Sustainable Biofuels – A Small Step towards Carbon Management

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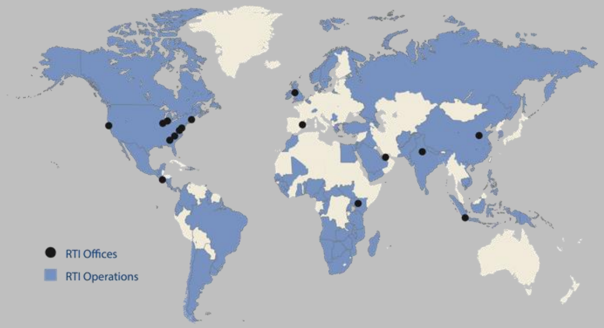
RTI International

Turning Knowledge Into Practice



One of the world's leading research organizations

3,700 staff
Work in 75 countries

1,800+
Active RTI projects

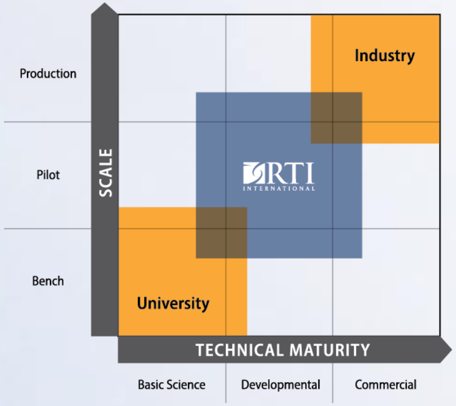
scientific staff
Highly qualified with tremendous breadth

$730 m
Research budget

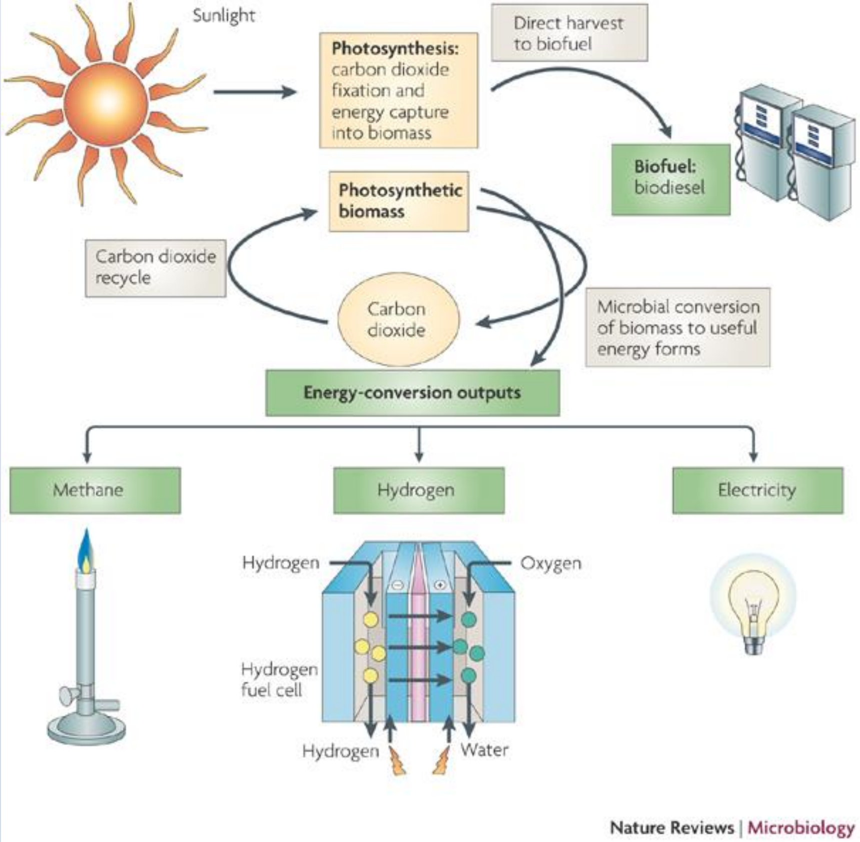
Energy Technologies

Developing advanced process technologies for energy applications by partnering with industry leaders

- Syngas
- Natural Gas
- Carbon Capture
- Industrial Water
- Biofuels

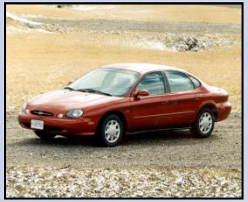


Photosynthesis - Biomass Production



The Challenge - Transportation Fuels

Gasoline (cars & trucks)



140 bgy

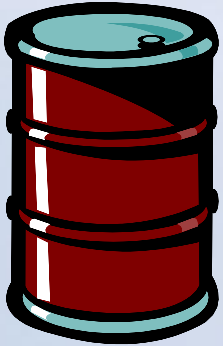
Diesel (on-road, rail)

43 bgy

Aviation (jet fuel)

25 bgy

19.5 MM barrels/day



71% for Transportation

Annual Transportation Fuels Use (2008)

Energy Independence and Security Act of 2007

- Raised CAFE fuel efficiency standards for cars to 35 mpg by 2020❖
- Minimum standard of 27.5 mpg for domestic passenger vehicles
- Set new efficiency standards for electric household devices (appliances, battery chargers, freezers, motors, light bulbs, etc.)
- **Established a new renewable fuel standard:**
  - **9 billion gallons/yr in 2008**
  - **36 billion gallons/yr by 2022, of which 21 billion gallons must be cellulosic**
  - **Biofuels must deliver a 20% lifecycle greenhouse gas reduction**

Biomass to biofuels -- a complex supply chain

Biomass-to-Biofuels Supply Chain Source

EERE Office of Biomass Program 2007 Multi-Year Program Plan

Feedstock Supply → *Feedstock Logistics* → *Biofuel Production* → *Biofuels Distribution* → *Biofuels Utilization*

