Liquid Fuels

Woody Biomass to Energy Workshop

March 25, 2010

UC Cooperative Extension

Eureka, California

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Contents

- Overview of Biofuel Pathways
- Starch to Ethanol
- Cellulose to Ethanol
- Conventional Biodiesel
- Thermochemical Biofuel Pathways / Syndiesel
- Efficiency, Greenhouse Gas Emissions, Cost Ranges

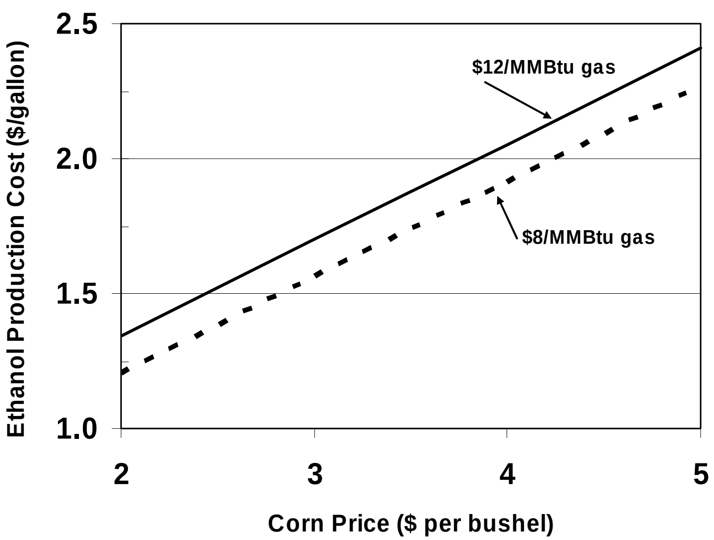
Biomass Conversion Pathways

- Thermochemical Conversion
  - Combustion
  - Gasification
  - Pyrolysis
- Bioconversion
  - Anaerobic/Fermentation
  - Aerobic Processing
- Physicochemical
  - Heat/Pressure/Catalysts
  - Refining
  - Using e.g., Esters (oils), Alkanes (waxes)

- Energy
  - Heat
  - Electricity
- Fuels
  - Solids
  - Liquids
  - Gases
- Products
  - Chemicals
  - Materials

Ethanol Fermentation:
Starch/Sugars

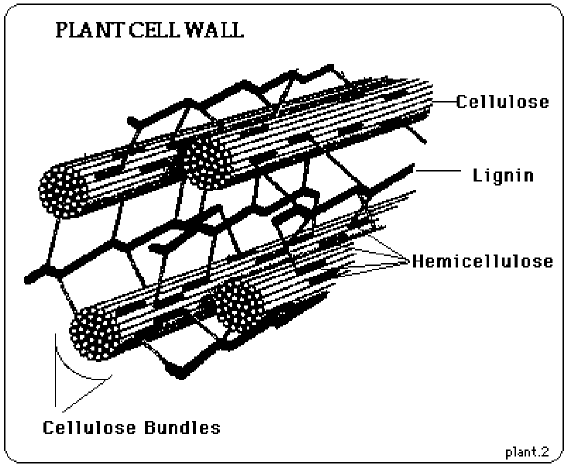
- Well known technology (glucose fermentation)
- Basis for corn grain-ethanol industry
- Efficiency improvements continuing
- Uncertainties regarding sustainability
- Sugar feedstocks similarly fermented (e.g. sugar from sugar cane in Brazil, sugarbeets possible)

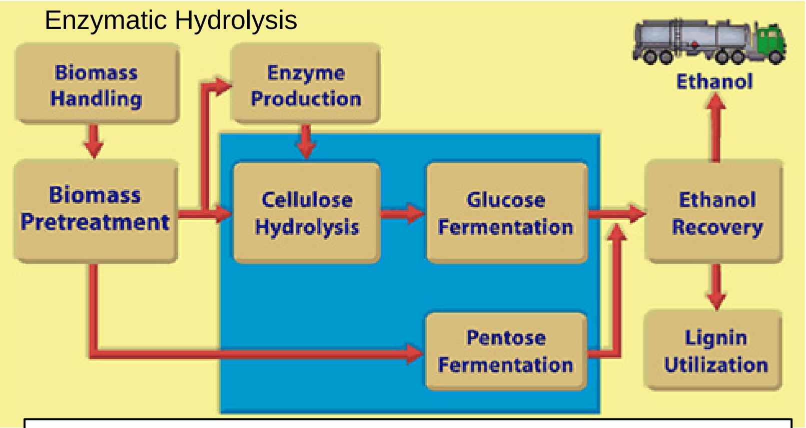


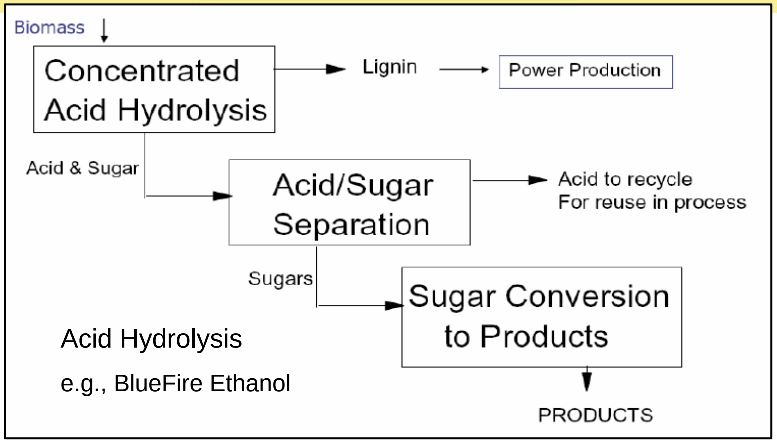
Ethanol Fermentation- Lignocellulosic Feedstocks

