$1 A GALLON SYNTHETIC LIQUID FUEL WITH NEAR-ZERO GHG EMISSIONS FROM COAL + BIOMASS USING NEAR-TERM TECHNOLOGY

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Viewgraphs for Presentation

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SUMMARY OF PRESENTATION

- Super-clean "*designer*" synfuels @ plant-gate cost ~ \$1.0-\$1.2 a gallon of gasoline equivalent (gge)* can be made via "*coordinated*" production from secure and abundant domestic coal + biomass
- Such designer fuels can facilitate shift to super-efficient Diesel cars
- Average GHG emission rate = that for H_2 from coal with CO_2 capture and storage (CCS)…*if CCS pursued for both coal and biomass*
- This strategy realizable with commercial/near-commercial technologies ➔ significant market penetration during 2010-2025 …long before H_2 economy can be established

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- For comparison, US refinery-gate gasoline prices:
  - \$1.0 a gge in 2003 (*for crude oil @ \$29/barrel*)
  - \$1.3 a gge in June 2004 (*for crude oil @ \$35/barrel*)
- For comparison, projected cellulosic ethanol costs::
  - \$1.6 a gge post-2010 (*NREL projection*)
  - \$1.0 - \$1.1 a gge *eventually* for "fully mature and optimized cellulosic production process" (NCEP, *Ending the Energy Stalemate*, 2004)

MAJOR CHALLENGES POSED BY OIL AND CARS

- Supply insecurity
- Oil price (*prospective peaking of global production*)
- Health impacts of air pollution (*especially for Diesel vehicles*)
- Climate change (*need to decarbonize energy for cars*)

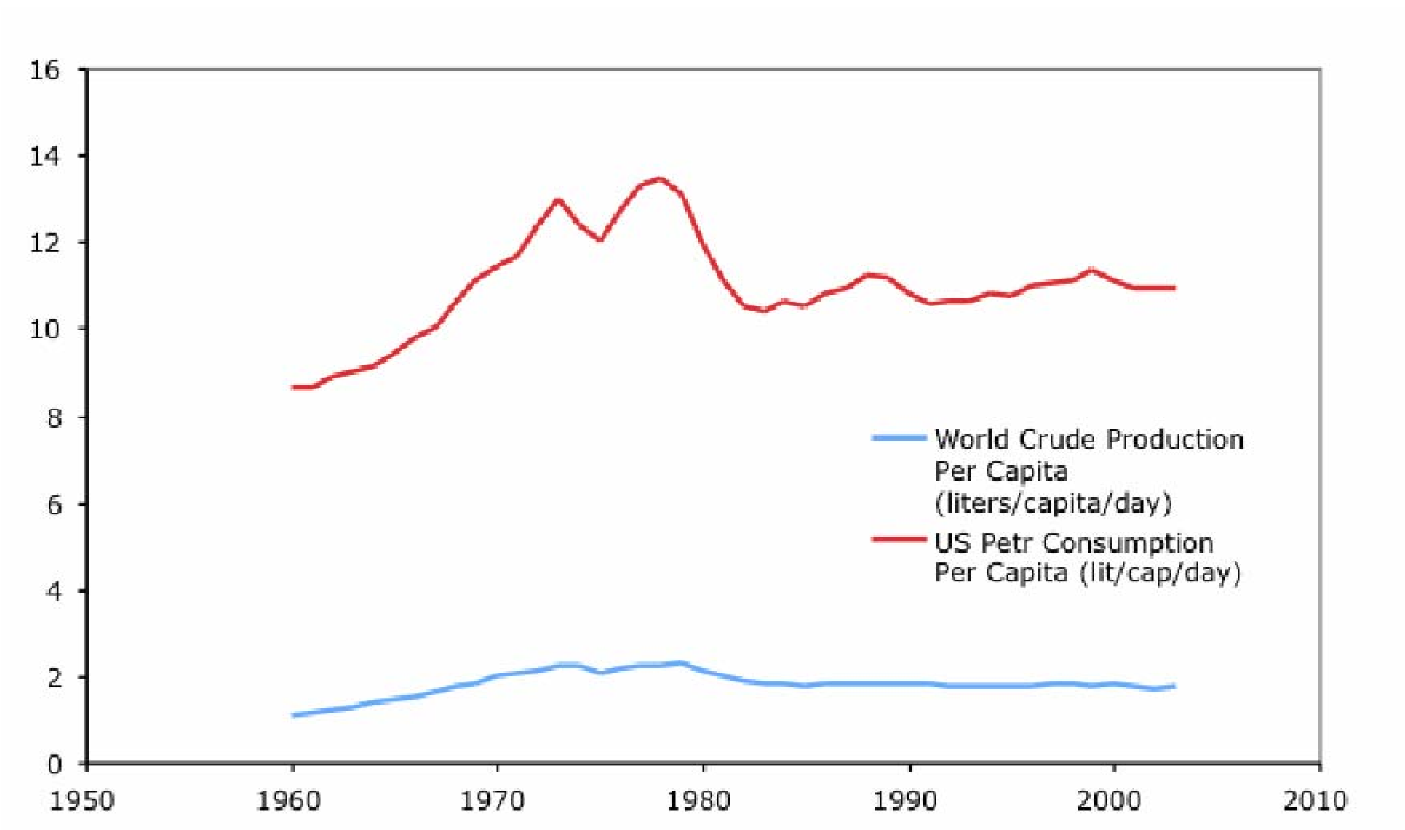
THE CAR'S CONTRIBUTION TO OIL, CLIMATE CHALLENGES

Year	2000	2030
Number of light-duty vehicles worldwide, 10^6	690	1270
Average fuel economy (mpg_{ge})	*24.4*	*28.0*
Crude oil consumed, 10^6 barrels/day (% of Persian Gulf production, 2000)	16.7 (*89*)	27.1 (*136*)
Fuel cycle-wide GHG emissions, GtC/year (% of global total, 2000)	0.74 (*11.6*)	1.20 (*18.8*)