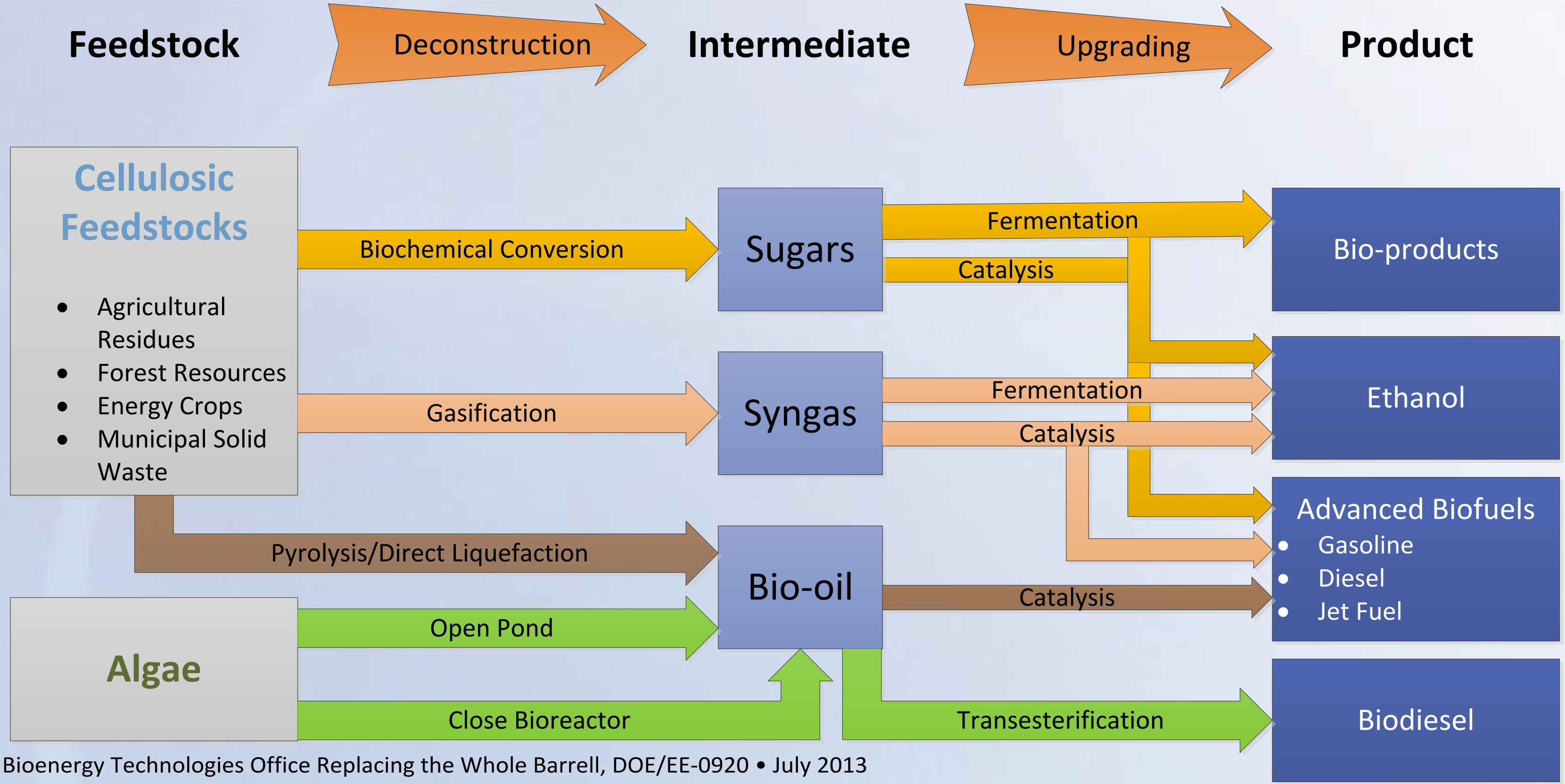
- *Agricultural Residues – corn stover, cereal straws*
- *Energy Crops -Woody and Perennial Herbaceous*
- *Forest Resources - Existing and Repurposed Pulp and Paper and Forest Products Mills*
- *Industrial and Other Wastes*
- *Algae*

- *Biochemical*
- *Thermochemical*
  - *Gasification*
  - *Pyrolysis*
- *Hydrothermal/Liquifaction*
- *Aqueous Phase Processing*

- *Bulk Distribution Infrastructure*
- *Retail Marketing Network*
- *Vehicles*

- Technology Development and Deployment
  - Engineering
  - Economics
  - Risk Management
- Other Considerations
  - Sustainability
  - Water
  - Greenhouse Gas Emissions
  - Policy and Regulatory
  - Mandates/subsidies
  - Financial Markets

Biofuels Technology Pathways



Source: Bioenergy Technologies Office Replacing the Whole Barrell, DOE/EE-0920 • July 2013

Biochemical Conversion

Feedstock Supply → Pretreatment/ Deconstruction → Hydrolysis → Sugars & Intermediates → C6/C5 Fermentation → Product Recovery (distillation) → Ethanol Butanol