- Cellulose, hemicellulose is the feedstock
- Bound by lignin – tough to get at – and lignin passes through process as a residue
- Pretreatment
  - Size reduction/grinding
  - Heating, Soaking, Steam explosion/AFEX, others
- Hydrolysis (cellulose depolymerization--glucose release)
  - Acid
  - Enzymatic
- Fermentation of sugars (C5 and C6)

- Product Recovery and Purification
  - Distillation and dehydration
  - Lignin separation (unfermented)
- Perhaps use lignin for process energy







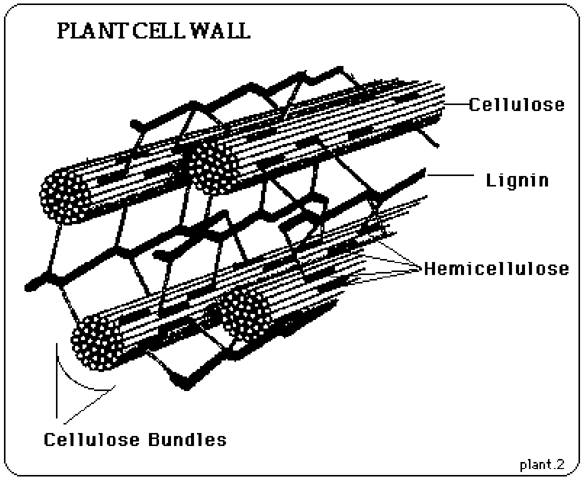
Ethanol Fermentation-Lignocellulosic Feedstocks

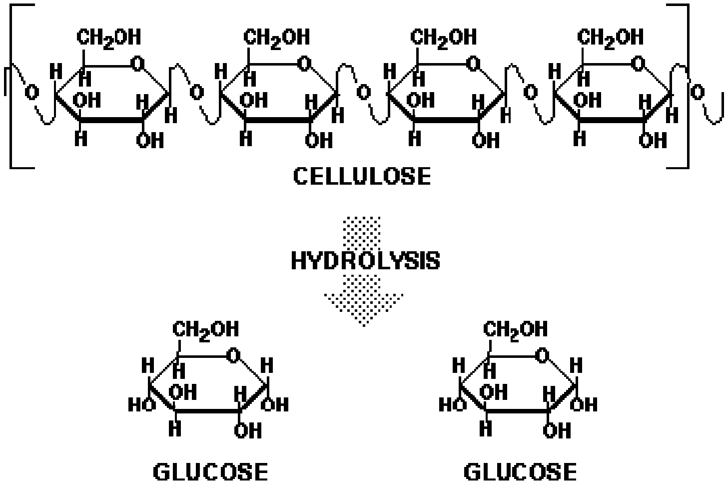
Not yet (again) commercial

- Acid hydrolysis of wood one of earliest technologies for fuel/industrial ethanol (WW I)
- BlueFire Ethanol (acid hydrolysis) demonstrated in Japan, planning / building in US
- US DOE, NREL, Novozymes, Genencor work on cellulase enzymes (enzymatic hydrolysis)
- DOE has awarded $$ to multiple cellulose to ethanol demonstrations ("Commercial Scale")
- Much entrepreneurial interest and venture capital

- Opportunity to use
  - the whole plant (corn + stover)
  - Non-food crops
  - Biomass residue (large amount)

  for biofuel production
- Should have improved lifecycle greenhouse gas performance compared to starch/sugar-to-ethanol
- Improved per acre biofuel yield for case of energy crops (sustainability issues need to be understood).





