Forestry and Agriculture Greenhouse Gas Modeling Forum, Workshop #4: Modeling Ag-Forest Offsets and Biofuels in US and Canadian Regional and National Mitigation

Section 4.4: Modeling Ag/Forestry and Energy Sector Market Linkages

Seeking Negative-Carbon Bioenergy Options: Cost-Competitive Synfuels from Coal and Sustainable Prairie Grass Biomass

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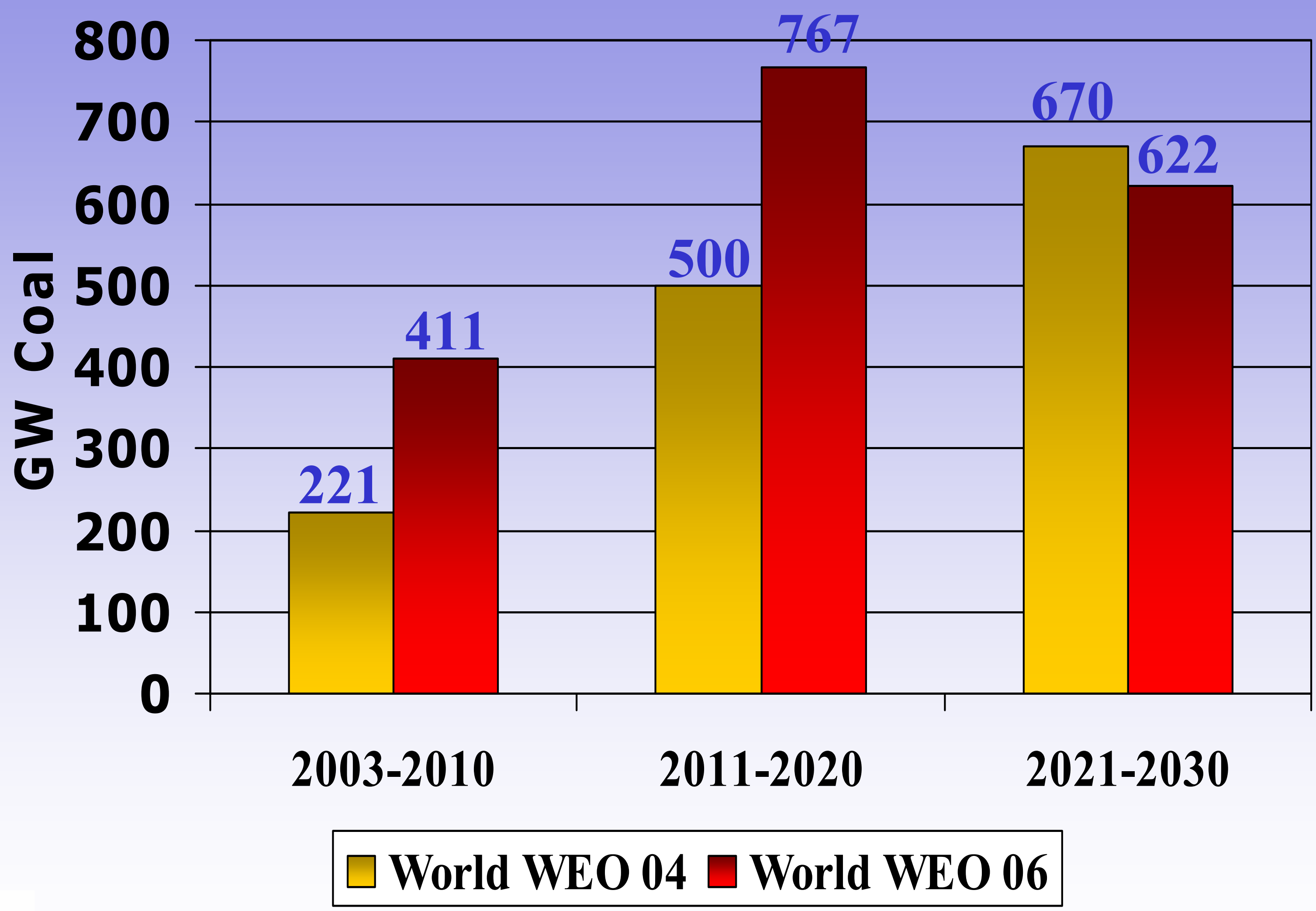
THE COAL CHALLENGE

- Coal accounts for ~ 40% of global CO_2 emissions from fossil fuels
- Rush to coal power
- Emergent interest in CTL (*Fischer-Tropsch liquids, DME*)
- Severe air pollution problems, mining hazards from coal use
- Not likely to be abandoned in face of climate challenge because of:
  - Coal's abundance:
    - Proved reserves ~ 200 y supply
    - Ultimately recoverable resources…might be up to ~2000 y supply
  - Coal's prices are low, non-volatile
- CO_2 capture and storage (*CCS*) necessary if coal is to continue being a major energy source in climate-constrained world
- Current wide interest in CCS for coal in light of
  - Awakening in US to need for climate change mitigation policy
  - IPCC *Special Report on CO_2 Capture and Storage* (2005)