C6/C5 Fermentation → CO_2

Sugars & Intermediates → Residual Lignin → Boiler → Heat & Power

Feedstock Supply
- Agricultural Residues
- Woody Biomass
- Grasses/Straws

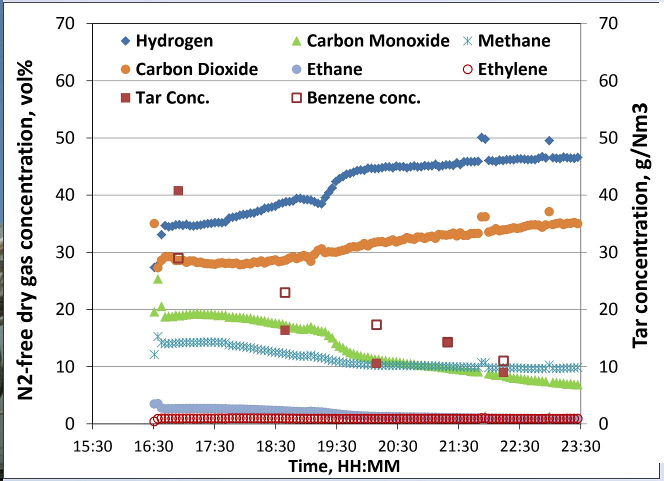
Pretreatment/Deconstruction
- Concentrated or dilute acid
- Ammonia Fiber Expansion (AFEX)
- Warm or Hot Water Washing

Hydrolysis
- Enzymatic
- Catalytic

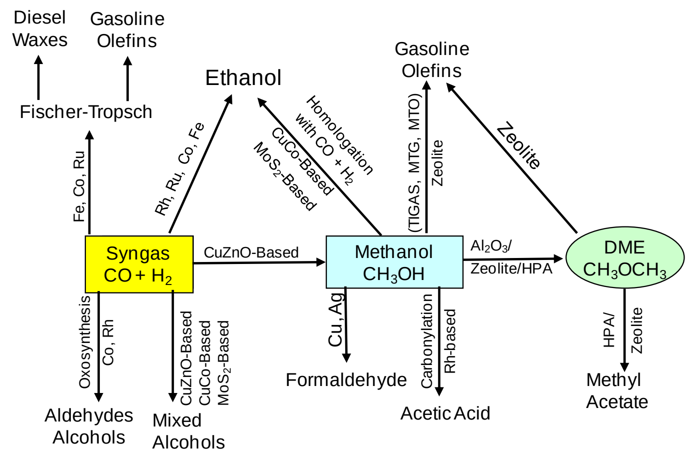
Thermochemical Conversion - Gasification

Feed Processing & Handling → Biomass Gasification → Syngas Cleanup → Syngas Conditioning → Catalytic Fuel Synthesis → Advanced Biofuels

http://images.nrel.gov/viewphoto.php?imageId=6312561



Indirect Biomass Gasification in a 50 kg/hr bubbling fluid bed gasifier

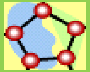


Catalytic Syngas Conversion to Fuels and Chemicals

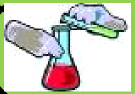
Syngas Utilization

Clean Syngas

H_2, CO, CO_2



Building Blocks for Fuels and Chemicals



Chemicals

Chemical Looping

$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$

$3FeO + H_2O \rightarrow Fe_3O_4 + H_2$

Hydrogen

Methanation

$CO + 3H_2 \rightarrow CH_4 + H_2O$

Methane (SNG)