Biodiesel

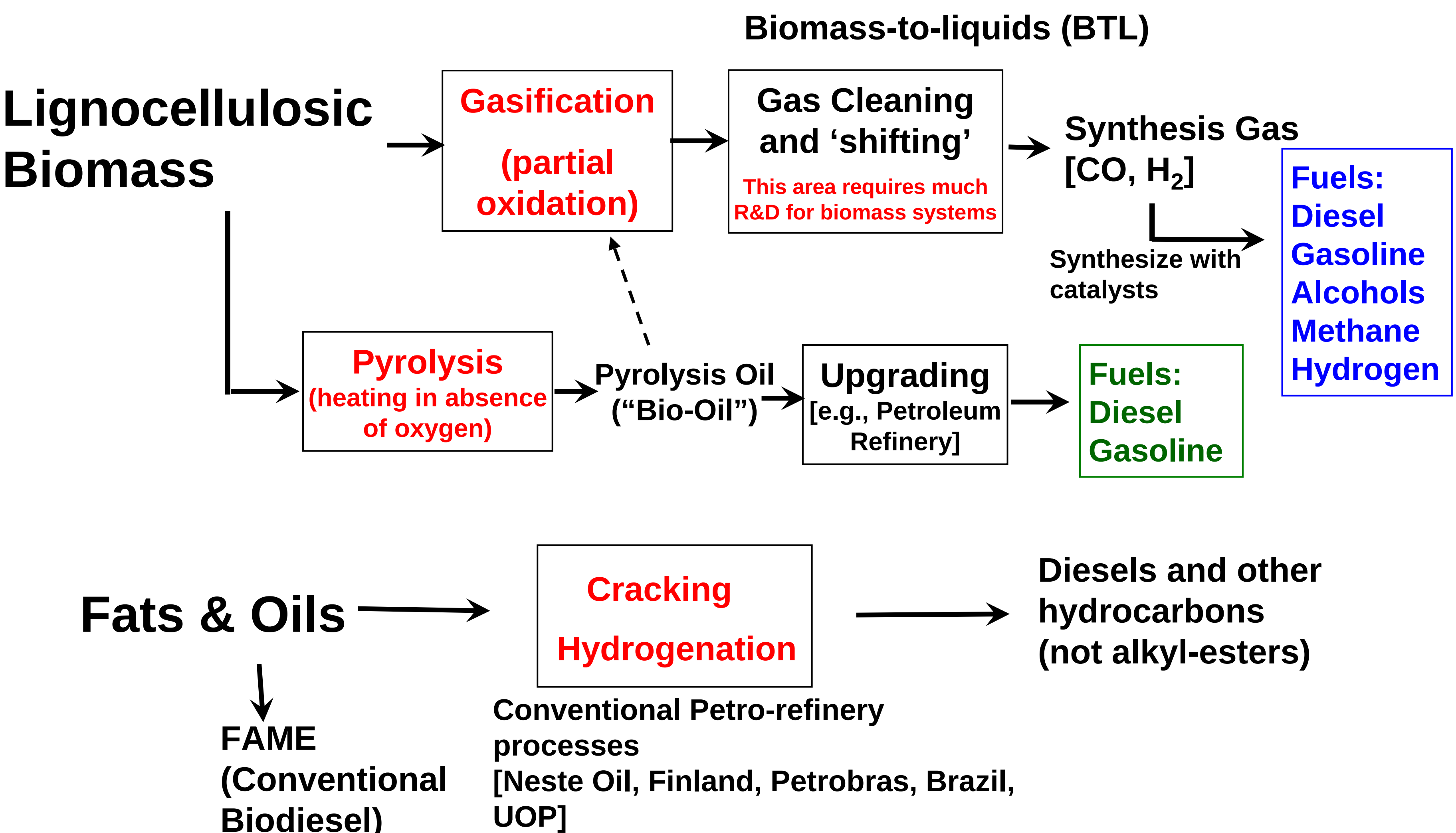
- Mono-alkyl esters of fatty acids derived from plant oils and animal fats (US)
- Transesterification
  - Reaction between lipid and alcohol using alkaline catalyst
  - Fatty acid methylester (FAME)
  - Fatty acid ethylester (FAEE)
- Some potential for cold weather flow ability problems
- Can have oxygen stability problems (shorter shelf life)
- Production to ASTM standards important – Engine OEMs hesitant to warranty due to off-spec product in the market.
- Considered Commercial Process but product is not fungible with current petroleum pipeline distribution system
- Many oil companies not interested in biodiesel- - want a hydrocarbon product from biomass that can be mixed / produced at the refinery and distributed w/ fossil products (engine OEMs would be happier too)

Renewable diesel or Renewable Synthetic diesels include

(these are the hydrocarbon liquids oil companies are looking for):

- Hydrotreatment, hydrothermal upgrading of vegetable oils and animal fats, other lipids and esters (e.g. Shell, Neste, Petrobras, UOP)
- Fischer-Tropsch diesels from gasified biomass (syngas)
  - FT diesels sulfur free
  - Wide product spectrum including gasolines, diesels, alcohols, waxes, aviation fuels, higher value consumer products
- Bio-oils (pyrolysis derived) Need further refining