Source: World Business Council for Sustainable Development, *Mobility 2030: Meeting the Challenges of Sustainability*, The Sustainable Mobility Project, 2004

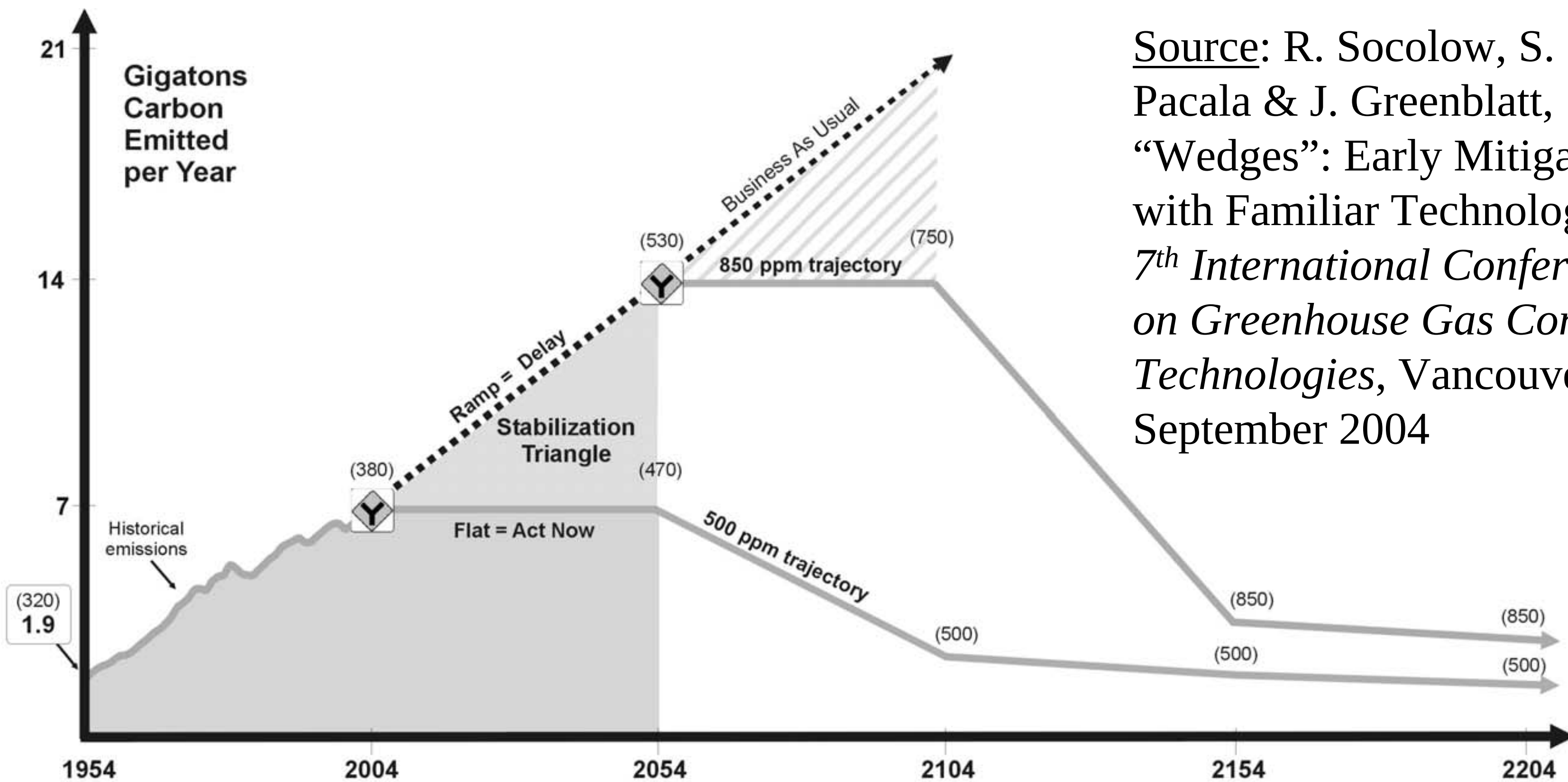
HIGH FUEL ECONOMY/SYNFUELS IMPERATIVE

World Oil Production/Capita Peaked before 1980
at Fraction of US Per Capita Oil Consumption Rate



➔ Both high fuel economy and alternative fuels are needed

WHAT IS REQUIRED TO STABILIZE ATMOSPHERIC CO_2 AT $\leq$ 2X PRE-INDUSTRIAL LEVEL?