Methanol Synthesis

$CO + 2H_2 \rightarrow CH_3OH$

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

$CO + H_2O \rightarrow CO_2 + H_2$

Transportation Fuels

Fischer-Tropsch Synthesis

$2nH_2 + nCO \rightarrow (-CH_2-) + nH_2O$

Gasoline and Diesel

Mixed Alcohol Synthesis

$2nH_2 + nCO \rightarrow C_nH_{2n+1}OH + (n-1)H_2O$

Ethanol and Gasoline Additive

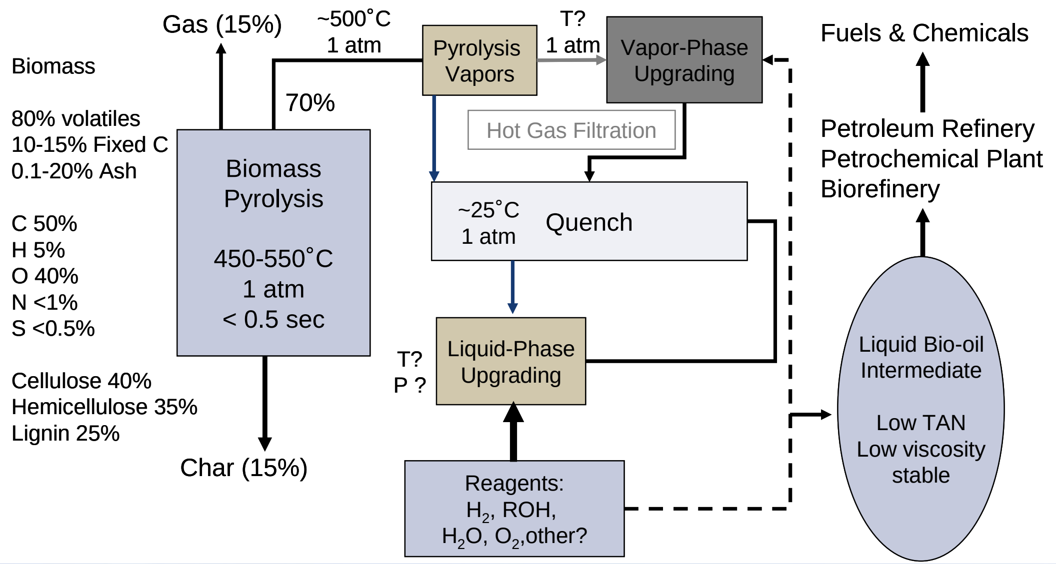
Dimethyl Ether Synthesis

$2CH_3OH \rightarrow CH_3OCH_3 + H_2O$

LPG and Diesel Fuel

LPG and Gasoline

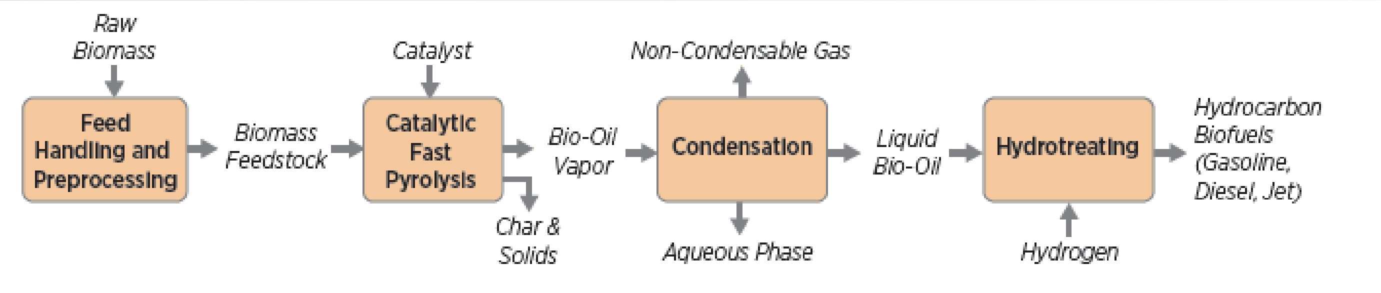
Thermochemical Conversion – Pyrolysis



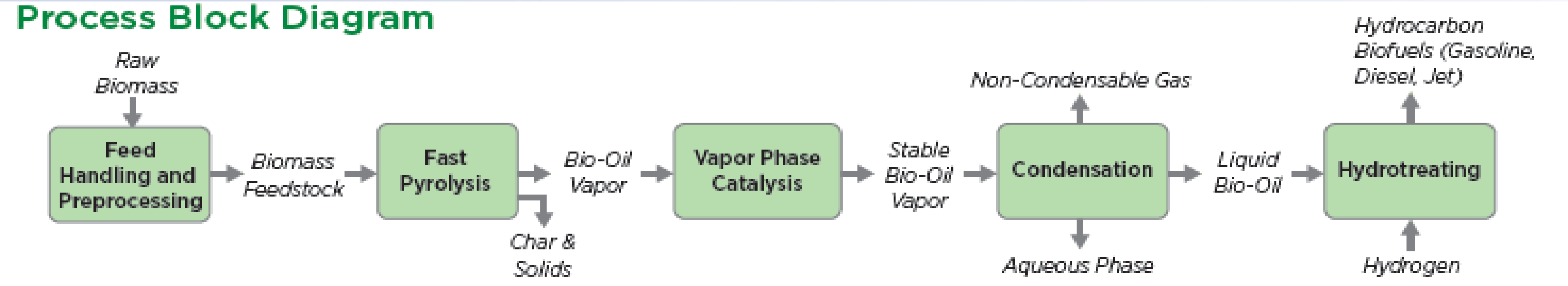
	Biomass (White Oak)	Baseline Bio-Oil	Baseline Char
Proximate Analysis (wt %)			
Volatile Matter	77.80	89.13	25.50
Fixed Carbon	18.06	10.92	68.02
Ash	0.38	0.05	4.22
HHV (BTU/lb)	7940	7082	11962
Ultimate Analysis (wt%)			
C	47.95	41.17	75.37
H	6.06	7.48	3.25
O	45.50	51.19	16.88
N	0.10	0.09	0.26
S	0.01	0.01	0.02
Ash	0.38	0.05	4.22

Catalytic Fast Pyrolysis Technology Options

In-situ



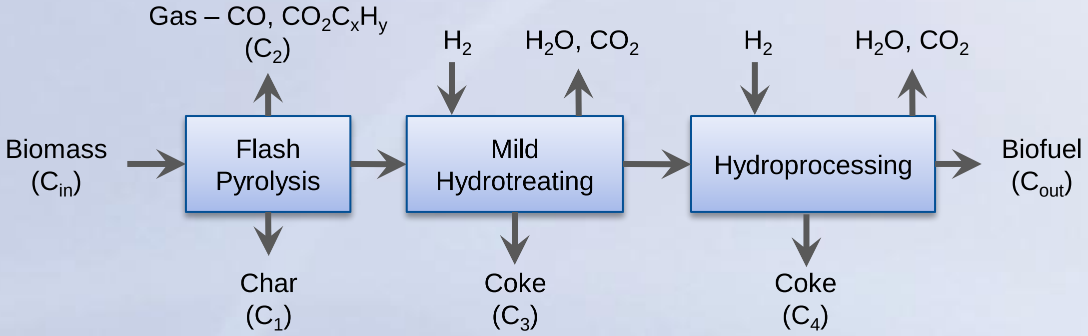
Ex-situ



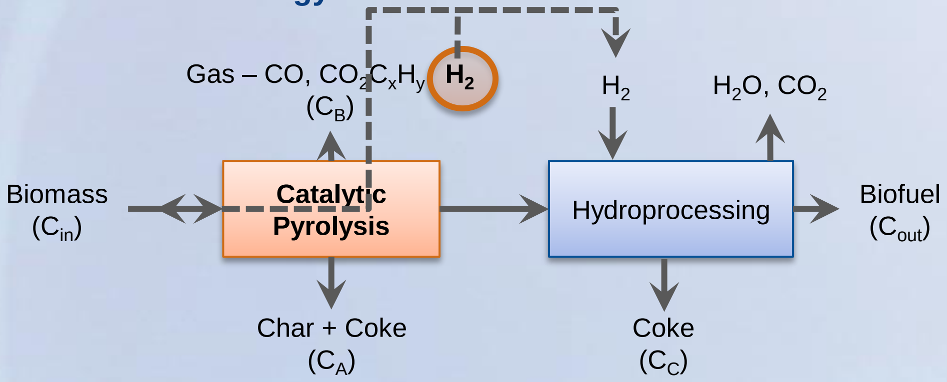
- Cost target: \$3.00 gal^{-1} by 2022
- Largest cost contributors: feedstock and capital
- Technology is much less developed than pyrolysis/hydrotreating
- Diesel and Jet fuels are more desirable.