Thermochemical Biofuel Pathways



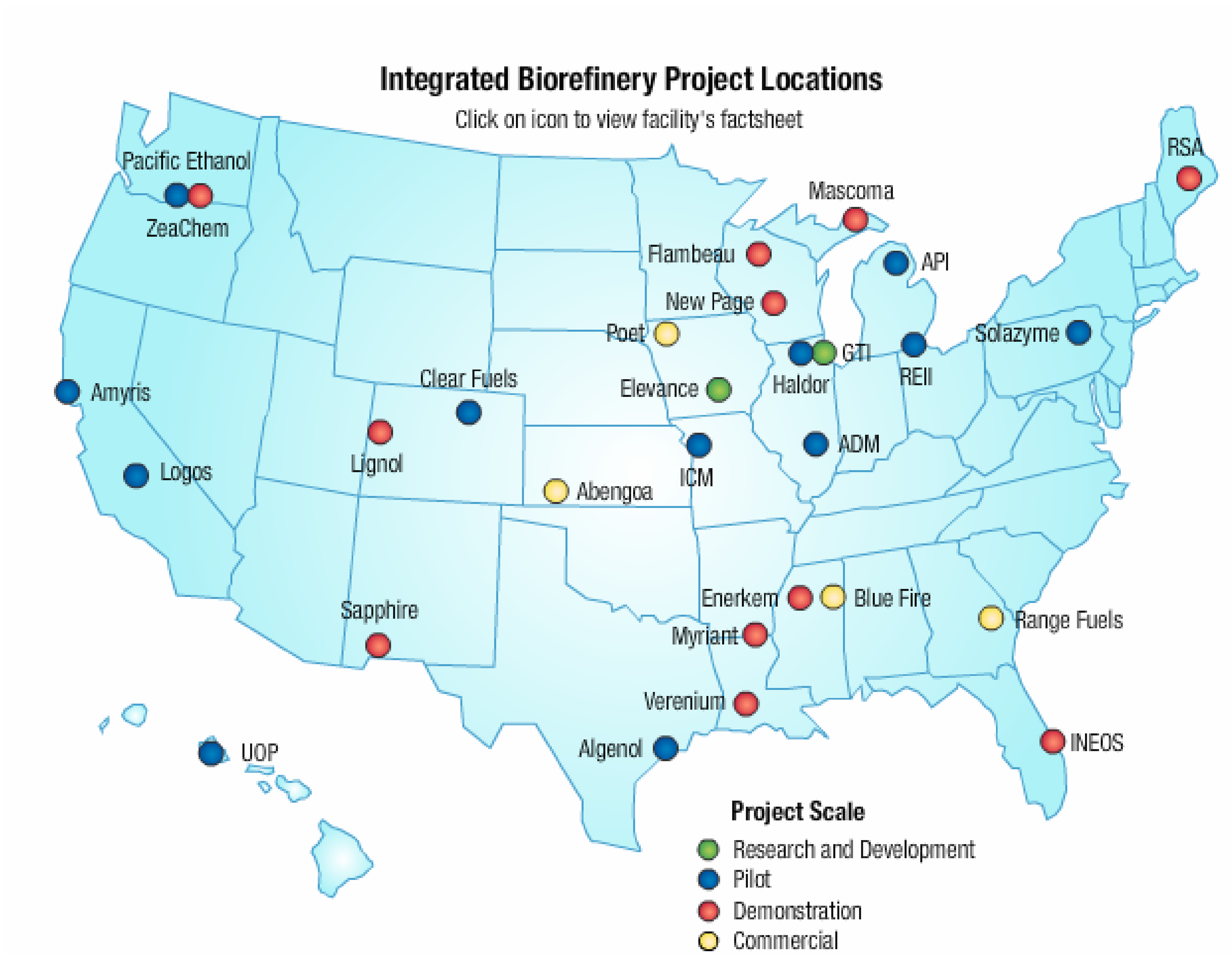
Biomass FT Development

- Värnamo, Sweden
  - pressurized fluidized bed gasifier
  - steam/oxygen blown
  - conversion of IGCC
- Choren, Germany
  - 2-stage gasification (‘Carbo-V’ process)
  - VW and Daimler (SunFuel)_
- Güssing, Austria
  - Indirect gasifier (operating CHP)
  - FT on slipstream for diesel production
  - Slurry FT reactor
- Others
  - NREL (& universities)
  - US private companies

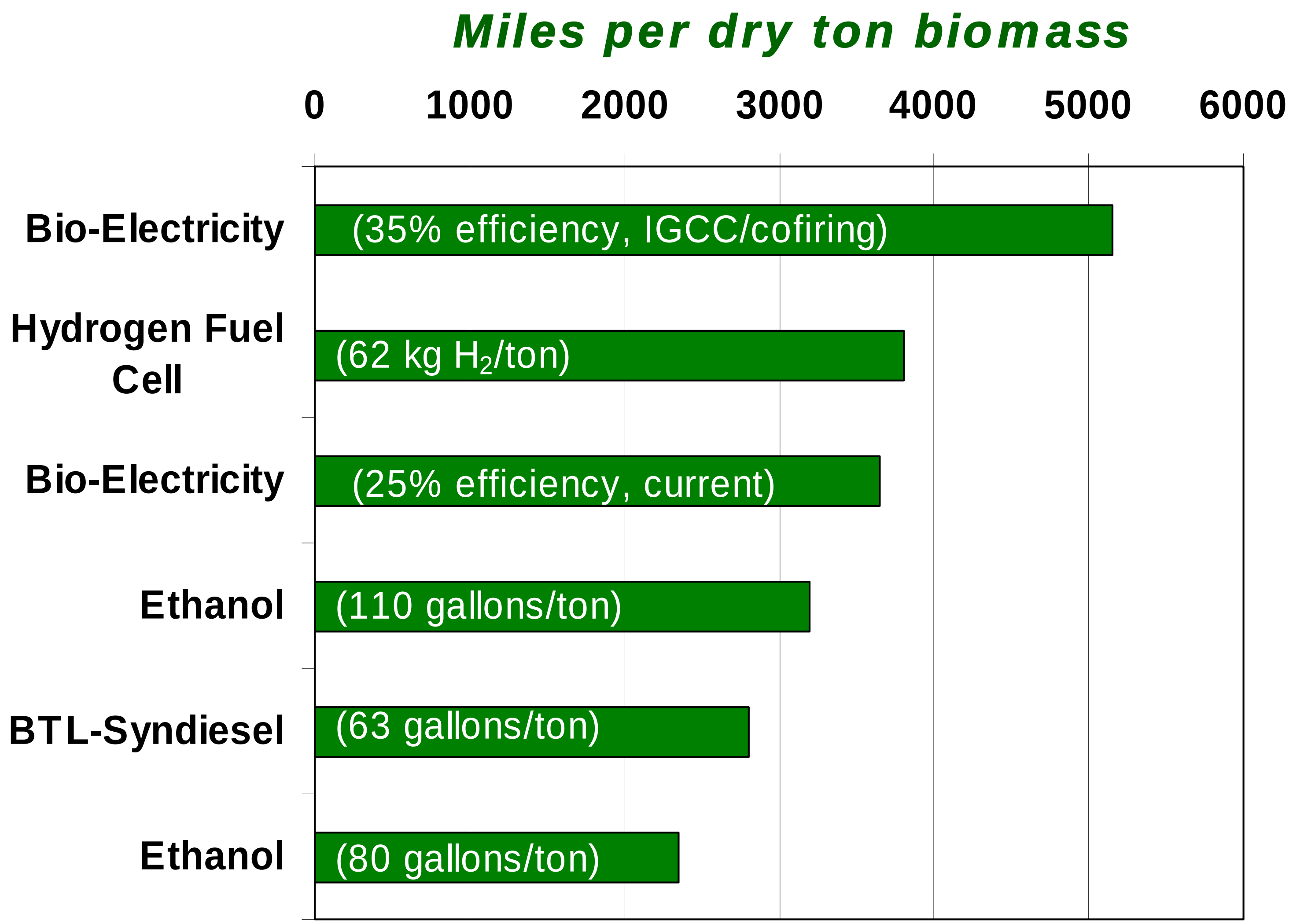
US Cellulosic Ethanol Projects under development

