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Chemicals from biomass:
A market assessment of bioproducts with near-term potential

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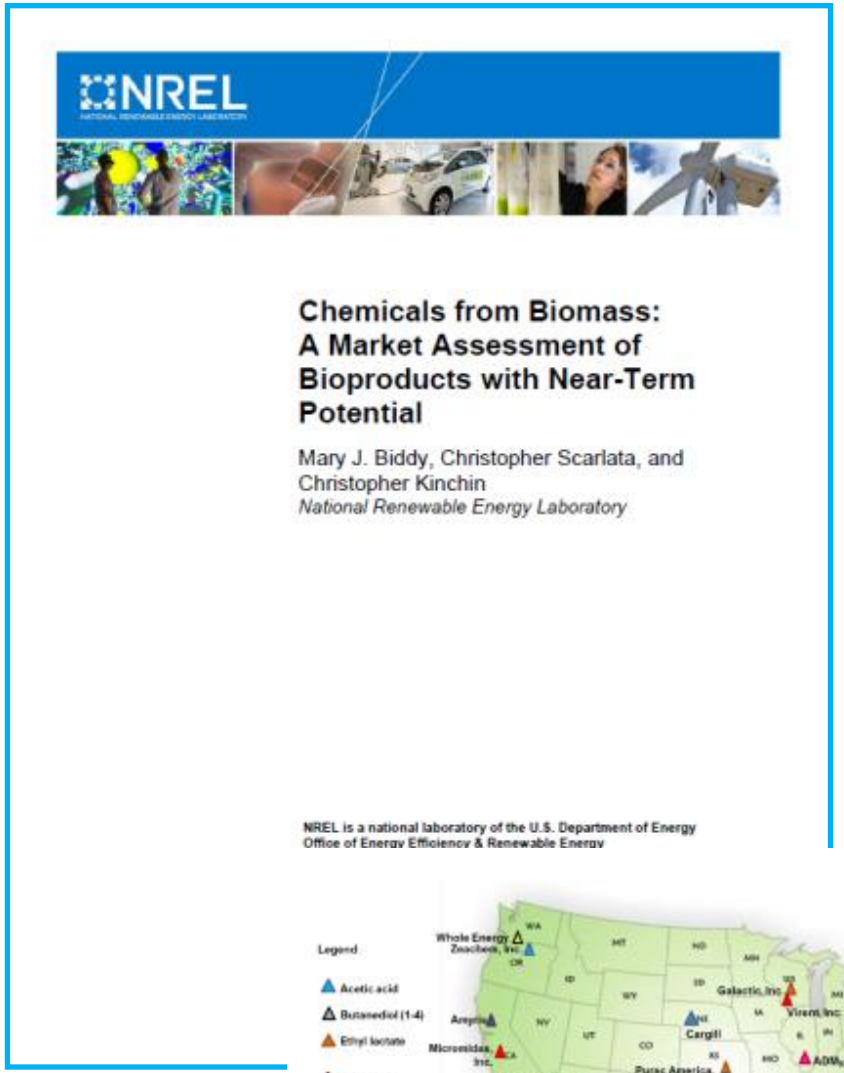
Review of Chemicals from Biomass Report

Significance and Impact

- Focus of report is on products that will have near-term market impact. These are bio-derived chemicals that are currently being produced either at demonstration or commercial scales.
- Reviews current projects and planned efforts for bio-derived chemicals.
- Identifies major drivers for moving biomass-derived products to market and the current market champions supporting these efforts.
- Assesses ways in which chemicals production can be leveraged to expand and accelerate the growth of biofuels.