Source: R. Socolow, S. Pacala & J. Greenblatt, "Wedges": Early Mitigation with Familiar Technology," *7th International Conference on Greenhouse Gas Control Technologies*, Vancouver, September 2004

Stabilizing @ 500 ppm CO_2

➔ by 2050 cut emissions ~ 7 GtC/y relative to BAU

Distribution of Global CO_2 Emissions from FFs (%)

Year	2000	2020	2050
Electricity generation	36	25-38	22-43
Industry (FUD only)	32	28-32	24-37
Transportation (FUD only)	21	21-25	18-33
Residential/commercial (FUD only)	12	12-20	11-19

Must decarbonize fuels used directly (FUD) as well as electricity

IEA data for 2000. Projections are for A1B-AIM, AIT-Message, A2-Image, B1-Image, B2-Message scenarios of IPCC's *Special Report on Emissions Scenarios* (IPCC, 2000)

COAL: CHALLENGE…AND OPPORTUNITY

- Coal = main challenge for energy w/r to climate change
- Also severe air pollution problems, mining hazards
- Coal not likely to be abandoned because of:
  - Abundance
  - Low, non-volatile prices
- Can coal be made environmentally acceptable? …Gasification is key, *as alternative to combustion*

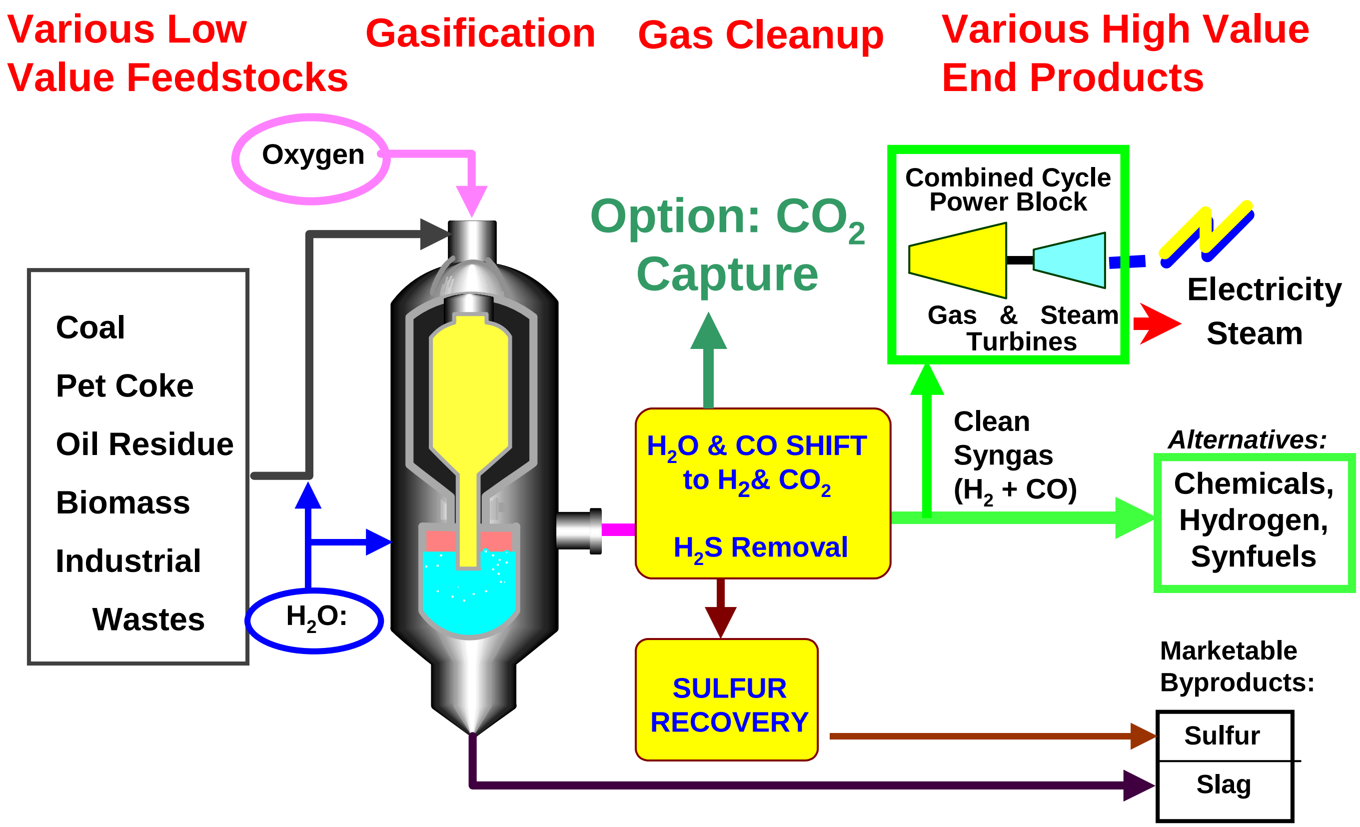
WHY SYNFUELS FROM COAL AND BIOMASS?

- Constraints on conventional oil, other unconventional oil
- Gasification-based coal synfuels are nearly commercially ready...and competitive at oil prices ~ $30 per barrel
- China is pursuing coal-derived liquid fuels
- Liquid synfuels derived from biomass + coal with CO_2 capture and storage (CCS) would be climate friendly
- Alternative options for decarbonizing FUD have limited potential for addressing challenges in this Qtr century:
  - H_2, fuel cell vehicles (*Administration*, *automakers focus*) cannot make major contributions before 2nd Qtr of 21st century
  - Land-use constraints ➔ biofuels *alone* cannot do the job

