Use of Sustainable Hydrogen to Produce Liquid Biofuels

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Goal

To provide transportation fuel sustainably
Biomass: Sustainable source of carbon but...

All US corn and soybean can meet only 12% of gasoline and 6% of diesel demand

Source. Hill et.al., PNAS, 103, 2006
Biomass: Sustainable source of carbon but...

All US corn and soybean can meet only 12% of gasoline and 6% of diesel demand

Therefore, one must use lignocellulosic mass to increase oil production.

Source. Hill et.al., PNAS, 103, 2006
Biomass to Synthetic Oil by Conventional Gasification Route

O₂

Biomass → Drier and Gasifier → Syngas → WGS reactor → H₂/CO=2 → H₂-CO to Liquid reactor → H₂O → CO₂

Liquid Hydrocarbon Fuel → 24 HR Diesel

Byproducts

Land area for 13.8 mbbl/d = 25-55% of the total US land area
Total US land area: 3.6 million mi²

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Currently Biomass alone can not supply all the liquid fuel for the US transportation sector
For H$_2$- economy to eventually get fully implemented:

- H$_2$ must be economically produced from a carbon-free energy source: Solar, Nuclear etc
- H$_2$ storage challenge must be met
- Fuel cell cost must be reduced
- A hydrogen infrastructure for distribution and dispensing must be built
Solution

Partnership between Biomass and $H_2$ from Carbon-free energy source
A Novel Biomass and H\textsubscript{2} from Carbon-free energy source partnership

A Hybrid Hydrogen-Carbon (H\textsubscript{2}CAR\textsuperscript{TM}) Economy!

Agrawal et.al., PNAS, 104, 2007
H₂CAR™ economy

- Biomass primarily supplier of carbon atoms
- H₂ from a sustainable carbon-free source
- H₂ converts every carbon atom to liquid fuel
- No release of CO₂ during conversion process
- CO₂ release only at end use
- A solution to store H₂ as a high density fuel
- A sustainable open-loop cycle for carbon

Agrawal et.al., PNAS, 104, 2007
A Novel H₂CAR™ Process

Biomass $\rightarrow$ Oxygen $\rightarrow$ Gasifier $\rightarrow$ Syngas $\rightarrow$ Carbon-free Energy source

$\rightarrow$ Syngas $\rightarrow$ H₂-CO Recycle $\rightarrow$ Liquid Hydrocarbon Fuel $\rightarrow$ Byproducts

Unreacted H₂, CO Recycle $\rightarrow$ CO₂ Recycle $\rightarrow$ CO₂

Energy source

H₂ - CO to Liquid reactor $\rightarrow$ H₂O

Agrawal et al., PNAS, 104, 2007
Production of 13.84 million bbl/d of synthetic oil using Biomass

Future Case\(^1\):
Gasifier Efficiency = 70%
Biomass growth rate = 1.5 kg dry mass/m\(^2\)/yr

<table>
<thead>
<tr>
<th>Case</th>
<th>Land area (million (\text{mi}^2))</th>
<th>Required (\text{H}_2) (Billion kg/yr)</th>
<th>Carbon Efficiency (%)</th>
<th>Energy Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Biomass</td>
<td>(\text{H}_2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>0.98</td>
<td>0</td>
<td>0</td>
<td>36.7</td>
</tr>
<tr>
<td>(\text{H}_2\text{CAR}^\text{TM})</td>
<td>0.36*</td>
<td>0.018*</td>
<td>239</td>
<td>~100</td>
</tr>
</tbody>
</table>

*Needs only 10% of the US land area or half of current cropland area!

Currently available: 700,000 \(\text{mi}^2\) cropland, 900,000 \(\text{mi}^2\) pasture land

\(^1\) NRC \(\text{H}_2\) Report
Billion ton annual biomass study\(^1\)

Estimate of total dry biomass available = 1.366 billion tons/year

<table>
<thead>
<tr>
<th>Case</th>
<th>(H_2) requirement (billion kg/yr)</th>
<th>Oil production as % of 13.8 mbbl/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>-</td>
<td>~30</td>
</tr>
<tr>
<td>(H_2)CAR(^TM)</td>
<td>238</td>
<td>~100</td>
</tr>
</tbody>
</table>