PROJECTED COAL CAPACITY ADDITIONS/DECADE



Source: IEA, WEO 2004, 2006

NRDC
THE EARTH'S BEST DEFENSE

Total capacity: 1235 GW (2004) → 2565 GW (2030)

SYNGAS-BASED SYNFUEL ACTIVITY WORDWIDE

- Fischer-Tropsch Liquids (FTL): Commercial technology provides zero-sulfur, high-cetane, low-particulate diesel blendstock and gasoline blendstock—modernized by Sasol (*South Africa*)
  - Explosion of investment globally in natural gas-FTL (*e.g., Qatar, Nigeria*)
  - Growing coal-FTL investments (*China, USA*)
  - Biomass-FTL interest (*Germany*)
- Dimethyl Ether (*DME*—CH_3OCH_3): Propane substitute or blendstock; no-S, no-particulate, high-cetane diesel fuel substitute
  - Commercial activity in China—many huge DME-from-coal plants being built
  - Growing commercial interest in Iran (producer), Japan (*consumer*) in DME from natural gas
  - Swedish interest—for truck/bus applications (*Volvo*) and from biomass
- Strong US political interest in CTL
  - Governor Schweitzer (Montana)—major promoter
  - DoD intends to make huge CTL purchases
  - Coal-to-Liquid Fuel Promotion Act of 2007—S. 155 (*12 sponsors*) & H.R. 370 (*29 sponsors*)—emergent likelihood that CCS will be required to get incentives

OPTIONS FOR CO_2 STORAGE

- Goal: store 100s to 1000s of Gt CO_2 for 100s to 1000s of years
- Major options, disposal in:
  - Deep ocean (*concerns about storage effectiveness, environmental impacts, legal issues, difficult access*)
  - Carbonate rocks [*100% safe, costly (huge rock volumes), embryonic*]
  - Disposal in geological media (*focus of current interest*)
    - Enhanced oil recovery (*30 million tonnes CO_2/y—4% of US oil production*)
    - Depleted oil and gas fields (*geographically limited*)
    - Beds of unminable coal (*CO_2 adsorbed in pore spaces of coal*)
    - Deep saline aquifers—huge potential, ubiquitous (*at least 800 m down*)
      - Such aquifers underly land area = ½ area of inhabited continents (*2/3 onshore, 1/3 offshore*)
    - Already: some experience with aquifers, gas fields (*e.g., Sleipner, North Sea; In Salah*, *Algeria*); extensive experience with CO_2-EOR

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…

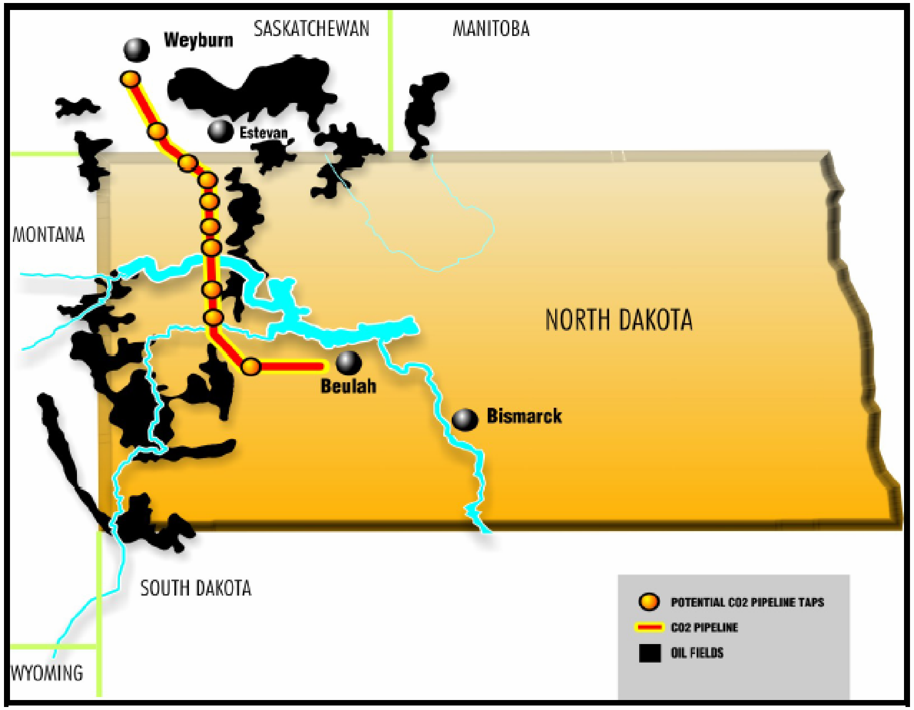
- On geography of sources and sinks for CO_2:

  …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* CO_2] 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…

PROJECT USING CO_2 COPRODUCT OF GASIFICATION ENERGY FOR ENHANCED OIL RECOVERY



- Synfuel plants are source of cheap CO_2 that can be used for EOR
- The $2.1 billion Great Plains Synfuels Plant at Beulah, ND, with capacity to produce up to 170 million cubic feet of methane daily from 18,500 tons of lignite, went on line in 1984.
- The GPSP generates as coproduct up to 3.8 million tonnes per year of nearly pure CO_2.
- Since 2000 the GPSP has sold 1.8 million tonnes of CO_2 annually to Encana Corporation for CO_2-EOR at the Weyburn oil field in Saskatchewan, Canada.
- The CO_2 is transported 330 km to the CO_2-EOR site via pipeline.

