Low-GHG Hydrocarbon
“Biofuels” Using Less Biomass

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Today’s Talk

• Role for bioenergy in mitigating climate change.
• Gasification-based technology for making hydrocarbon biofuels.
• Biofuels co-production with pulp and paper
• Co-processing of biomass with coal and using CO₂ capture and storage to co-produce low-GHG fuels and electricity.
• Wrap-up
Atmospheric CO$_2$ Since 900 AD

- South pole
- Siple
- D47 en D57 (Adelie land)
- Mauna Loa, Hawaii
- DE08 en DSS (Antarctica)
Atmospheric CO₂ Since 900 AD
A “wedge” is a strategy that (a) reduces carbon emissions, with reduction growing from 0 to 1 GtC/yr over 50 years, and (b) is already demonstrated at scale somewhere.
15 Wedges (Among Others)

Source: Socolow and Pacala, Scientific American, September 2006, p.54

Biofuels
Transportation Services from Biomass Per Hectare

- Dimethyl ether, lignocellulose (future)
- Fischer-Tropsch, lignocellulose (near future)
- Methanol, lignocellulose (near future)
- Ethanol, lignocellulose (further future)
- Ethanol, lignocellulose (future)
- Ethanol, lignocellulose (near future)
- Ethanol, sugarcane (Brazil)
- Ethanol, sugar beets (Netherlands)
- Ethanol, wheat (Netherlands)
- Ethanol, maize (USA)
- Biodiesel, rape (Netherlands)

1000 vehicle-km per hectare per year
Gasification-Based Hydrocarbon Biofuels

Fischer-Tropsch Liquids (FTL)
- Synthetic crude refinable to zero-sulfur, high-cetane, low-particulate diesel blendstock, jet fuel blendstock, and gasoline blendstock.
- Large global investments in gas-to-liquids GTL (e.g., Malaysia, Qatar, Nigeria)
- Growing investments in coal-to-liquids, CTL (China, USA).
- Demonstration interest in biomass-to-liquids, BTL (Germany, Finland, US)

Dimethyl Ether (DME) (first cousin of methanol)
- Propane substitute/blendstock or zero-S, zero-PM, high-cetane diesel fuel.
- Huge commercial investments in DME and methanol from coal in China;
- Swedish demonstration of DME from biomass at pulp mill. Volvo DME trucks.

Synthetic gasoline (via methanol, MTG)
- 1st commercial plant operated in New Zealand (natural gas feed) for about a decade starting in 1985. (ExxonMobil synthesis technology.)
- Renewed interest globally, including projects in China (1 demonstration operating and additional projects announced) and in US (e.g., DKRW coal-to-MTG project in Wyoming).
Gasification-Based Fuels and/or Electricity Production

Low value feedstocks

Gasification

Gas Cleanup

High-Value Products

Oxygen

Coal
Pet Coke
Oil Residue
Biomass
Wastes

CO₂ Storage

WGS: CO + H₂O → H₂ + CO₂

H₂S Removal

CO₂ Removal

SULFUR RECOVERY

Clean Syngas (H₂ + CO)

Combined Cycle Power Block

Gas & Steam Turbines

Electricity
Steam

Marketable Byproducts:

Sulfur
Slag

FT diesel
Methanol
DME
Gasoline etc.

H₂O

Coal, H₂, H₂S, H₂O, CO₂

CO, H₂, H₂O, CO₂
U.S. Kraft Pulp/Paper Industry

• Uses >1.5 quads/yr bioenergy, mostly black liquor.
• Needs new technology to stay globally competitive.
• Aging black liquor boiler fleet provides window of opportunity for introducing gasification.
• BL gasification being commercialized in Sweden.
Kraft Pulping Process

1 t wood logs

WOOD DEBARKING, CHIPPING

0.09 t hog fuel

HOG FUEL BOILER

0.91 tons wood chips

WOOD DIGESTORS

black liquor

PULP WASHING

black liquor

BLACK LIQUOR EVAPORATORS

steam

STEAM TURBINE

steam

Steam extracted for process use

STEAM TURBINE

steam

Steam extracted for process use

electricity for process use

LIME KILN

CaCO_3 + heat \rightarrow CaO + CO_2

black liquor

white liquor (Na_2S, NaOH, CaCO_3 [dead load])

smelt (Na_2S, Na_2CO_3)

black liquor makeup CaO

Na_2CO_3 + CaO + H_2O \rightarrow 2NaOH + CaCO_3

0.42 t pulp to paper

electricity for process use
DME Production at a Pulp Mill

Pressurized, high-temperature, oxygen-blown (Chemrec) black liquor gasifier is near commercially ready:

- Pilot-scale (20 tpd BLS) pressurized gasifier tests in Sweden since mid-2006.
- Demonstration of DME from black liquor initiated in 2010 @ 4 t/day (38 bbl/d) capacity.