Company	Proposed Location	Method	Proposed Feedstocks	**Proposed Capacity** (M gallons per year)
Abengoa Bioenergy	Kansas	Combined Thermo- and Biochemical	Stover, straws, switchgrass, other	11.4
Abengoa Bioenergy	Nebraska	Biochemical	Stover, straws, switchgrass, other	11.5
AE Biofuels	Montana	Enzymatic Hydrolysis - Fermentation	Switchgrass, seed, straw, stover	small scale
BlueFire	Mississsippi	Concentrated Acid- then Fermentation	Sorted green and wood waste	19
BlueFire	California	Concentrated Acid- then Fermentation	Sorted green and wood waste	3.1
Coskata	PA	Fermentation	Biomass, MSW, Ag residue	(40 thousand gpy)
Dupont	TN	Enzymatic Hydrolysis - then fermentation	Switchgrass, stover, corn cobs	(250 thousand gpy)
Ecofin, LLC	Kentucky	Altech solid state fermentation	Corn cobs	1.3
ICM	Missouri	Enzymatic Hydrolysis - Fermentation	Switchgrass, forage, sorghum, stover	0.5
Lignol Innovations	Colorado	biochem - organosolve	Woody biomass, ag. residues, hard and soft woods	2.5
Mascoma	New York	Enzymatic	Switchgrass, paper sludge, wood	5
New Planet Energy	Florida	Gaddy - BRI (gasification, ferment syngas	MSW, demolition debri, green waste	8-100
New Page	Wisconsin	Black Liquor gasification -to - liquid	woody biomass , mill residues	5.5
Pacific Ethanol	Oregon	Enzymatic - then fermentation	wheat straw, stover, poplar residues	2.7
Range Fuels	Georgia	Gasification w/ catalytic upgrading of syngas	Purpose grown trees and forest wood wastes	20
POET	Iowa	Enzymatic - then fermentation	corn fiber, cobs, and stover	31
Zeachem	Oregon		Poplar, sugar and wood chips	1.54

California Air Resources Board – LCFS various reports- see: http://www.arb.ca.gov/fuels/lcfs/lcfs.htm



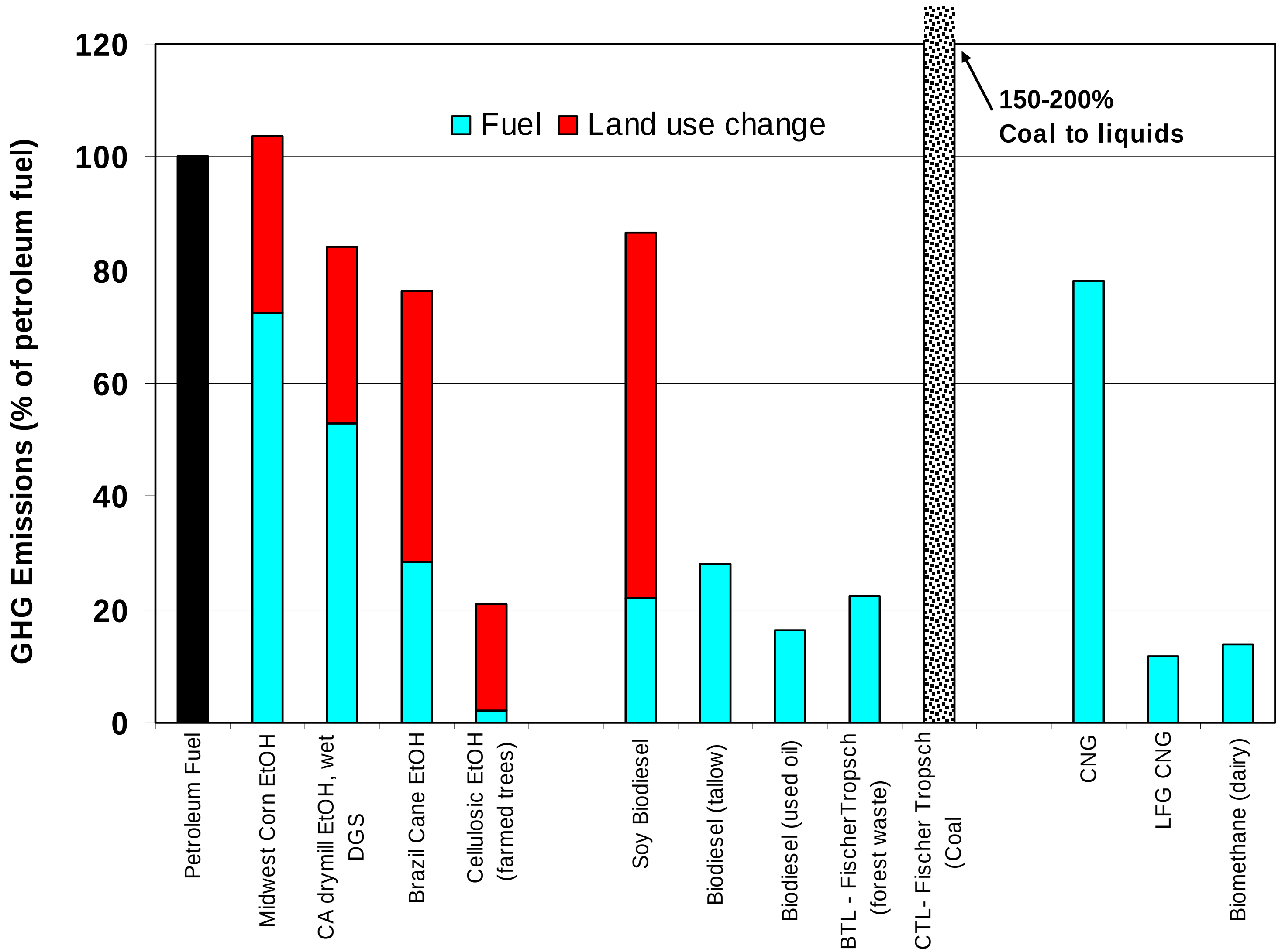
http://www1.eere.energy.gov/biomass/integrated_biorefineries.html