DILEMMA FOR CONVENTIONAL BIOFUELS

- Advantages:
  - Carbon neutrality
  - Renewability
- Downside:
  - Scarcity of high-quality land (*competition with food production*)
  - Biodiversity loss concerns about monoculture crops for energy
- Challenges can be addressed via
  - exploiting "negative emissions" potential of biomass
  - biomass/coal coprocessing for energy

TWO PART C-STORAGE STRATEGY FOR ADDRESSING DILEMMA

- ***Biomass, C-neutral* → *C-negative*** via two-part strategy:
  - *First part,*
    - Convert biomass via gasification
    - Separate out/store underground (*in geological formations*) as CO_2 most C in biomass not needed in final energy product ➔ negative CO_2 emissions
    - Coprocess biomass with coal (*also gasified*) to make synfuels and/or electricity—to exploit scale economies of coal conversion, low coal prices
  - *Second part,*
    - Grow biomass as *mixed grasses on C-depleted soils* ➔ more negative CO_2 emissions via soil C/root C buildup
- 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 stored underground as CO_2 along with CO_2 from coal if biomass/coal gasified to make synfuels/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*)

- Biomass = mixed prairie grasses grown on C-depleted soils ➔ soil/root C builds up—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**

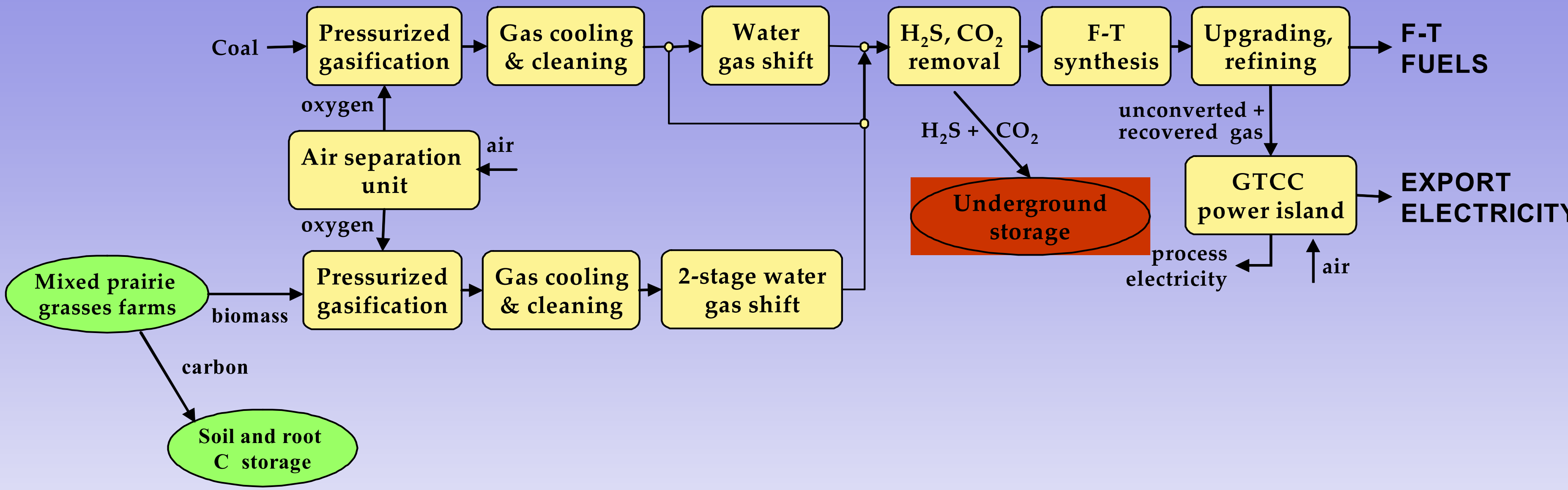
- Implications:
  - Large potential role for biomass energy
  - Local biodiversity gains

MAJOR FINDINGS OF TILMAN GROUP'S RESEARCH ON MIXED PRAIRIE GRASSES GROWN ON CARBON-DEPLETED SOILS

- Sustainable grass yield increases monotonically with # of species
- Soil/root C build-up increases montonically with # of species
- Soil C build-up continues for ~ century or more
- Once mixed prairie grasses have been established, only modest additional inputs are needed with annual harvesting
- High (energy output)/(energy input) ratio
- Local biodiversity gain vs. net biodiversity loss for monocultures