Effective Liquid Fuel Yields

Gallons of Ethanol Equivalent per Dry Tonne Biomass

- Black liquor (and some woody biomass) are charged against services provided to the mill (chemical recovery, process steam and power) – not against liquid fuel.
- A biorefinery integrated with a pulp mill effectively requires much less biomass per unit of liquid fuel produced vs. “stand-alone” biofuel production.

Different fuel:electricity co-production ratios.

Gallons of Gasoline Equivalent per Dry Tonne Biomass
$280 million incremental capital investment (process configuration DMEb) (2005$)
$78/bbl crude oil scenario
Electricity sale price: 5.2 c/kWh (without incentives)
Incentives examined:
  - Excise Tax Credit (ETC): Equivalent to existing (in 2006) $0.51/gal for ethanol on energy basis.
  - Investment Tax Credit (ITC): 20% gasification tax credit (under EPAct 2005).
  - Production Tax Credit (PTC): $9/MWh for 10 years (on incremental electricity relative to Tomlinson).
  - Renewable Energy Credit (REC): $20/MWh (e.g., under RPS or green credits). Applies only to incremental electricity.
  - CO₂ Credits: $25/ton CO₂ applied to net reductions (including grid offsets and petroleum displaced)
Pulpmill-Integrated Biofuel Production

• Pulpmill-integrated N\textsuperscript{th}-plant biorefinery efficiency and economics are favorable due largely to integration → capital and fuel shared with mill.

• Most technology components are already commercial (in other industries); gasification is not yet, so there are risks for the 1\textsuperscript{st} or 2\textsuperscript{nd} full-scale biorefinery.

• U.S. pulp/paper industry has the potential to produce >14 billion gallons per year (ethanol equivalent) of hydrocarbon fuels – comparable to corn ethanol industry output today.
Coal-to-Liquids (CTL)

- There is intense commercial interest in coal-to-liquids (CTL), especially 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 for CTL can be reduced to same level as for petroleum fuels.
  
  ☹️ not good enough (especially for U.S.) to stabilize CO$_2$. 
GHG-Friendly Biofuels from Coal (?)

Co-processing coal and biomass with CCS

• Offsets GHG emissions from coal-to-liquids (CTL) by “negative” emissions from underground storage of photosynthetic CO₂.
• Is feasible with gasification-based systems:
  – One commercial plant co-gasifies coal and biomass for power generation (Buggenum, The Netherlands).
  – Several coal/biomass gasification projects are proposed.
• Enables coal conversion capital cost scale economies to be exploited by biomass
• Reduces average feedstock costs compared with a biomass-only system.
• Enables higher yield of low-GHG liquid fuel per unit of biomass converted than when making a “pure” biofuel.
Coal-to-Liquid (CTL)

Carbon Flows

- Vehicle tailpipe
- Flue gases
- Coal upstream emissions
- Fuel
- Char
Coal-to-Liquid (CTL) with CCS

Coal upstream emissions

vehicle tailpipe

flue gases

coal

CO$_2$ storage

fuel

Coal-to-Liquid (CTL) with CCS
Biomass-to-Liquid (BTL) with CCS

- Photosynthesis
- Biomass
- Vehicle tailpipe
- Flue gases
- Biomass upstream emissions
- CO₂ storage
- Char
Coal/Biomass-to-Liquids (CBTL) with CCS
Includes emissions from coal & biomass production, FTL production, and FTL use in vehicle
Why Co-Production?

- Energy efficiency gain relative to producing fuels and electricity in separate facilities.
- Low CO$_2$ capture cost compared to CO$_2$ capture for stand-alone power plants.
- Credit for co-product sales.
- Better economics than separate production under a variety of conditions.
CO$_2$ Storage

• Goal: store 100s to 1000s of gigatons CO$_2$ for 100s to 1000s of years.

• Major possible options are storage in:
  – Deep ocean
  – Carbonate rocks
  – Geological media
    • Enhanced oil recovery (*used today*)
    • Depleted oil and gas fields (*geographically limited*)
    • Beds of unminable coal (*CO$_2$ adsorbed in pore spaces*)
    • Deep (> 800 m depth) saline aquifers (*aquifers underlie an area = ½ the area of inhabited continents: 2/3 on-shore 1/3 off-shore*)
IPCC Special Report on CCS* -- Main Messages

• IPCC is:
  – positive on geological storage
  – not so positive on ocean storage or mineralization

• 66-90% \textit{(high)} probability that worldwide geological storage capacity is at least 2000 Gt CO$_2$
  – \textit{For comparison, fossil fuel emissions = 31 Gt CO$_2$ in 2010}

• Geological storage, fraction retained:
  – 90-99\% \textit{(very high)} probability retained fraction >99\% over 100 y
  – 66-90\% \textit{(high)} probability retained fraction >99\% over 1000 y