Based on hybrid vehicle with 44 miles per gallon fuel economy on gasoline, 260 Wh/mile battery (source: B. Epstein, E2). Electricity includes generating efficiency, transmission, distribution, and battery charging losses. Ethanol, BTL-Syndiesel, and H_2 include fuel distribution transport energy.

Source: B.M. Jenkins

Relative Greenhouse Gas Emissions of Alt. Fuels compared to conventional gasoline/diesel



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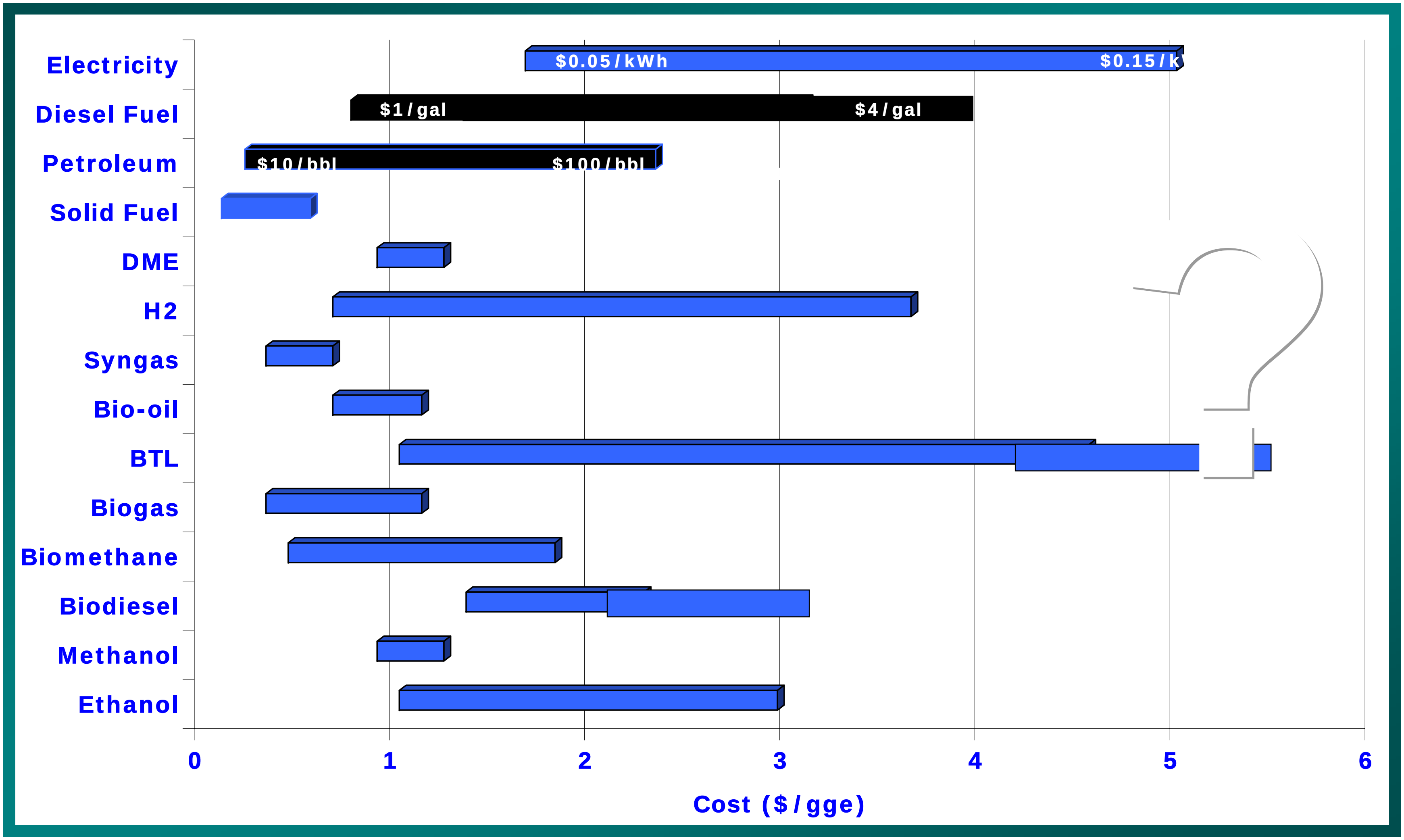
WELL-TO-WHEELS ANALYSIS OF FUTURE AUTOMOTIVE FUELS AND POWERTRAINS IN THE EUROPEAN CONTEXT *http://ies.jrc.cec.eu.int/media/scripts/getfile.php?file=fileadmin/H04/Well_to_Wheels/WTT/WTT_Report_030506.pdf*