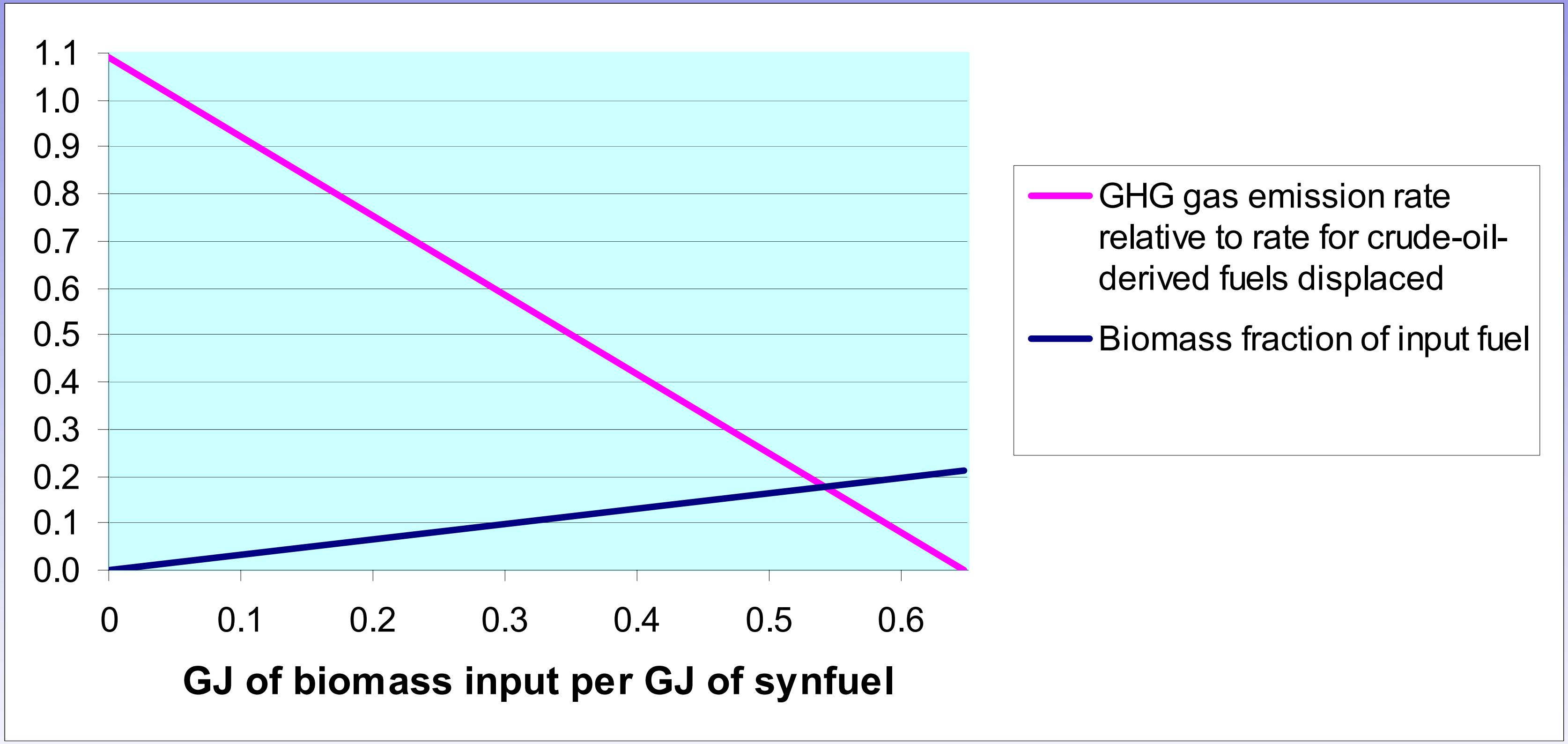
Source: D. Tilman et al., *Science,* **314**: 1598-1600, 8 December 2006

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



- Mixed prairie grasses are grown on C-depleted soils ➔ substantial build-up of C in roots/soils…up to 0.6 tC per tC in harvested biomass
- H_2 is made from biomass via gasification to compensate for H_2 deficit in coal syngas in manufacture of F-T liquids
- Photosynthetic CO_2 coproduct (~ 90% of C in harvested biomass) is stored with coal-derived CO_2 in deep geological formations

RELATIVE GHG EMISSION RATE & BIOMASS INPUT FRACTION VS (PRAIRIE GRASSES INPUT)/(FTL OUTPUT) FOR COAL/BIOMASS F-T POLYGEN PLANT w/CCS