OPTIONS FOR CO_2 DISPOSAL

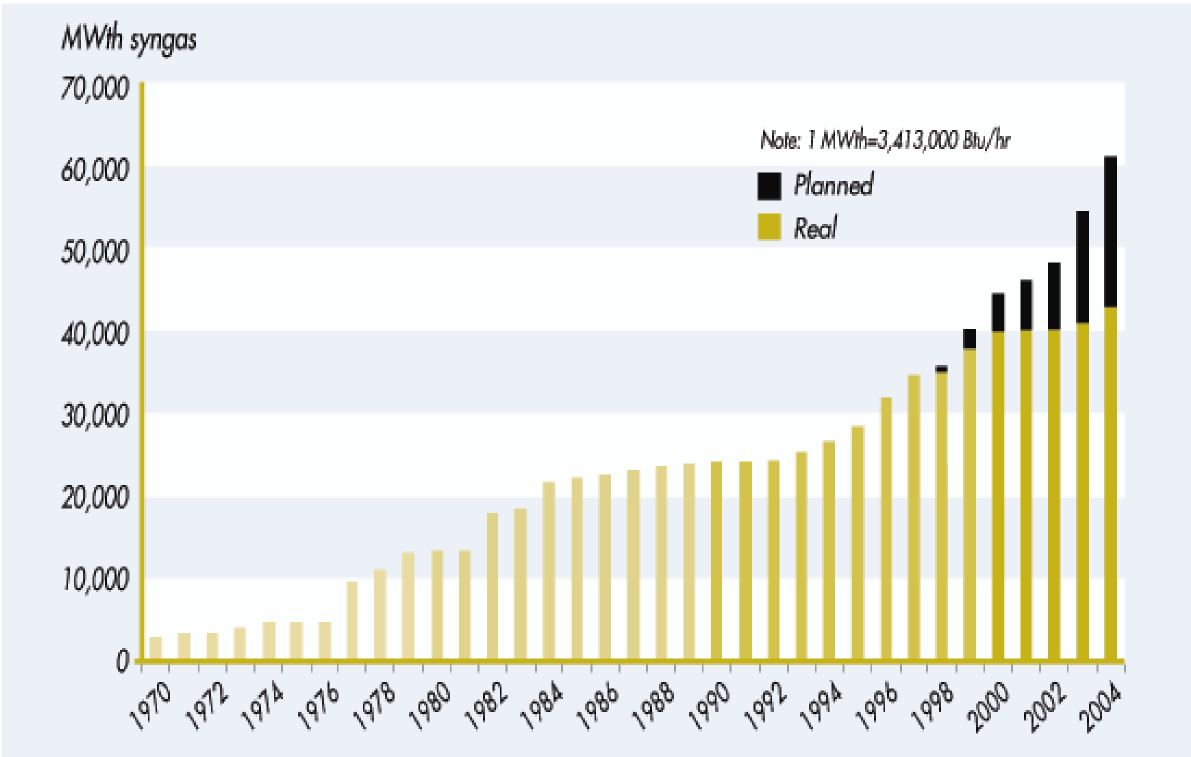
- Goal: store 100s to 1000s of GtC for long periods (*100s to 1000s of y*)
- Major options, disposal in:
  - Deep ocean (*concerns about storage effectiveness, environmental impacts, legal issues, difficult access*)
  - Carbonate rocks [*100% safe…but costly (huge rock volumes), embryonic*]
  - Disposal in geological media (*focus of current interest*)
    - Enhanced oil recovery (*30 x 10^6 tonnes CO_2/y—for 4% of US oil*)
    - 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*)
  - Most large anthropogenic CO_2 sources within 0-200 km of geological disposal sites (*800 km = longest US CO_2 pipeline for EOR*)
  - Already some experience (*e.g., Sleipner, North Sea; EOR*) but many more "megascale" CO_2 storage demos needed

GASIFICATION TO CONVERT LOW-VALUE FEEDSTOCKS INTO HIGH-VALUE PRODUCTS



Gasification is key to low cost CO_2 capture and storage (CCS) and thus coal's playing major roles in a climate-constrained world

GASIFICATION IS BOOMING GLOBAL ACTIVITY



Worldwide gasification capacity is increasing by 3 GW_{th} per year and will reach 61 GW_{th} in 2004

- **In 2004**
- By activity:
- 24 GW_{th} chemicals
- 23 GW_{th} power
- 14 GW_{th} synfuels
- By region:
- 9 GW_{th} China
- 10 GW_{th} N America
- 19 GW_{th} W Europe
- 23 GW_{th} Rest of world

By feedstock:

- 27 GW_{th} petroleum residuals
- 27 GW_{th} coal
- 6 GW_{th} natural gas
- 1 GW_{th} biomass

Current market dominated by polygeneration of chemicals, electricity, process heat via petroleum residuals gasification…largest potential = polygeneration of synfuels, electricity, processs heat via coal gasification

SYNFUEL OPTIONS VIA COAL GASIFICATION

F-T liquids →
- Blend with crude oil-derived liquids
- Use as substitute for crude oil-derived liquids

MeOH →
- Convert to gasoline (*Mobil process*)
- Use directly as fuel
- Convert to DME via dehydration