Production costs and prices



BM Jenkins and literature

Thank You

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- Developmental for biomass feedstocks
- Yields expected to be 60 -80 gallons liquid hydrocarbon product per dry ton biomass
- Low life-cycle greenhouse gas emissions
- Capital intensive
  - Desire large plant for economies of scale
  - Therefore requires large flow of feedstock

Thermochemical Biofuel Pathways

- Biomass-to-liquids **(BTL)**
  - sometimes referred to as “second generation biofuels” (where starch-to-ethanol, oil-to-FAME are “first generation biofuels”)
- Synthesis gas (CO, H_2) conversion to liquids (Fischer-Tropsch process)
  - Developed by Fischer and Tropsch in Germany (1920’s – 1930’s) using coal gasification and iron/cobalt catalysts (Germany had coal reserves, no petroleum)
  - Used extensively by Germany and Japan in WWII for diesel and aviation fuel
  - SASOL (South Africa) developed process further for coal to liquids fuel due to international sanctions against South Africa

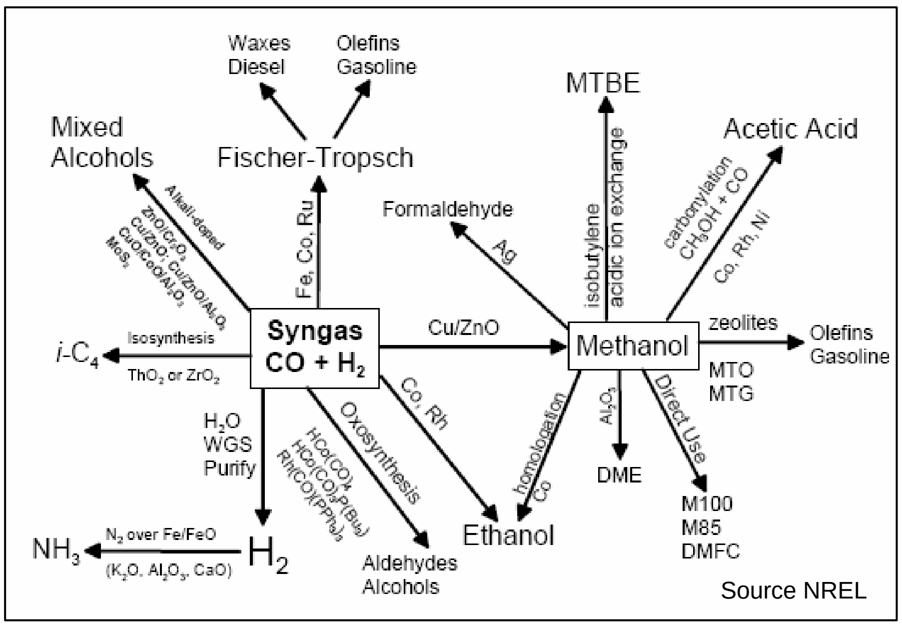
Thermochemical Biofuel Pathways

Biomass-to-liquids (BTL)

Lignocellulosic Biomass → **Gasification (partial oxidation)** → **Gas Cleaning and 'shifting'** (This area requires much R&D for biomass systems) → **Synthesis Gas [CO, H_2]**