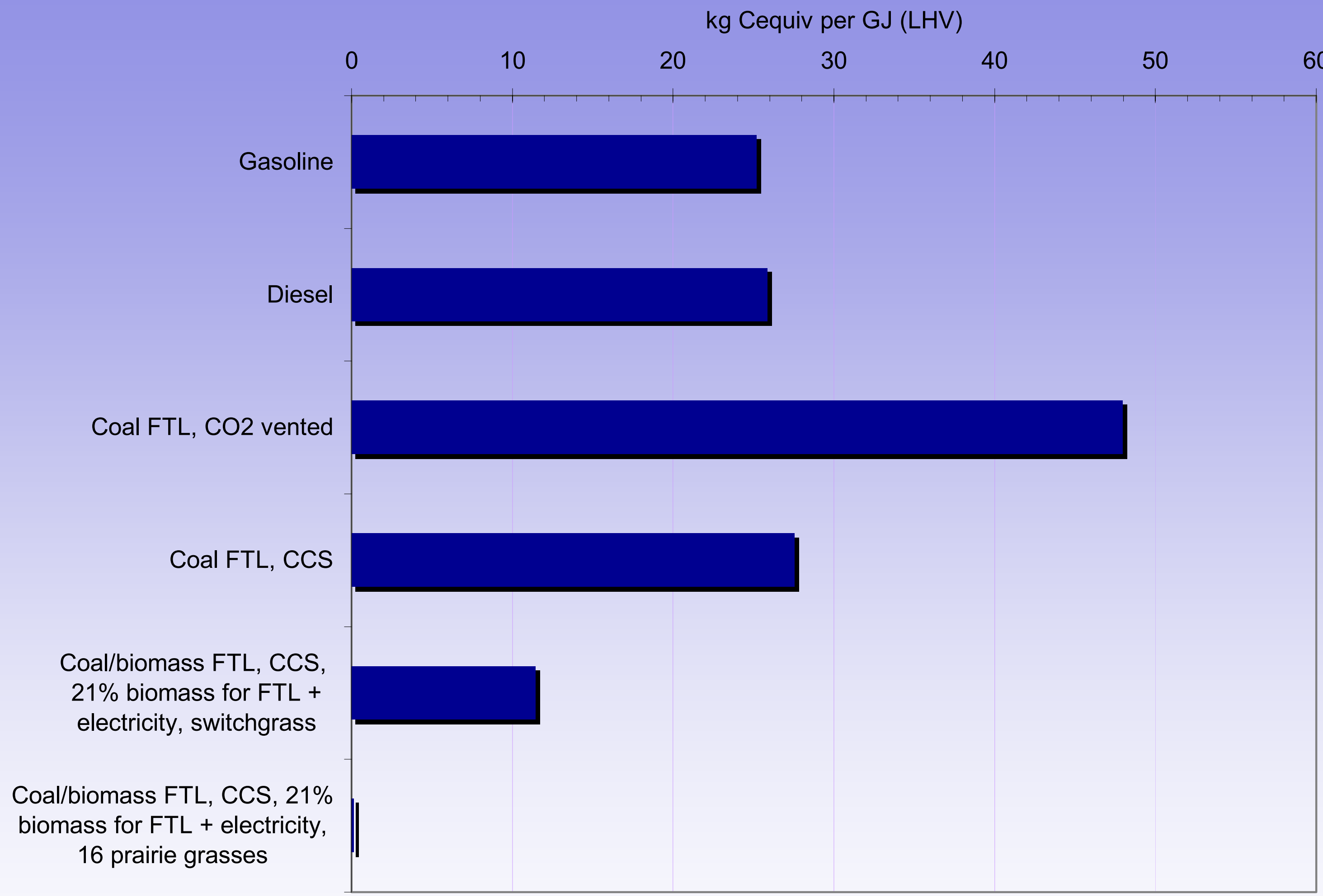


<u>Assumptions</u>:

- 90% of C in harvested prairie grasses is stored as CO_2
- soil/root C storage rate = 60% of C in harvested prairie grasses