DME → Use directly as fuel

F-T = Fischer-Tropsch; MeOH = methanol; DME = dimethyl ether

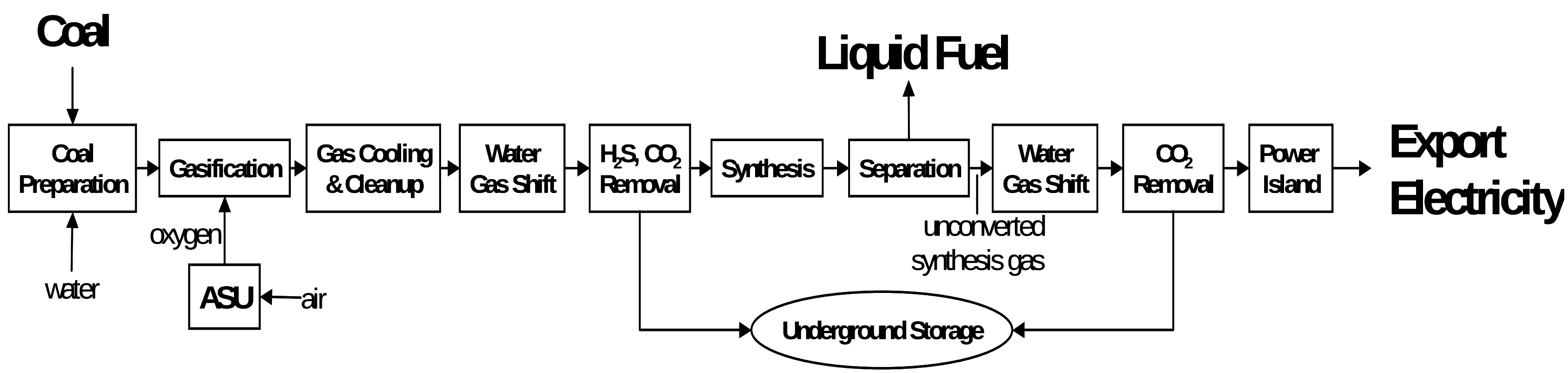
CANDIDATE DESIGNER FUEL: DME (CH_3OCH_3)

- Ozone-safe aerosol propellant and chemical feedstock
- Production ~ 150,000 t/y by MeOH dehydration (*small plants*)
- Clean cooking fuel—LPG supplement—esp. for LDCs
- Outstanding Diesel engine fuel:
  - high cetane #
  - no sulfur, virtually no soot formation ➔ no PM/NO_x tradeoff in quest for low emissions, so low NO_x emission rate readily achievable

    ➔ Can facilitate shift to super-efficient Diesel or Diesel/hybrid vehicles
- Drawbacks:
  - Gas at atmospheric pressure—mild pressurization (*as for LPG*) needed

    ➔ new infrastructure for transport…but far more modest challenge than for H_2
  - Further engine developments needed before DME is ready for transport markets
- Production plans (*targeting domestic fuel applications*):
  - NG → DME: 110,000 t/y (*Sichuan, China, 2005*); 800,000 t/y (*Iran, 2006*)
  - Coal → DME (*800,000 t/y project approved, Ningxia, China*)

MOST COST-EFFECTIVE PLANTS WOULD OFTEN PRODUCE LIQUID FUEL + ELECTRICITY

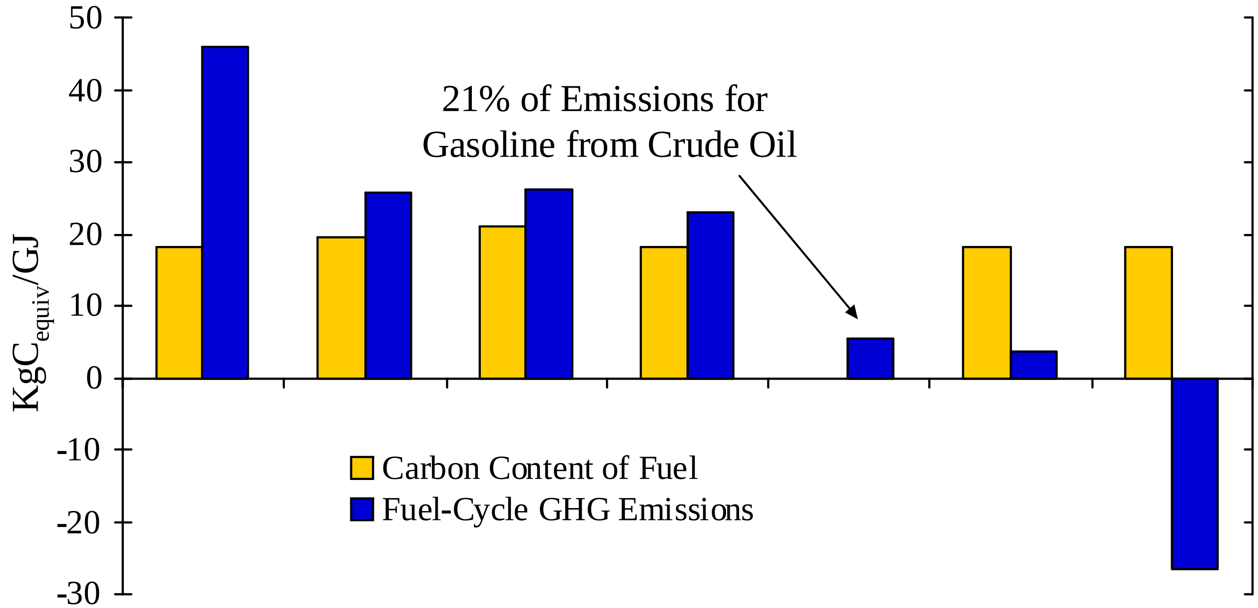


Under climate constraint, CO_2 can be captured both upstream and downstream of synthesis reactor

Fuel-cycle-wide GHG emissions for coal-derived liquid fuels ~ 80-90% of emissions for crude-oil-derived hydrocarbon fuels with CCS…but must do *much better* under C constraint.