http://www.nrel.gov/docs/fy16osti/65509.pdf

Motivation for Chemicals from Biomass

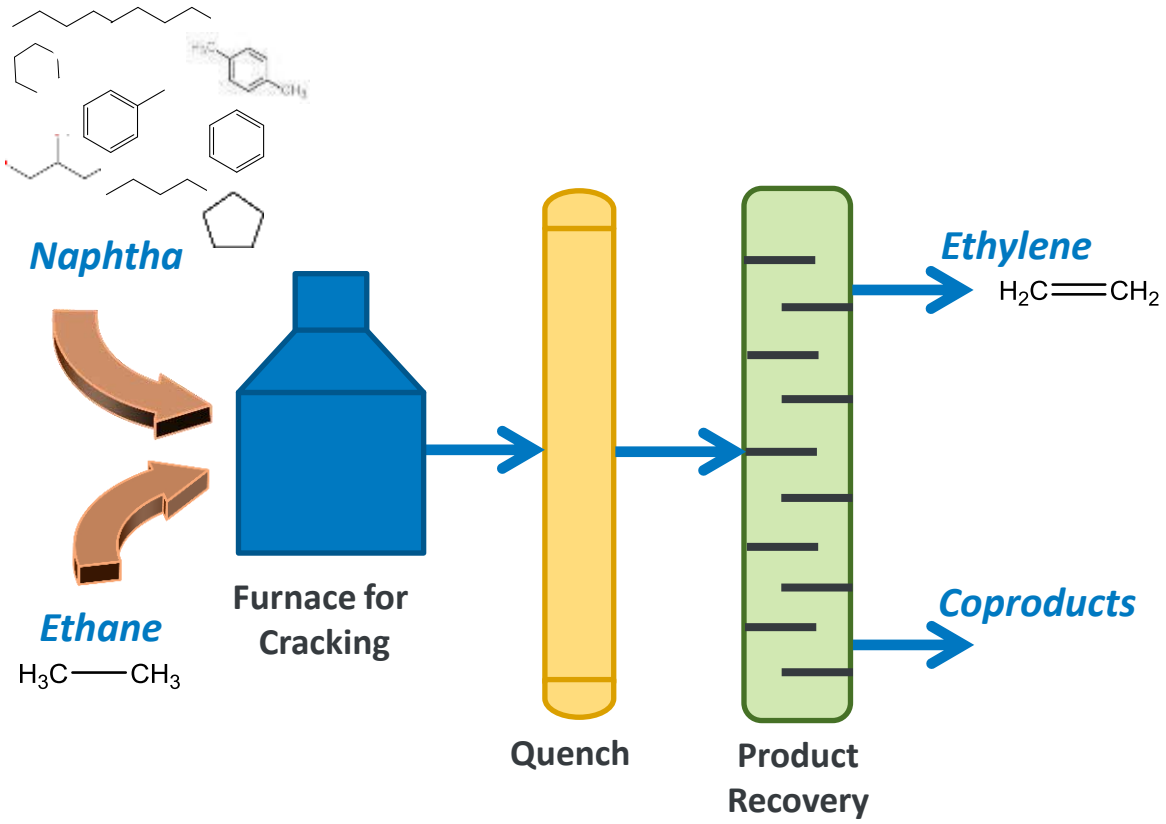
- The U.S. Chemical Industry provides over **15% of the worlds' chemicals** and since 2010 has accounted for about **2% of the US GDP**.[1,2,3]
- Replacing the entire barrel of oil – **15% of the entire barrel of oil** goes toward the production of chemical products, while chemical products account for **nearly 50% of the profits**.[4,5]
- The chemicals industry accounts for **30% of the total industrial energy** demand worldwide and is responsible for **20% of the industrial greenhouse gas emissions** (IEA).[6]
- In 2013, the overall bio-based products industry supported four million jobs with **a value of $369 billion to the U.S. economy** (USDA).[7]

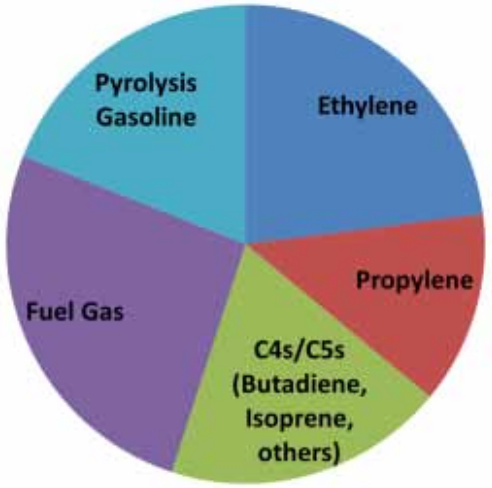
1. American Chemistry Council, "Chemistry Industry Facts and Figures" (Washington, DC: American Chemistry Council, June 2015).
2. Office of Energy Efficiency & Renewable Energy, "Chemical Industry Profile."
3. Bureau of Economic Analysis, "GDP by Industry and Input-Output," U.S. Department of Commerce
4. Bioenergy Technologies Office. 2015. Bioenergy Technologies Office Multi-Year Program Plan: March 2015 Update. edited by Department of Energy. Washington, DC.
5. Rinaldi, R., and F. Schuth. 2009. "Design of solid catalysts for the conversion of biomass." Energy & Environmental Science 2 (6):610-626. doi: Doi 10.1039/B902668a.
6. IEA. 2013. Technology Roadmap Energy and GHG Reductions in the Chemical Industry via Catalytic Processes. International Energy Agency.
7. Golden, J.S., R.B. Handfield, J. Daystar, and T.E. McConnell. 2015. "An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America."