➔

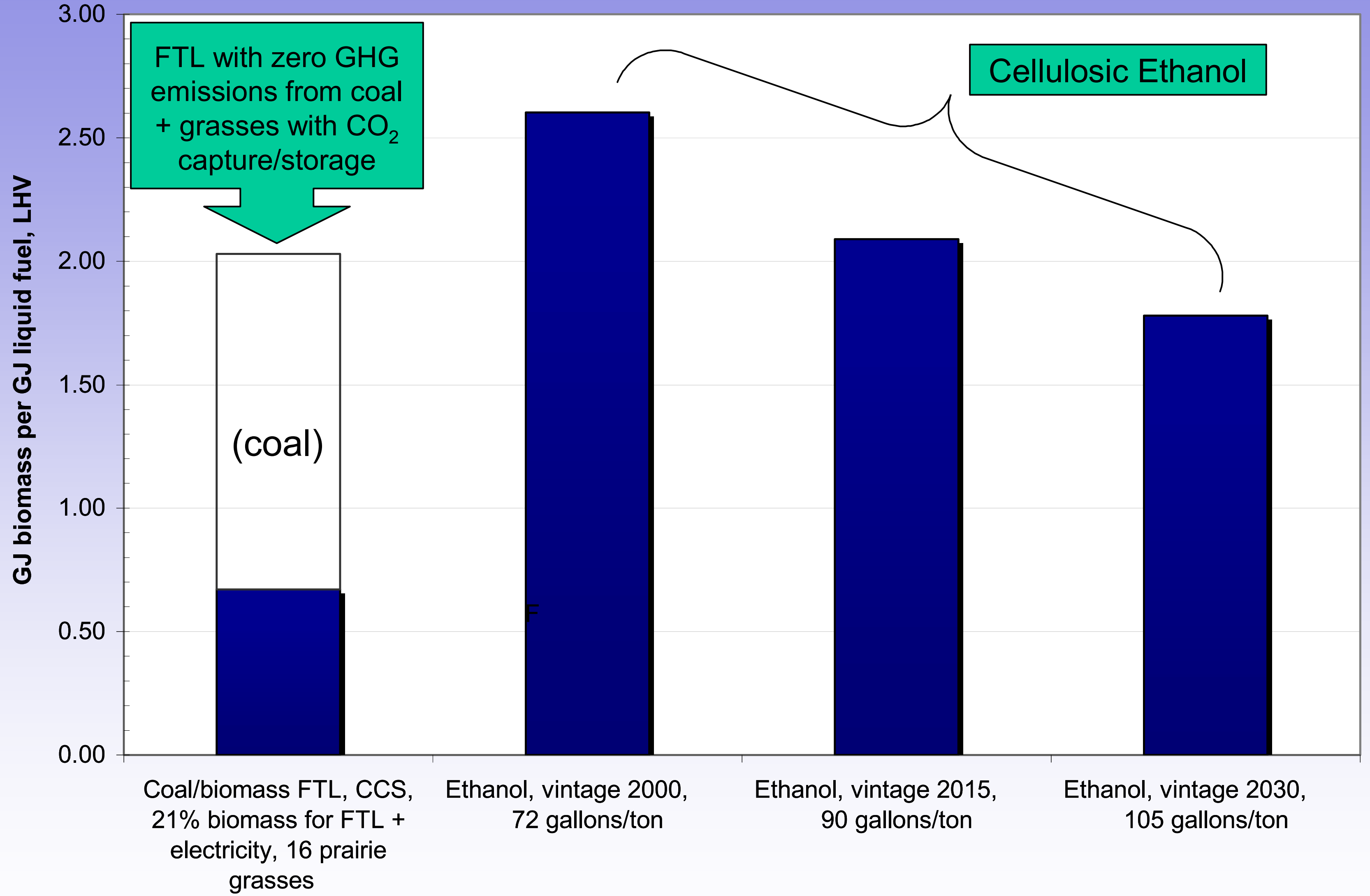
GHG Emission Rates for Fuel Production and Use



Penultimate case w/switchgrass (*45% of emission rate for gasoline*) exploits negative CO_2 emissions potential of photosynthetic CO_2 storage in geological media

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

Biomass Required to Make 1 GJ of Liquid Fuel



Coal use (*in FTL bar*) = (total coal use for plant)

– (coal required for making same electricity in stand-alone IGCC with CCS)

ESTIMATING VALUE OF STRATEGY TO FARMER

- Consider first coal F-T polygeneration plant with CCS
  - Capacity: 17,900 B/D (*gasoline equivalent*) + 430 MW_e
  - Site: North Central Iowa (*corn country*)
  - Feedstock: bituminous coal from Illinois Basin
  - GHG emissions price: $100/tC

  ➔
  - Breakeven crude oil price = $50/barrel
  - FTL selling price = $1.65/gallon ge
  - Electricity selling price = $66.5/MWh

- Next consider coal/biomass F-T polygen plant with enough prairie grass input to reduce GHG emisison rate to zero for FTL & assume:
  - Expected yield (7.9 t/ha/y) for mixed prairie grasses on degraded lands there
  - Assume essentially same outputs/exactly same product prices as for coal only plant ➔ determines "willingness" of synfuel producer to pay for prairie grasses

- **What is income to farmer if mixed prairie grasses displace corn in relation to income from corn?**

ECONOMICS OF SHIFTING IOWA CORN TO MIXED PRAIRIE GRASSES FOR MAKING FTL WITH COAL

Assumed carbon price, $ per tonne of C	100
Breakeven oil price for coal FTL, $ per barrel	50
FTL price, $/gallon of gasoline equivalent	1.65
Assumed prairie grasses yield, dry tonnes per hectare per year	7.9
Prairie grasses price, $ per short dry tonne	
Willingness to pay for prairie grasses at FTL plant	100
Cost of harvesting, grinding, storing grasses	-28
Biomass transport cost	-7
Income to farmer	66
Income per unit of land area for Kossuth, Winnebago, Hancock counties, $/ha/y	
To farmer for sale of grasses to FTL plant	**519**
Average CRP rental rate	343
Corn returns (*average for 2001-2004*)	**518**
Corn returns – (loan deficiency/counter-cyclical payments), 2001-04 ave	**356**

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

for C/B-FT polygen plants with soil/root C storage,

in $/GJ, HHV (and $/dry tonne for mixed prairie grasses)

	Net profit for farmers	Harvesting, grinding, 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	-	-	**1.36**	0.10	1.07	-	**2.53**
prairie grasses	3.48 (*$65*)	1.88 (*$35*)	**5.36 (*$100*)**	0.13	-2.29	-1.61	**1.60**

~ 1/2 of payment to farmer would be for C storage in soil and roots

THOUGHT EXPERIMENT: BIOMASS/COAL FOR SMP TRANSPORT ENERGY SCENARIO (2050)

Conventional wisdom: Not enough land to solve oil insecurity/climate change challenges posed by transport fuels with biomass…but what if opportunities for photosynthetic CO_2 storage are exploited?

