



# "Drop-in" transport fuels via hydrolysis of biomass An economic option for negative emissions?

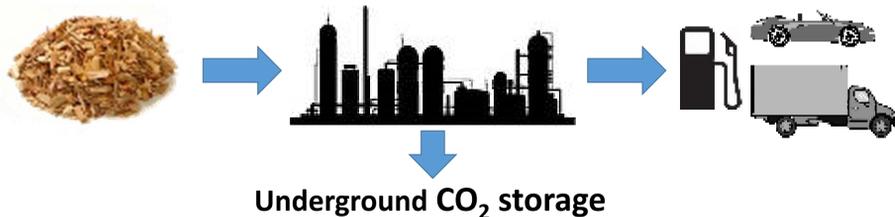
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Prepared for the 16<sup>th</sup> Annual Meeting of the Carbon Mitigation Initiative at Princeton University, 4-5 April 2017

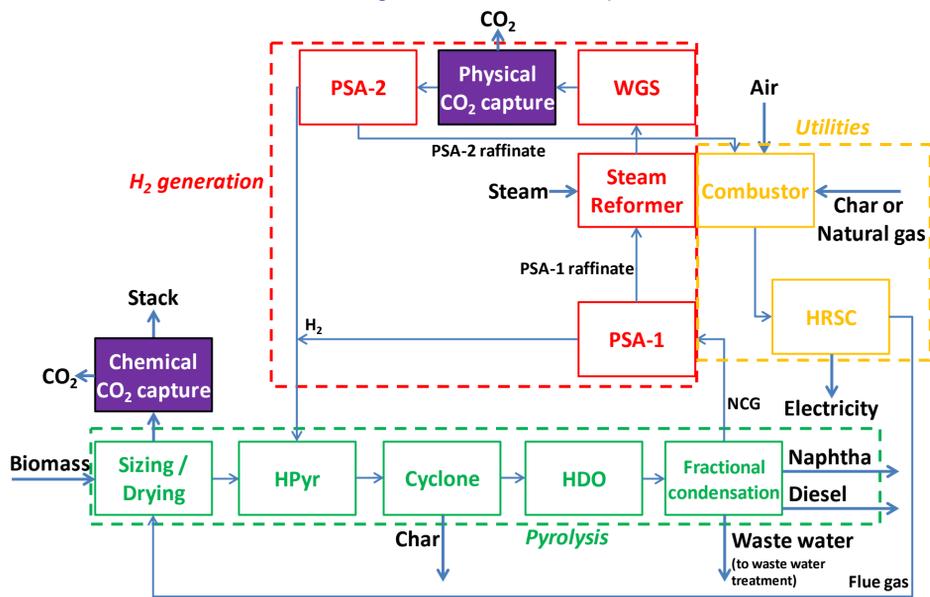
## INTRODUCTION

Fuels made from ligno-cellulosic biomass via catalytic pyrolysis in an H<sub>2</sub> atmosphere (catalytic hydrolysis) can be used to reduce net GHG emissions from the transportation sector. By integrating CO<sub>2</sub> capture and underground geological storage (CCS), CO<sub>2</sub> can effectively be removed from the atmosphere. This poster presents the results of a detailed assessment of the performance of a prospective first-of-a-kind (FOAK) commercial-scale catalytic hydrolysis facility converting woody residues into "drop-in" transportation fuels with and without CCS.



## CATALYTIC HYDROLYSIS

Catalytic hydrolysis involves heating biomass to about 400°C in a pressurized H<sub>2</sub>-fluidized catalyst bed. The biomass decomposes into solid char, condensable bio-oil components and non-condensable gases. The bio-oil components are separated into naphtha and diesel-like streams using fractional condensation. Final upgrading can be done in existing refineries to produce drop-in transportation fuels. The non-condensable gases are used to generate the H<sub>2</sub> consumed in the pyrolysis and hydrodeoxygenation (HDO) reactors. The char and residual gases can be combusted to supply process heat and generate electricity, or natural gas can be substituted for the char and the char might be landfilled to sequester carbon.



## PROCESS DESIGNS INVESTIGATED

We designed and simulated FOAK catalytic hydrolysis facilities processing 1 million t<sub>dry</sub> biomass per year. We investigated designs for three levels of CO<sub>2</sub> capture (no CO<sub>2</sub> capture, physical-absorption CO<sub>2</sub> capture and chemical-absorption CO<sub>2</sub> capture). For each of these, one set of process configurations was developed assuming the char is burned for energy and a second set was developed assuming natural gas (NG) is substituted for the char. The four red cases gave the most interesting results and are discussed in this poster.