Catalytic Biomass Pyrolysis State-of-Technology

Current State-of-the-Art



RTI's Translational Technology



Primary Technical Objectives

- Maximize biofuel output
- Minimize external H_2 consumption
- Reduce process complexity
- Maximize heat integration

Technical Barriers to Overcome

- Utilize H_2 produced *in-situ*
- Reduce oxygen content of biocrude
- Improve bio-crude thermal stability to maximize energy recovery
- Minimize coke formation
  - $C_B < C_2$
  - $C_A << C_1+C_3$
  - $C_C \approx C_4$

Catalytic Upgrading of Biocrude Intermediates to Hydrocarbons

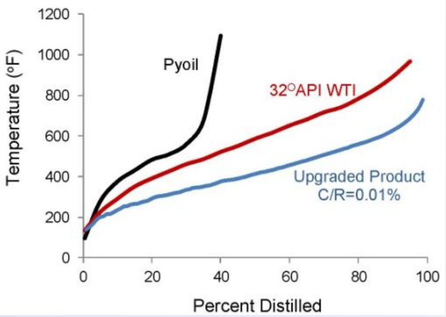
Feedstocks
Woody biomass
Switchgrass
Corn Stover

→ **Conversion Technology**
Catalytic Biomass Pyrolysis

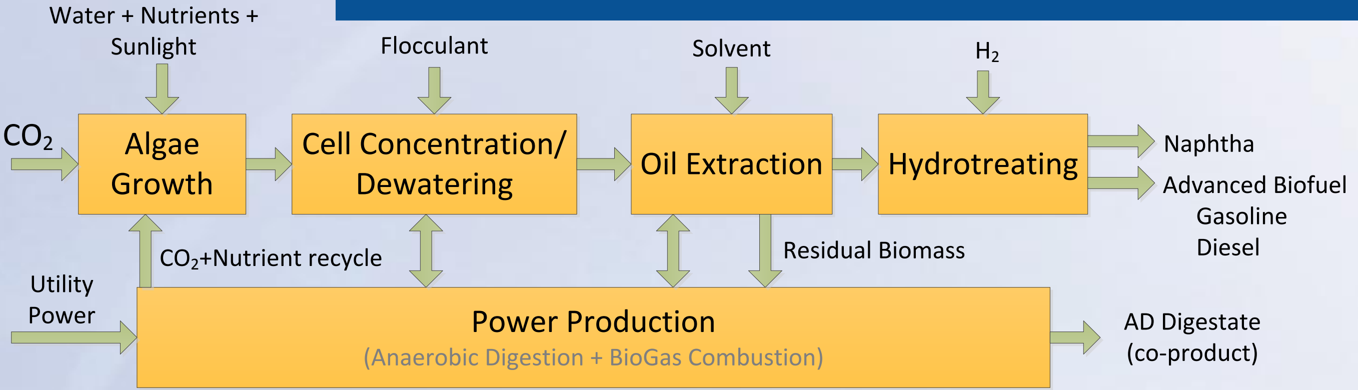
→ **Upgrading Technology**
Hydroprocessing

→ **Advanced Biofuels**
Diesel (F-76)
Jet Fuel (JP-5, JP-8)

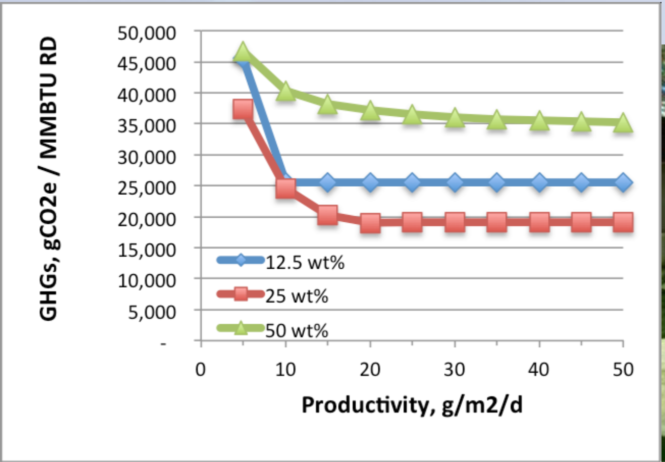
- Integrate novel catalytic biomass pyrolysis step with hydroprocessing step
- Optimize the catalytic biomass pyrolysis process to achieve high degree of deoxygenation, while maximizing the bio-crude yield
- Improve bio-crude thermal stability
- Evaluate the impact of bio-crude quality in the hydroprocessing step
- Minimize hydrogen demand of the integrated process and maximize biofuels yields
- Leveraging $4.0 M DOE/EERE funding to develop, design and operate small integrated pilot system