• CO$_2$ pipeline risks are comparable to, or less than, risks with hydrocarbon pipelines operating today

North Dakota/Saskatchewan

- The Great Plains Synfuel Plant in Beulah, ND, produces synthetic natural gas from lignite coal. A pure stream of CO$_2$ is produced as a byproduct.
- Online since 1984, the GPSP generates 10,500 t/day of nearly pure CO$_2$.
- Since 2000 the GPSP has sold 5000 tonnes of CO$_2$ per day in a 330 km pipeline to the Weyburn oil field in Saskatchewan, where it is injected for enhanced oil recovery and long-term underground storage.
CCS Projects Worldwide - 2011

http://www.sccs.org.uk/storage/globalsitesmap.html
Performance and cost analysis for 16 designs for FTL fuels production*

- Coal feedstock, biomass feedstock, coal + biomass feed.
- Range of fuel-to-electricity output ratios.
- CO₂ vented or captured/stored (mild or aggressive capture).
- Comparisons with cellulosic ethanol.**


\[ \text{GHGI} = \frac{\text{Lifecycle Plant Emissions}}{\text{Lifecycle BAU Emissions}} \]

BAU = Business-as-Usual = Electricity from Coal + Vehicle Fuels from Petroleum

Near-zero GHG emissions: hydrocarbon fuels + electricity.
• One unit of a “pure” biofuel, made thermochemically or biochemically, requires about the same amount of biomass feedstock.

• Co-processing biomass with coal to make a unit of zero-GHG liquid fuels requires $\frac{1}{2}$ to $\frac{1}{3}$ of the biomass required for “pure” biofuels.
• Replace switchgrass with mixed prairie grasses (MPGs) grown on carbon-depleted soils (see Tilman et al., Science, Dec. 2006.)

• Additional negative GHG emissions benefit of up to 0.6 tC per tC in harvested biomass, based on trials with 16 grass species in Minnesota.
Breakeven Oil Price vs. GHG Emission Price

- Coal price: $1.7/GJ
- Biomass price: $5/GJ (~$90/dry t)
- Plant capacity factor: 90%. Capital charge rate = 15%/yr.
- Electricity sale price: $60/MWh + CO₂ em charge (636 kgCO₂eq/MWh)

Graph shows the relationship between breakeven crude oil price and GHG emission price, with lines indicating different scenarios:

- CTL
- CTL-CCS
- CTL-vent
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BETTER ECONOMICS IF CO₂ WERE STORED VIA ENHANCED OIL RECOVERY
Levelized Cost of Electricity

GHG emissions price, $ per tonne of CO2eq

- - - Sup PC-V

Levelized Cost of Electricity, $ per MWh

Coal price = $1.86/GJ_{HHV}
Capital charge rate = 14.4%/yr
Biomass price = $5/GJ_{HHV}
Capacity factor = 90%
Coal price = $1.86/GJ$_{HHV}$
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Levelized Cost of Electricity

GHG emissions price, $ per tonne of CO2eq

- Sup PC-V
- CBTL-OT-CCS, $75/barrel
- CIGCC-CCS
- CBTL-OT-CCS, $100/barrel
- Sup PC-CCS

Coal price = $1.86/GJ_{HHV}
Capital charge rate = 14.4%/yr
Biomass price = $5/GJ_{HHV}
Capacity factor = 90%
Potential impact of CBTL on U.S. energy security and GHG emissions

• Future U.S. biomass availability ≈ 0.55 billion t/yr (NRC, America’s Energy Future, 2009)

• If all biomass were used in CBTL-CCS systems designed to maximize liquids output,
  • 5.9 million bbl/day transport fuels could be produced.
    ≈ U.S. domestic crude oil production.
    ≈ ½ of U.S. oil imports.
  • ~10% of current U.S. CO$_2$ emissions could be avoided.
Hurdles to a CBTL-CCS Industry

- Lack of confidence/demonstration of CCS at scale.
- Carbon emissions value not high enough to induce CCS as commercial activity.
- Optimum economics favor cross-industry alliances that have little historical precedent, e.g., collaboration of coal, ag, oil, and power industries.
- High cost of first few plants requires government incentives (justifiable on the basis of future public benefits.
- Some strongly object to continued coal use, especially for liquid fuels: mining impacts, “bait and switch”,...
Take-Home Messages

• As the only renewable carbon source, biomass has an especially important potential role to play in supply of low-GHG liquid transportation fuel.

• There are more and less land-efficient ways to utilize biomass for biofuels.

• Gasification-based biomass conversion systems integrated with existing industrial processes or that co-process coal and use CCS offer opportunities for major improvements in the effectiveness of using biomass for biofuels. (Co-production offers better economics than single-product facilities.)

• Challenges to implementation include the need for a greenhouse gas emission price and new institutional collaborations.
THANK YOU

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