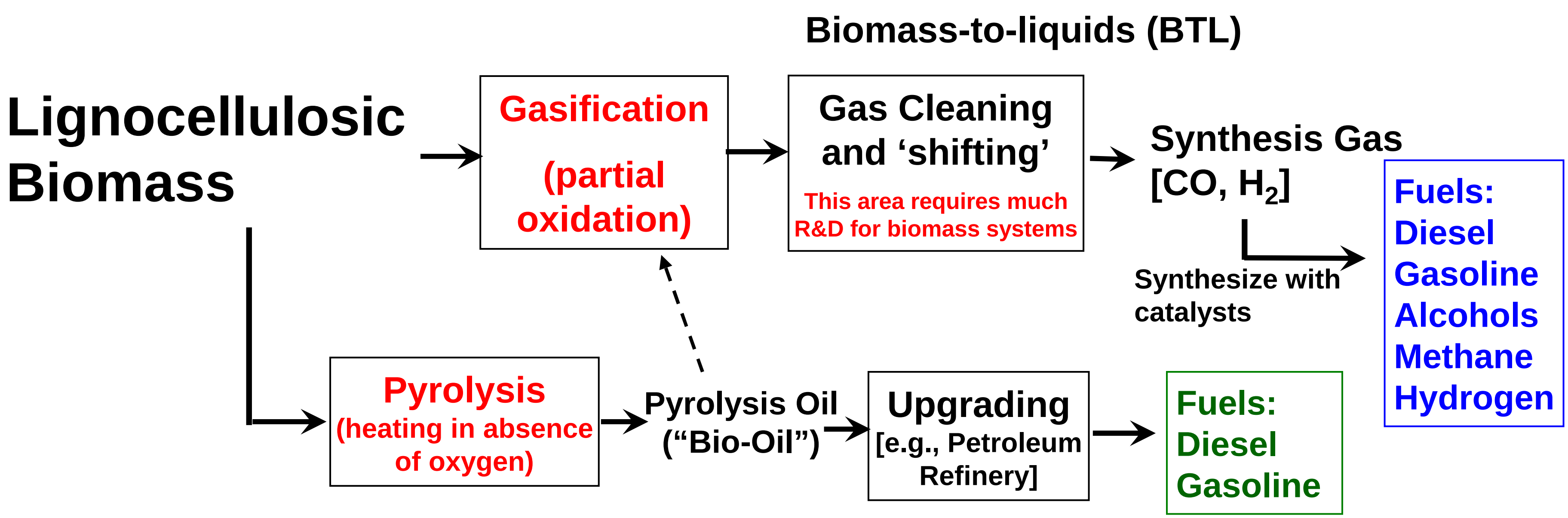
Synthesize with catalysts →

Fuels:
Diesel
Gasoline
Alcohols
Methane
Hydrogen

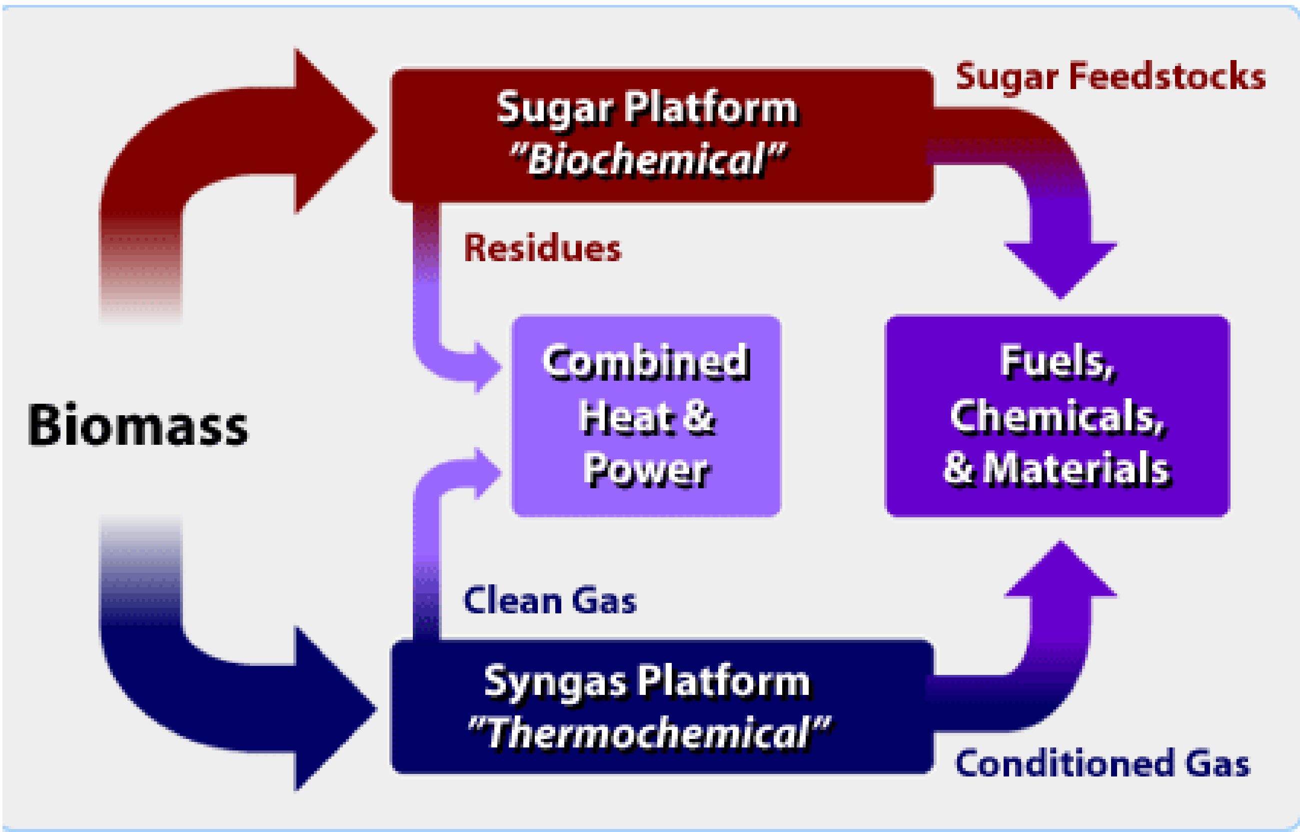


Source NREL

Thermochemical Biofuel Pathways



Biorefinery Concept



http://www.nrel.gov/biomass/biorefinery.html