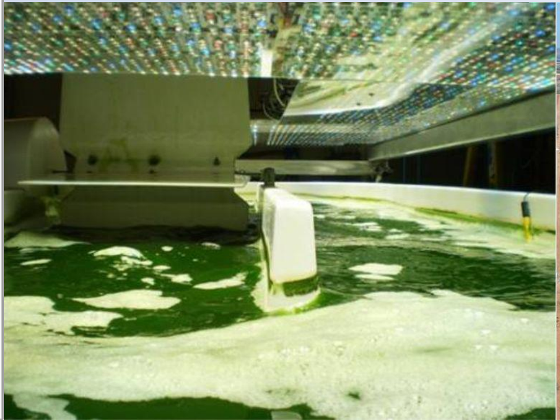


Algal Biofuels



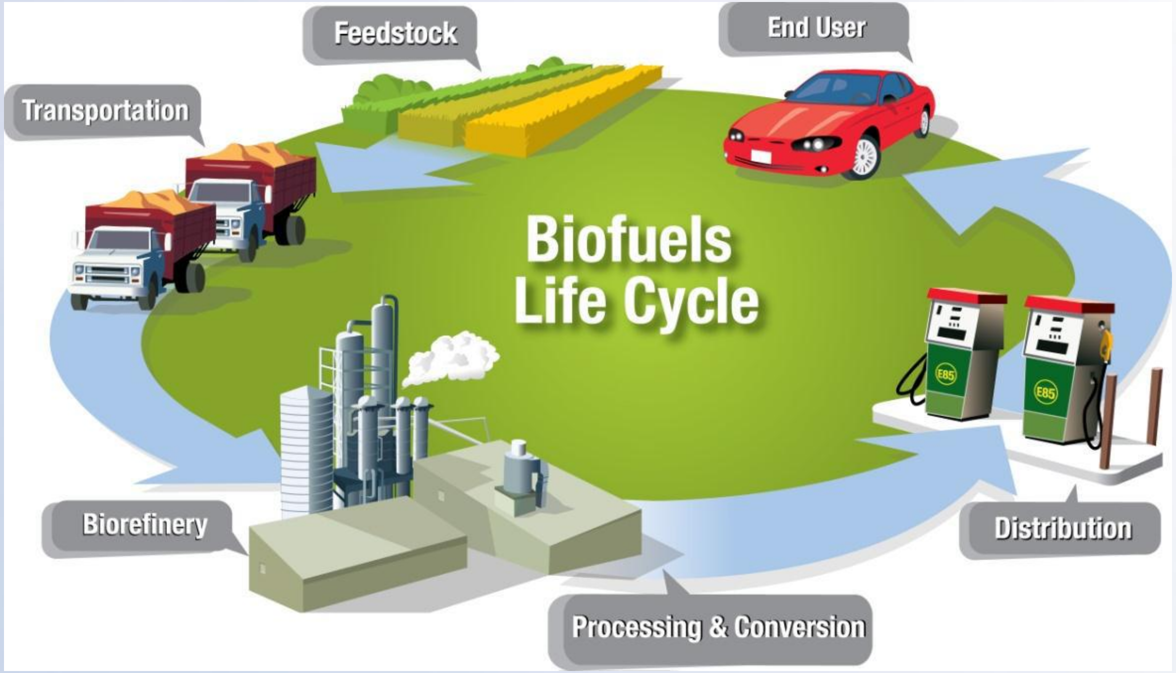
Source: Bioenergy Technologies Office Algal Lipid Upgrading Fact Sheet, DOE/EE-0803 • November 2012



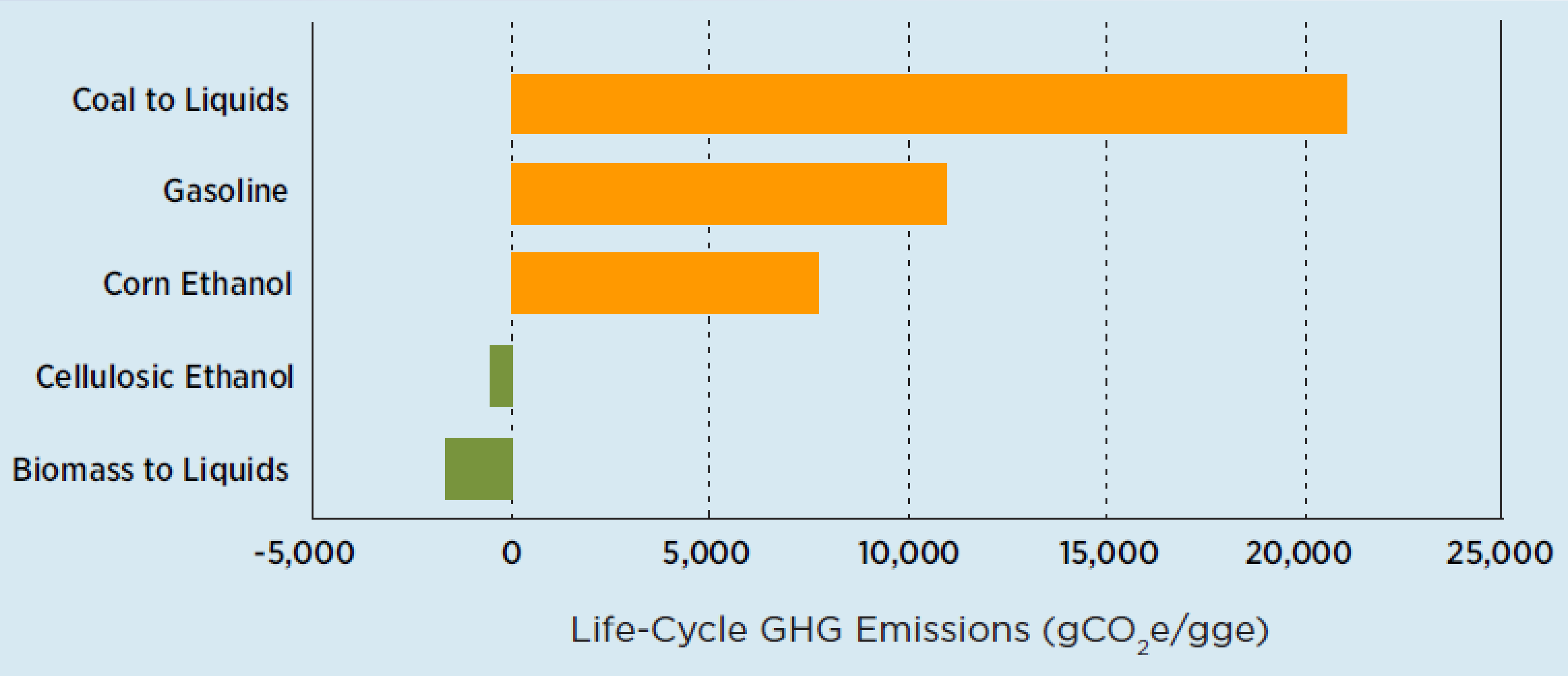


Life-cycle Assessments

- State-of-Technology Techno-economic Analysis
- GIS-based assessment of optimal feedstock resource potential
- Land-use change model development
- Well-to-wheels analysis and expansion of GHG Emissions and Energy Use in Transportation (GREET) model for emerging biofuels production pathways

