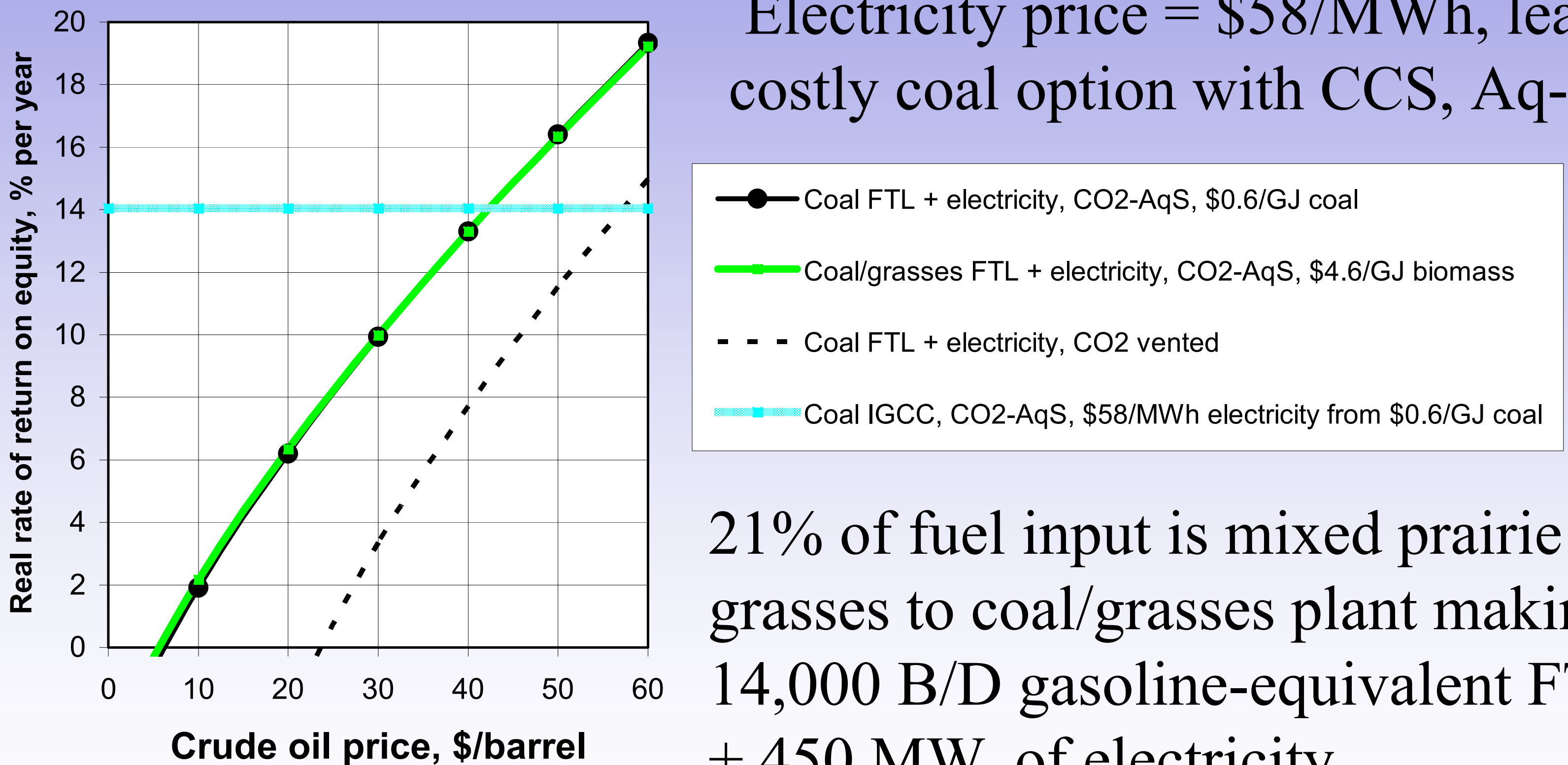
- Not only would cellulosic ethanol be able to provide much less low GHG-emitting liquid fuel than would proposed coal/biomass FTL strategy, but also its potential might be constrained by biodiversity loss concerns
- Although converting into useful fuel heterogeneous feedstock like biodiversity-enhancing mixed prairie grasses is always more challenging than for homogenous feedstock, challenge is far less daunting for thermochemical conversion (*e.g., gasification*) than for biochemical converson (*e.g., fermentation to ethanol*)
- Gasification conversion route might prove to be key in addressing effectively biodiversity loss challenge posed by conventional biofuels such as ethanol, which are likely to be based on monoculture feedstocks

FINANCIAL/COST PARAMETERS FOR IRR ANALYSES

Construction period (y)	4
Inflation rate (%/y)	2
Book/tax life (y)	30/20
Depreciation (for tax purposes)	MACRS
Corporate income tax rate (%)	38
Property taxes & insurance (%/y)	2
Nominal (real) return on equity (%/y)	Determined by market prices of products via IRR analysis
Nominal (real) return on debt (%/y)	6.5 (4.4)
Equity/Debt ratio	45/55

Coal (*prairie grasses*) price = $0.63 (*$4.87*) per million BTU—Montana conditions
GHG emissions price = $100/tC—assumes climate change mitigation policy is in place
CO_2 storage in saline formations 100 miles from plant
Oil prices ranging from $0 to $60 a barrel

At $100/tC, making ultra-low GHG emitting synthetic fuels + electricity from $0.63/MBTU coal + $4.87/MBTU mixed prairie grasses would be as profitable as making same products from low-cost coal only



Electricity price = $58/MWh, least-costly coal option with CCS, Aq-S

21% of fuel input is mixed prairie grasses to coal/grasses plant making 14,000 B/D gasoline-equivalent FTL + 450 MW_e of electricity

Plant-gate synfuel price = $1.4 per gallon gasoline equivalent when crude oil price = $40/barrel

COMPARING MARKET & EFFECTIVE PRICES FOR COAL & PRAIRIE GRASSES WHEN GHG EMISSIONS PRICE = $100/tC

FOR SYNFUEL PLANTS WITH CO_2 CAPTURE/STORAGE

(*$ PER MILLION BTU*)

	payment to farmers	**harvesting, storage, and transport**	**plant-gate market price**	**upstream GHG emissions**	**Net CO_2 emissions from plant + FTL use**	**soil and root C storage**	**effective price**
coal	-	-	**0.63**	0.11	1.13	-	**1.87**
prairie grasses	2.36 (*$38/ton*)	2.50 (*$40/ton*)	**4.87** (***$78/ton***)	0.14	-2.41	-1.70	**0.90**

More than 70% of payment to farmer would be for C storage in soil and roots

SUGGESTED ACTIONS

- Incentives for commercializing biomass gasification technologies
- R&D initiative for biomass production on C-depleted soils—state programs + supplemental federal support …2007 Farm Bill
- Policy to encourage coal/biomass coprocessing with CCS as major activity in Great Plains (GP) states, beginning with residues
- Policy to facilitate development of infrastructure for biomass harvesting, storage, and transport for energy
- Policy to promote improved fuel economy for motor vehicles
- Climate change mitigation policy for transportation fuels, including:
  - *Requirement that no coal synfuel plant be built without CCS*
  - *Low C obligation for fuels*
- Global initiative for low-intensity biomass production on C-depleted lands involving, *inter alia*, China—where there are huge amounts of degraded grasslands and pressing need to make China's emerging coal syfuels program climate-friendly