Consider thought experiment in context of world demand for transport energy in 2050 as projected by World Business Council for Sustainable Development in *Mobility 2030: Meeting the Challenges to Sustainability*—the 2004 report of the Sustainable Mobility Project

	2000	2050
# LDVs, 10^9	0.7	2.0
LDV fuel economy (*mpg*)	22.5	27.6
Transportation Fuel Use, EJ/y		
LDVs	34	73
Total	77	176
GHG emissions w/oil, GtC/y	1.73	3.92

THOUGHT EXPERIMENT: BIOMASS/COAL FOR SMP TRANSPORT ENERGY SCENARIO (2050)

Should not pursue options to address oil challenges only on supply side

Will construct coal/biomass thought experiment for modified SMP demand scenario in which average LDV fuel economy in 2050 increases

27.6 mpg_{ge} → 60 mpg_{ge}

	2000	2050	
# LDVs, 10^9	0.7	2.0	
LDV fuel economy (*mpg*)	22.5	27.6	60
Transportation Fuel Use, EJ/y			
LDVs	34	73	26
Total	77	176	138
GHG emissions w/oil, GtC/y	1.73	3.92	3.05

BIOMASS SUPPLIES IN 2050 FOR THOUGHT EXPERIMENT

Biomass required to displace 100% of oil & reduce GHG emissions 90% at low end of estimates of global biomass energy potential
[*World Energy Assessment* (2000) est. potential~ 100-300 EJ/year]

	2000	2050	
# LDVs, 10^9	0.7	2.0	
LDV fuel economy (*mpg*)	22.5	27.6	60
Transportation Fuel Use, EJ/y			
LDVs	34	73	26
Total	77	176	138
GHG emissions w/oil, GtC/y	1.73	3.92	**3.05**
Biomass in 2050 with alternative coal/biomass FTL fueling, EJ/y			
Residues @ 0.89 GJ/GJ FTL (*no soil/root C storage*)			**52**
Mixed grasses @ 0.67 GJ/GJ FTL (*soil/root C storage*)			**52**
GHG emissions with coal/biomass FTL fueling, GtC/y			**0.305**

COAL & C STORAGE REQUIREMENTS IN 2050 FOR THOUGHT EXPERIMENT

	2000	2050	
# LDVs, 10^9	0.7	2.0	
LDV fuel economy (*mpg*)	22.5	27.6	60
Transportation Fuel Use, EJ/y			
LDVs	34	73	26
Total	77	176	138
GHG emissions w/oil, GtC/y	1.73	3.92	3.05
Biomass in 2050 with alternative coal/biomass FTL fueling, EJ/y			
Residues @ 0.89 GJ/GJ FTL (*no soil/root C storage*)			52
Mixed grasses @ 0.67 GJ/GJ FTL (*soil/root C storage*)			52
GHG emissions with coal/biomass FTL fueling, GtC/y			0.305
Coal in 2050 with coal/biomass FTL fueling, EJ/y			**149**
CO_2 storage rate in 2050, GtC/y			**3.0**
Soil/root C storage rate in 2050, GtC/y			**0.9**

ALTERNATIVE THOUGHT EXPERIMENT:
NO SOIL/ROOT C STORAGE

	2000	2050	
# LDVs, 10^9	0.7	2.0	
LDV fuel economy (*mpg*)	22.5	27.6	60
Transportation Fuel Use, EJ/y			
LDVs	34	73	26
Total	77	176	138
GHG emissions w/oil, GtC/y	1.73	3.92	**3.05**
Biomass in 2050 with alternative coal/biomass FTL fueling, EJ/y			
Residues @ 0.89 GJ/GJ FTL (*no soil/root C storage*)			52
Mixed grasses @ 0.67 GJ/GJ FTL (*no soil/root C storage*)			52
GHG emissions with coal/biomass FTL fueling, GtC/y			**1.19**
Coal in 2050 with coal/biomass FTL fueling, EJ/y			149
CO_2 storage rate in 2050, GtC/y			3.0
Soil/root C storage rate in 2050, GtC/y			**0.0**

GLOBAL LAND REQUIREMENTS FOR GROWING PRAIRIE GRASSES IN THOUGHT EXPERIMENT FOR ALTERNATIVE AVERAGE YIELDS

WITH COMPARISON TO LAND AREAS IN CROPS/GRASSES

	Average Yield (t/ha/y)	Land Area (10^6 hectares)
Energy crops (*52 EJ/y*)	5	600
	10	300
Global Cropland	-	1500
Global Grasslands	-	3400

- Some mix of grasslands/croplands would be used to grow grasses

WHY FARMERS SHOULD BE INTERESTED IN GEOLOGICAL STORAGE OF PHOTOSYNTHETIC CO_2

- Coal is abundant & cheap—much of which is likely to be used
- Solving climate problem requires solving coal climate problem
- CO_2 capture/storage (CCS) essential in solving coal climate problem
- If CCS works for coal, it should also be considered for biomass
- Pursuing CCS + soil/root C buildup for biomass makes it feasible to solve entire transportation climate problem with biomass (+ coal)
- With two-part photosynthetic CO_2 storage strategy pursued in conjunction with synfuels production from coal/biomass, farmer would have much more market power than in selling biomass for the production of any conventional biofuel