Can do much better with coordinated development of synfuels from coal + biomass (*not necessarily at same site*)…with CCS in both instances…biomass plants would be similar to coal plants

FUEL C CONTENT, FUEL-CYCLE GHG EMISSIONS FOR A LIMITED SAMPLE OF FUELS/PRIMARY ENERGY SOURCES

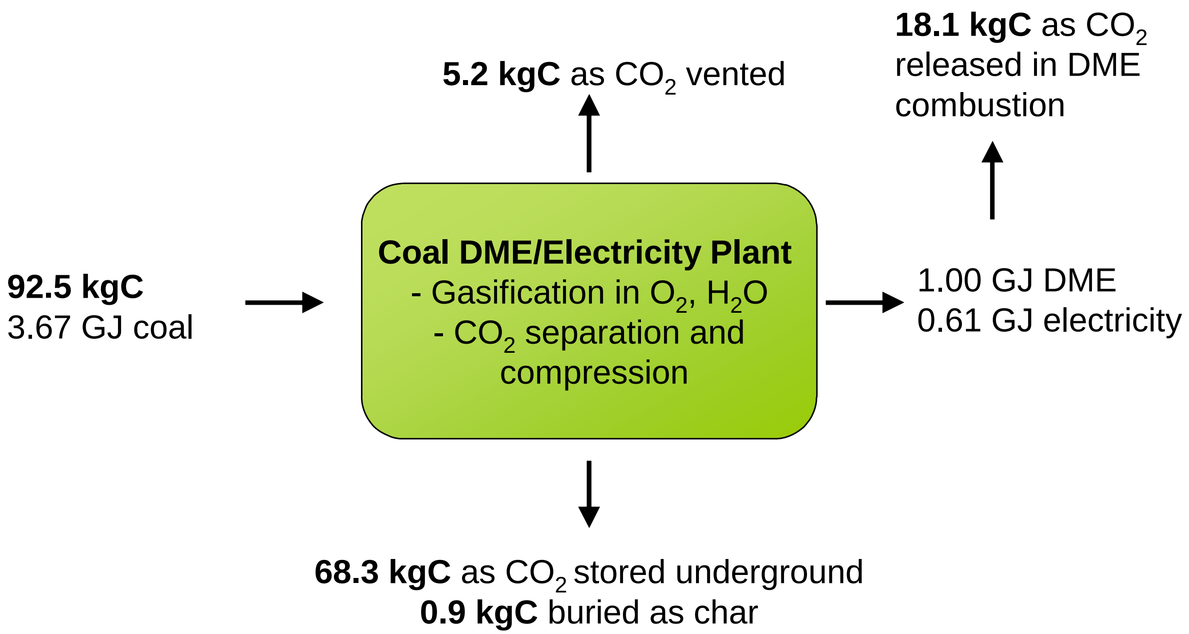


Energy Carrier	DME	Gasoline	Diesel	DME	Hydrogen	DME	DME
Primary Energy Source	Coal	Crude Oil	Crude Oil	Coal	Coal	Biomass	Biomass
CO_2 Capture and Storage?	No	No	No	Yes	Yes	No	Yes

Consider coordinated production of DME from coal + biomass with CCS (*not necessarily at same site*) such that GHG emission rate = that for H_2 from coal with CCS