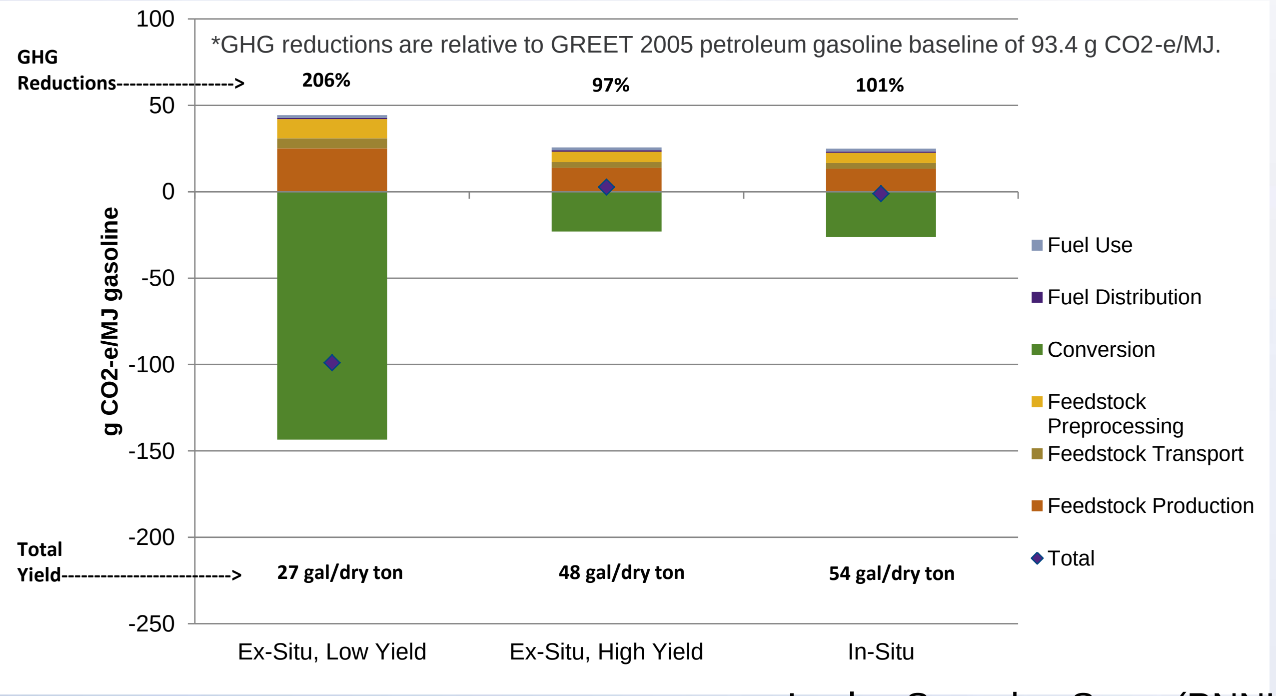


Life-cycle Carbon Emissions from Various Transportation Fuels



Source: U.S. Energy Department, Quadrennial Technology Review, September 2011

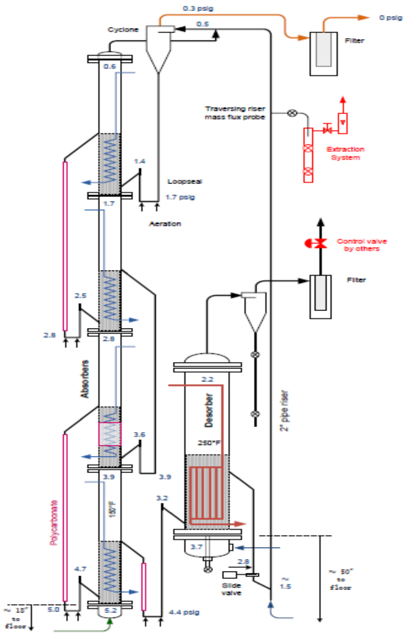
Preliminary GHG Analysis for Catalytic Pyrolysis and Upgrading



Lesley Snowden Swan (PNNL)

- Electricity and fuel yield are the primary GHG drivers for the conversion plant
- Higher fuel yields mean less off gas to raise steam and generate power (GHG credits)

Carbon Capture R&D Activities at RTI



Post-Combustion Capture

- Non-Aqueous Solvents
- Advanced Solid Sorbents
- Membrane Processes
- Hybrid Processes

Pre-Combustion Capture

- Sorbents for warm CO_2 removal from syngas
- Integration of advanced CO_2 capture processes with RTI's Warm Desulfurization Process

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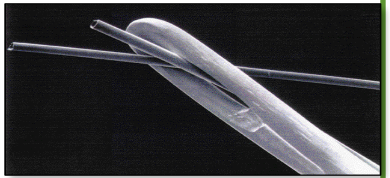
RTI's Carbon Capture Technologies

Non-Aqueous Solvents* (Post-CC)

Advanced Solid Sorbents* (Post-CC)

Polymeric Membranes (Pre- & Post-CC)