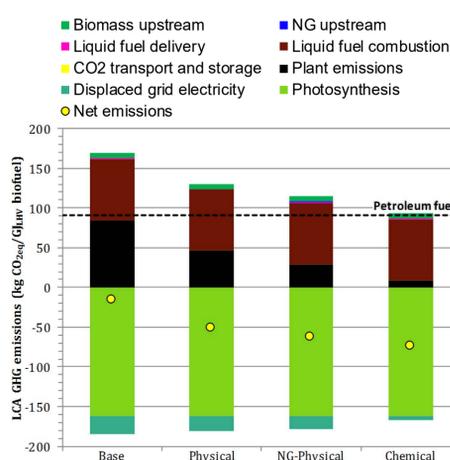
	Char is combusted	Char is sequestered
No CO <sub>2</sub> capture	Base	NG-Base
Physical CO <sub>2</sub> capture	Physical	NG-Physical
Chemical CO <sub>2</sub> capture	Chemical	NG-Chemical

## NET LIFECYCLE GREENHOUSE GAS EMISSIONS

With the **Base** configuration, sustainable photosynthetic uptake of atmospheric CO<sub>2</sub> exactly balances emissions of biogenic origin. Net lifecycle GHG emissions are slightly negative despite some emissions associated with upstream biomass activities (collection and transport) because exported electricity displaces some fossil fuel generated electricity from the grid.

Applying CCS results in greater negative GHG emissions, with the largest negative emissions achieved with the **Chemical** design.

The lower carbon intensity per unit energy of NG compared with char accounts for the slightly lower net emissions in the **NG-Physical** configuration than in the **Physical** configuration.



## PERFORMANCE ESTIMATES

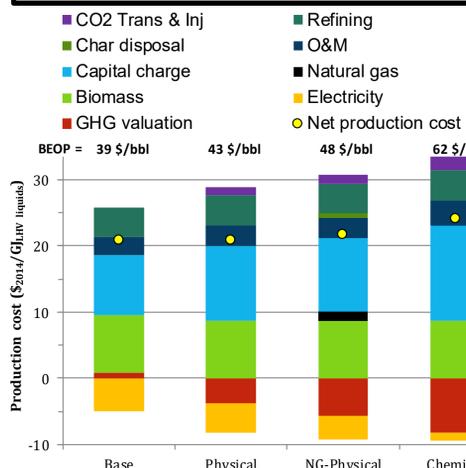
The simulated catalytic hydrolysis converts 1 t<sub>dry</sub> woody residue into 2.2 barrels of liquid transport fuels, preserving 65% of the chemical energy in the biomass.

This yield corresponds to 144 gal EtOH<sub>eq</sub>/short ton<sub>dry</sub> woody biomass, which compares favorably with 80-90 gal EtOH<sub>eq</sub>/short ton<sub>dry</sub> for fuels production via gasification (i.e., FT synthesis) or via a biochemical route (i.e., cellulosic EtOH).

Electricity exports are lower when CCS is employed. The reduction is relatively small when using physical CO<sub>2</sub> capture compared with chemical capture due to the smaller amount of CO<sub>2</sub> captured and the lower utility demands with the former.

	Base	Physical	NG-Physical	Chemical
<b>Input (MW LHV)</b>				
Biomass	687	687	687	687
Natural gas			99	
<b>Output (MW LHV)</b>				
Hydrocarbons	446	446	446	446
Electricity	55	48	39	13
Char			131	
<b>Efficiency (-)</b>				
Liquid eff.	65%	65%	57%	65%
Total eff.	73%	72%	78%	67%
<b>Input (t C/hr)</b>				
Biomass	71	71	71	71
Natural gas			5	
<b>Output (t C/hr)</b>				
Hydrocarbons	34	34	34	34
Char			13	
Captured		17	17	34
Emitted	37	20	13	4

## ECONOMIC ASSESSMENT



Detailed capital and operating cost estimates were made for FOAK facilities.

Our estimated break-even oil price (BEOP) for a facility with the **Base** design is < 100 \$/bbl in the absence of any GHG emissions valuation.

Adding CCS to a facility becomes interesting economically with a sufficiently high GHG emissions valuation. At 120 \$/t CO<sub>2,eq</sub> the BEOP for the **Physical** design is 28 \$/bbl and equals the BEOP for the **Base** design.

The **Chemical** design needs a much higher GHG emissions valuation to be competitive due to the much higher capital cost and energy-performance penalties.

## TECHNOLOGY STATUS

Catalytic hydrolysis is not yet a commercial technology. Our simulations were calibrated using experimental data from a 50 kg/d pilot plant. A 5 t/d demonstration facility is currently under construction in Bangalore, India by Shell India, a subsidiary of Royal Dutch Shell.

## CONCLUSIONS

- Catalytic hydrolysis has higher yields of liquid transportation fuels from ligno-cellulosic biomass compared with other biofuel pathways.
- Incorporating CCS into process designs provides fuels with strongly negative carbon footprints.
- Economics appear attractive for a first-of-a-kind (FOAK) facility without CCS when oil prices are less than 100 \$/bbl.
- Because of negative carbon footprints, break-even oil prices (BEOP) in the presence of a GHG emissions valuation are considerably lower: with a 100 \$/t CO<sub>2,eq</sub> emissions price the BEOP is below 50 \$/bbl for a FOAK facility in all designs investigated except the **Chemical** design.
- While prospective economics of biofuels produced via catalytic hydrolysis are favorable, demonstrations at scale are required to verify these results.

For details, see Meerman, J.C. and Larson, E.D. "Negative-carbon drop-in transport fuels produced via catalytic hydrolysis of woody biomass with CO<sub>2</sub> capture and storage", *Sustainable Energy and Fuels*, in press (April 2017).

## SPONSORS