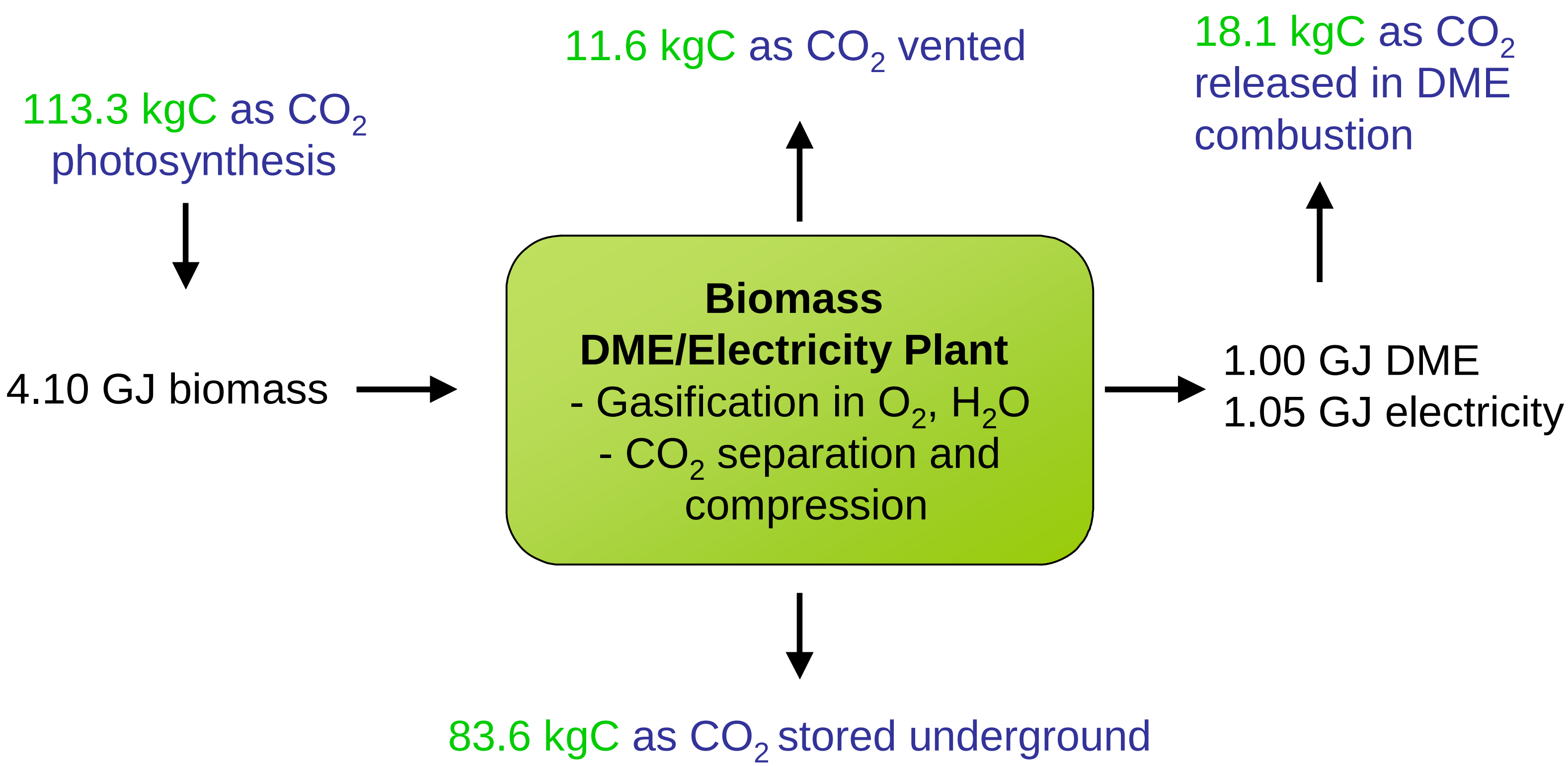
The coal DME CCS option is a once-through configuration with CO_2 capture both upstream and downstream of synthesis. The biomass DME with CCS option is a recycle configuration with CO_2 capture only upstream of synthesis

CARBON/ENERGY BALANCES IN MAKING DME + ELECTRICITY FROM COAL w/CO_2 CAPTURE/STORAGE



- For this system: ~ ¾ of coal C stored underground
- GHG emission rate per GJ of synfuel would be (*slightly*) less than for crude-oil-derived hydrocarbon fuel
- In climate-constrained world, a much lower GHG emission rate may be necessary

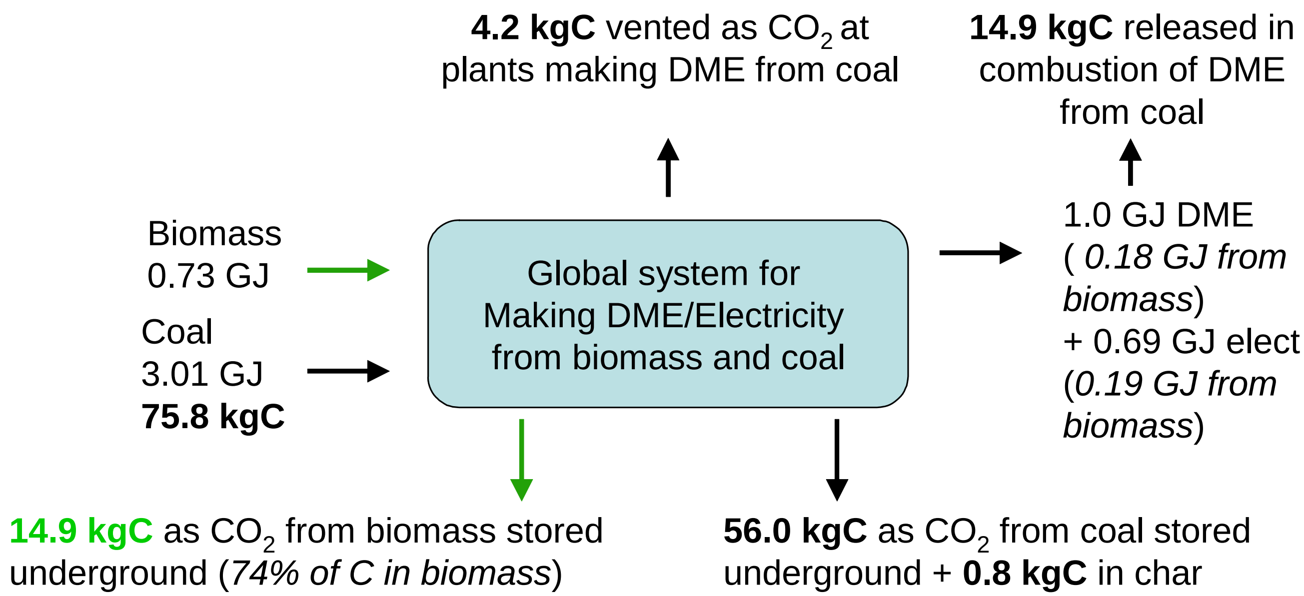
CARBON/ENERGY BALANCES IN MAKING DME + ELECTRICITY FROM BIOMASS w/CO_2 CAPTURE/STORAGE