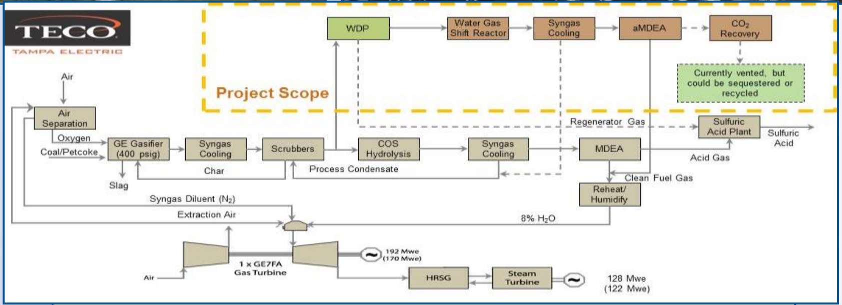


Warm CO_2 Removal from Syngas* (Pre-CC)

Warm desulfurization enabling advanced CC process*

Advanced sorbents for warm CO_2 removal from syngas

RTI Warm Syngas Desulfurization Technology – Scale-up History



Pilot testing (2006-2008)

- Eastman Chemical Company
- 3000hr pilot test, coal-derived syngas
- > 99.9% removal of H_2S and COS (< 5 ppmv S) at > 600ºF & > 600 psig

Demonstration (2010-2015):

- Tampa Electric IGCC Plant, Florida
- $168.8MM DOE funding to design, construct, operate
- 50 MW_e equivalent scale (~20% syngas slip-stream)

Invention (2001)

- Proprietary Desulfurization Sorbent - R&D 100 Award (2004)

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RTI 50-MWe Warm Syngas Cleanup Demonstration Project - Construction

Installing Warm Syngas Desulfurization Equipment

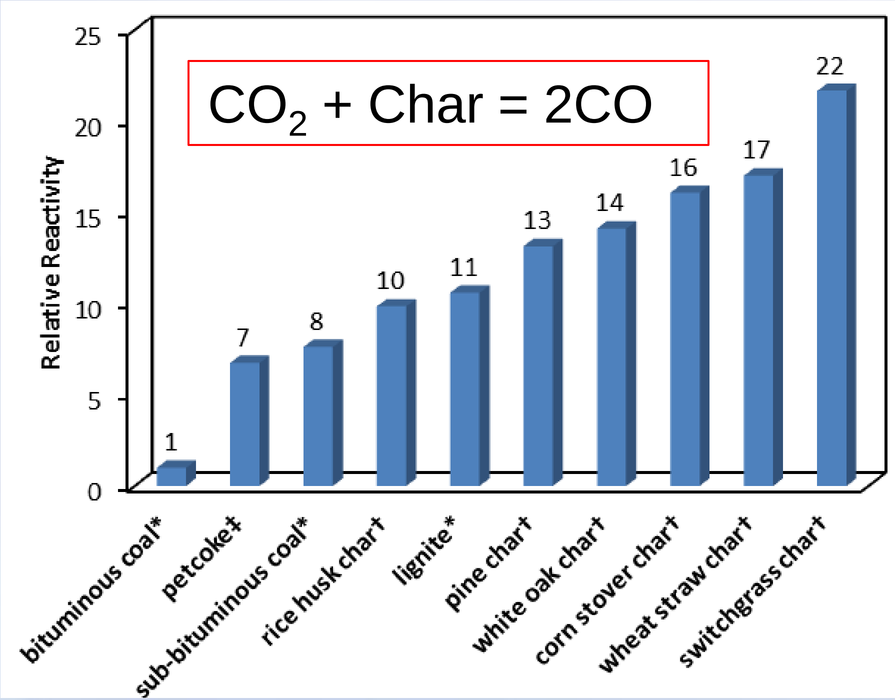
Installing WGS Reactors

Installing Carbon Capture System

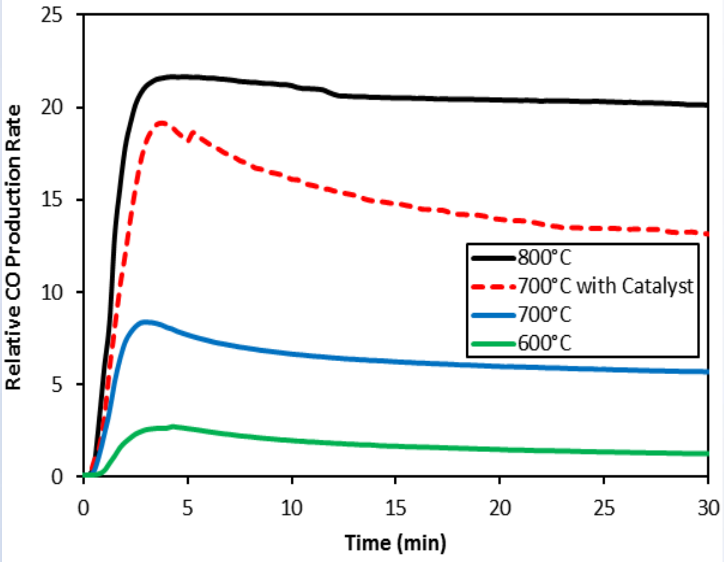
Completed Construction – 50-MWe Demonstration Project

Site Aerial View – Near Completion

CO_2 can be used an oxidant for biomass conversion



CO can be used as a building block for producing fuels and chemicals.



Sustainability

Key Aspects

- **Water Quantity and Quality**
- **Soil Health and Agronomics**
- **Climate Change and Air Quality**
- **Land Use**
- **Biodiversity**

Feedstocks

- Promote nutrient and carbon cycling
- Minimize impact on land and biodiversity

Conversion Technology

- Minimize water consumption
- Minimize air pollution
- Maximize efficiency

Product Distribution

- Reduce carbon footprint of new facilities
- Utilize co-products and fully integrate systems

Product End Use

- Evaluate air quality impacts
- Avoid negative impacts on human health

This work has been done by this team…

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