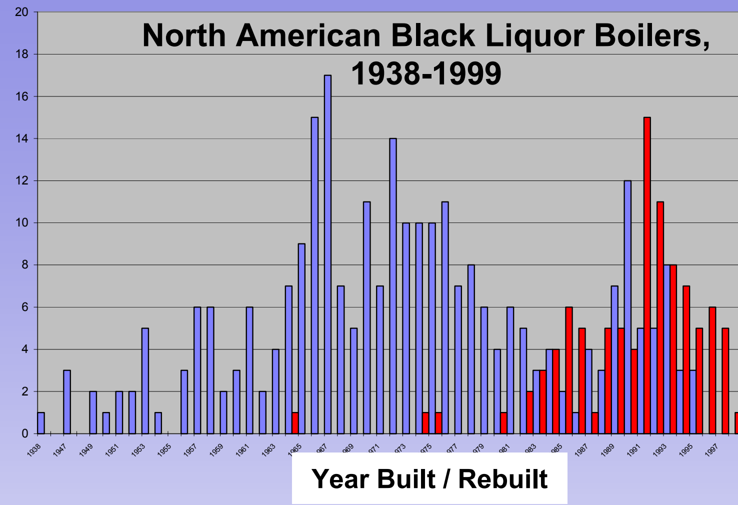

KING COAL
GRO MOR
CARS R US
BIG OIL

MODELING/RESEARCH/ASESSMENT PRIORITIES FOR BIOFUELS

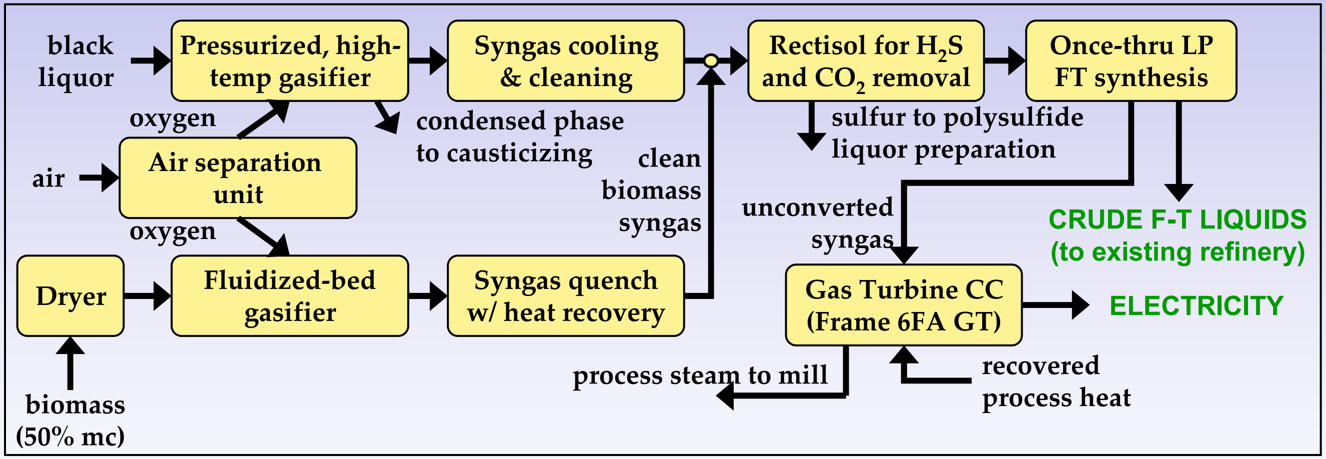
- Relative merits of biochemical/thermochemical conversion processes?
- Relative ease of processing mixed prairie grasses with biochemical /thermochemical processes?
- Biodiversity losses/gains with alternative biomass production options?
- Optimal grasses mix by region?
- Global potential for mixed grasses on degraded grasslands?
- Verification of soil/root C storage, protocols for same
- Geographical distribution of opportunities of coal/biomass coproduction?
- Relative merits of plants making only liquid fuels, plants making only electricity, and polygeneration plants?
- Where to get started with gasification energy strategies for biomass?

PULP MILL-INTEGRATED BIOREFINING

- > 1.2 EJ/yr black liquor (BL) energy used in USA.
- Tough global competition in pulp production…can integrated biorefinery be helpful? **Way to get started with biofuels via thermochemical conversion?**
- Pulp industry interest in gasification…Swedish BL gasifier technology near commercial demonstration.
- Aging black liquor boiler fleet provides economic window of opportunity for gasification.



- FTL biorefinery at pulpmill in Southeast USA:
  - 4,800 bbl/day oil equiv.
  - 78 MW_e (for pulp mill)
- $330 million incremental capital investment
- ~ 18% IRR for $50/bbl crude oil and $53/MWh electricity



- **Much better economics than for stand-alone biofuels** (*which need high C price*)
  - Integration with pulpmill ➔ capital cost-sharing, low bio feedstock cost
  - But pulp industry is technology risk-averse.
- **How about integration with coal gasification and CCS for FTL + electricity?**