Gasifier Efficiency = 70%

\(^1\) Perlack et. al. The technical feasibility of a billion ton annual supply (2005)
Effect of Biomass growth rate on land area

Gasifier Efficiency = 70%
Total US land area = 9.2 million km²
Energy source for a barrel of oil

Gasifier Efficiency = 70%

<table>
<thead>
<tr>
<th></th>
<th>Biomass (MJ)</th>
<th>Hydrogen (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>8779</td>
<td>-</td>
</tr>
<tr>
<td>( \text{H}_2\text{CAR}^{\text{TM}} )</td>
<td>3193</td>
<td>3799</td>
</tr>
</tbody>
</table>

Large amount of \( \text{H}_2 \) can be potentially stored
Effect of PHEVs on land area

Agrawal et al., PNAS, 104, 2007
Why Concept Works?
Problems with current gasification processes

Carbon efficiency of 30-40% results in large land area requirements
How 60-70% carbon is lost in biomass case?

Syngas composition normalized to 100 moles carbon in biomass

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2$</td>
<td>47</td>
</tr>
<tr>
<td>$\text{CO}$</td>
<td>47</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>53</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>88</td>
</tr>
<tr>
<td>$T$ (°C)</td>
<td>1100-1300</td>
</tr>
<tr>
<td>$\text{H}_2/\text{CO}$</td>
<td>1</td>
</tr>
</tbody>
</table>

To obtain $\text{H}_2/\text{CO}=2$, additional 16 $\text{CO}_2$ are lost due to WGSR $\text{CO}+\text{H}_2\text{O}=\text{CO}_2+\text{H}_2$

Additional losses occur in FT reactor
Efficiency for H$_2$ production is at least 10 times greater than that of biomass growth.
H$_2$CAR$^\text{TM}$ Process is Sustainable

Entire US transportation sector can be potentially supported

- With manageable land area
- Much higher carbon efficiency
- Higher energy efficiency

Sustainable addiction to “oil” ?
Advantages of Biomass H₂CAR™

- Crop Diversity (Biodiversity vs Monocultures)
- Tailor biomass to maximize carbon pickup
- Reduction in land area radius to support a plant
- Reduction in biomass storage space
- Reduced energy input
Advantages of Biomass H$_2$CAR™ (contd.)

- Decreased use of fertilizer and pesticides
- Decreased wear and tear to land
- Plausible use of carbonaceous municipal waste
- Synthesis of desired hydrocarbon molecules
- Large H$_2$ storage capacity
- Uses existing fuel infrastructure
Application of H$_2$CAR™ for coal to liquids
A Novel H₂CAR™ Process

Coal → Gasifier

CO₂ Recycle

Syngas

Unreacted H₂, CO Recycle

H₂-CO to Liquid reactor

H₂O

Liquid Hydrocarbon Fuel

Byproducts

Carbon-free Energy source

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Production of 13.84 million bbl/d of synthetic oil using coal as carbon source

Gasifier Efficiency = 75%

<table>
<thead>
<tr>
<th>Case</th>
<th>Amt of Coal (Billion ton/yr)</th>
<th>Required $H_2$ (Billion kg/yr)</th>
<th>$CO_2$ Sequestered (Gtc/yr)</th>
<th>Carbon Efficiency (%)</th>
<th>Energy Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>1.97</td>
<td>--</td>
<td>0.9</td>
<td>39.9</td>
<td>50.7</td>
</tr>
<tr>
<td>$H_2$CAR$^{TM}$</td>
<td>0.83</td>
<td>211.46</td>
<td>0</td>
<td>~100</td>
<td>65.2</td>
</tr>
</tbody>
</table>

No need for $CO_2$ sequestration!
Advantages: Longevity of Coal

- Life time of coal at current consumption rate 244 years
- It drops to 89 years if coal to liquids is used to supply transportation need
- \( H_2 \text{CAR} \) increases life time of coal from 89 years to 144 years
To Sum Up:

- Biomass alone can not sustain the entire US transportation sector
- Proposed a novel partnership between biomass and H₂ from carbon-free energy source
- H₂CAR™ Biomass process can potentially support entire US transportation sector
- An alternative for on-board H₂ storage no longer needed
- Existing fuel infrastructure can be used
- No need for CO₂ sequestration from coal
Acknowledgement

- Center for Coal Technology Research (CCTR)
- Energy Center at Purdue University
....Thank you