- Here ~ ¾ of biomass carbon can be stored underground

➔ "negative" CO_2 emissions that "make room in the atmosphere" for coal liquids

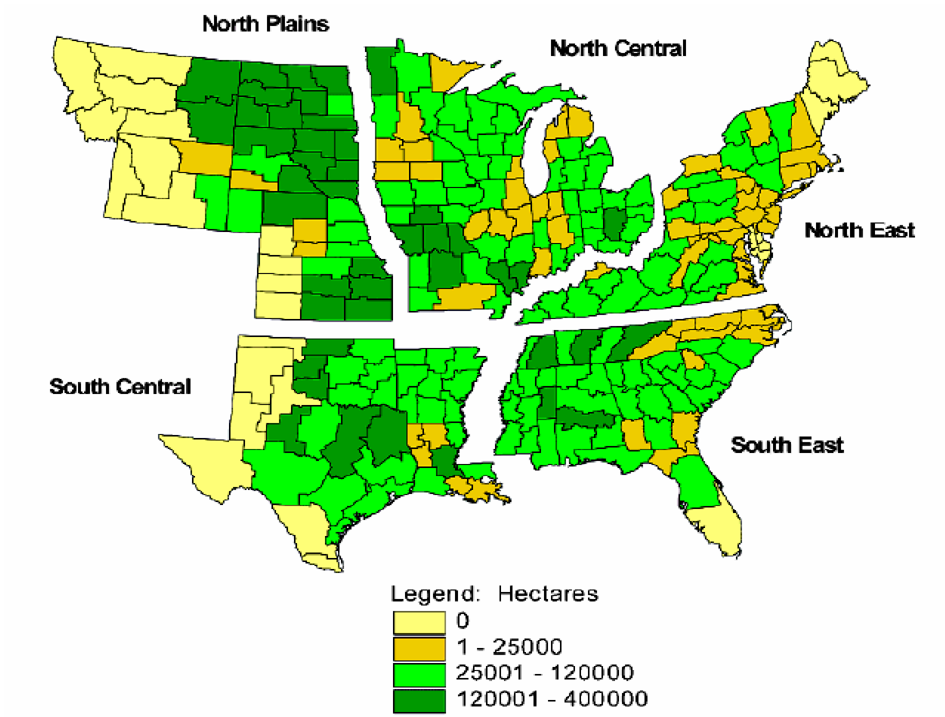
ENERGY/CARBON BALANCES FOR DME FROM COAL/ BIOMASS HYBRID WITH NEAR-ZERO GHG EMISSION RATE



- Hybrid can provide liquid fuel @ $1.0 - $1.2/gge by exploiting:
  - Low cost, abundance of coal
  - Negative emissions potential of biomass
- Can provide 2.3 X as much liquid fuel with a near-zero GHG emission rate as conventional biofuel with CO_2 vented
- Can be established commercially during 2010-2015

BIOMASS FEEDSTOCK OPTIONS

- Agricultural/forest product industry residues in near term
  - DME from pulp and paper residues (*Sweden*)
  - Sugar cane in developing countries (*esp. Brazil*)
- Energy crops—e.g., switchgrass in Great Plains—for longer-term



Source: McLaughlin et al., 2002: High-value renewable energy from prairie grasses, *Envir. Sci.& Tech.*, **36** (10): 2122-2129

This study projects that if the market valued switchgrass at current average farm-gate cost ($44/t), 41 million acres would be converted to switchgrass.

Delivered cost of switchgrass is high with current technology ~ $3. 1 per million BTU (*~ 2.5 X coal price for US power plants*)

SCENARIO FOR DME FROM COAL/SWITCHGRASS

- Make DME + decarbonized electricity from US switchgrass/coal with:
  - DME used in 52 mpg_{ge} fuel-efficient (*e.g.*, *hybrid-electric*) Diesel-type cars
  - Decarbonized electricity displaces coal steam-electric plants
- Primary energy inputs:
  - switchgrass (*farmgate price = $44/t*, *today's technology*) on 41 x 10^6 acres (*equivalent to 1.35 X land idled under Conservation Reserve Program*)
  - New coal = 18% of coal for US power, 2002
- DME would fuel 130 x 10^6 cars
  - Plant-gate DME cost ~ $1.0 to $1.2 a gge
  - ~ 1/10 GHG emission rate per car of today's average gasoline car
  - Oil import reduction ~ 5.6 million barrels/day (*53% of imports, 2002*)
- Decarbonized power for 37% of coal power generation, 2002
- Reduce GHG emissions by 26% of US CO_2 emissions, 2002
- CO_2 storage rate ~ 1 billion tonnes CO_2/year

CONCLUSIONS

- It is feasible to make a major contribution in addressing challenges posed by the automobile—*in this Qtr century*—via production/use of designer synfuels from coal/biomass with CCS
  - Major technical uncertainty is "gigascale" viability of CO_2 storage—many more "megascale" CO_2 storage demos needed…soon
  - Biomass gasification technology must be demonstrated and commercialized …new Swedish biomass synfuel test facility at former biomass gasifier combined cycle demo site
  - Synfuel plants with CCS must be demonstrated…but radical new technologies not needed
- Carbon mitigation policy needed to drive technology adoption
- Institutional/cultural challenges:
  - Overcoming widespread ill feelings about coal synfuels—costly synfuels failures of late 1970s-early 1980s
  - Ambitious automotive efficiency improvements
  - Coalition-building for proposed strategy—across multiple industries and involving international collaborations (*e.g., among Australia, Brazil, China, US*)


BIG COAL
GRO MOR
CARS R US
BIG OIL

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