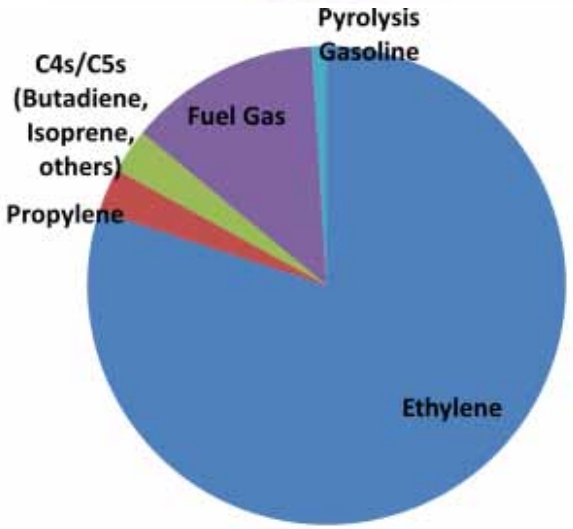
Products Considered in Market Report

Chemical	Type	Conversion Pathway	TRL Level based on commodity feedstocks	R&D on-going for lignocellulosic feedstocks
Butadiene (1,3-)	Drop-in	BC – Biological TC/BC – Gasification/Fermentation	6	Y
Butanediol (1,4-)	Drop-in	BC – Biological	8	Y
Ethyl Lactate	Functional	BC– Biological	9	Y
Fatty Alcohols	Drop-in	TC – Gasification, BC – Biological, Algae	9	Y
Furfural	Functional	TC– Pyrolysis, BC – Catalytic	9	Y
Glycerol	Functional	Algae	9	Y
Isoprene	Drop-in	BC – Biological	6	
Lactic Acid	Functional	BC – Biological	9	Y
Propanediol (1,3-)	Functional	BC – Biological	9	
Propylene Glycol	Functional	BC – Biological	9	
Succinic Acid	Functional	BC – Biological	9	Y
Xylene (para)	Drop-in	BC – Catalytic TC – Pyrolysis	6	Y

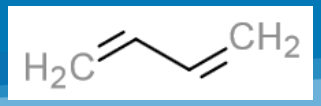
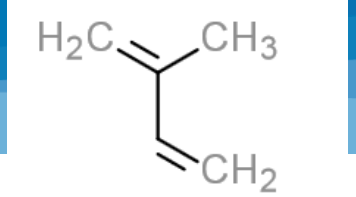
Market Driver 1: Supply/Demand





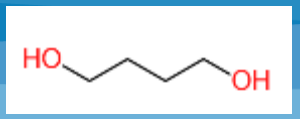


- Lighter feedstocks result in lower yields of coproducts.

Butadiene  and Isoprene 

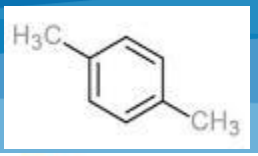
- Primarily manufactured as a coproduct in ethylene production which has led to price volatility.
- Both can be produced via biological conversion, and butadiene via syngas fermentation.
- Market champions:
  - Butadiene - *Genomatica and Braskem and Versalis; Global Bioenergies and Synthos; INVISTA and Arzeda; INVISTA and Lanzatech; Cobalt; Michelin, Axens, and IFP Energies Nouvelles*
  - Isoprene - *Amyris, Braskem, and Michelin; Goodyear and DuPont Industrial Biosciences, Glycos Biotechnologies and Bio-XCell*
- Possible market expansion due to low cost natural gas.

Market Driver 2: Consumer demand - Butanediol

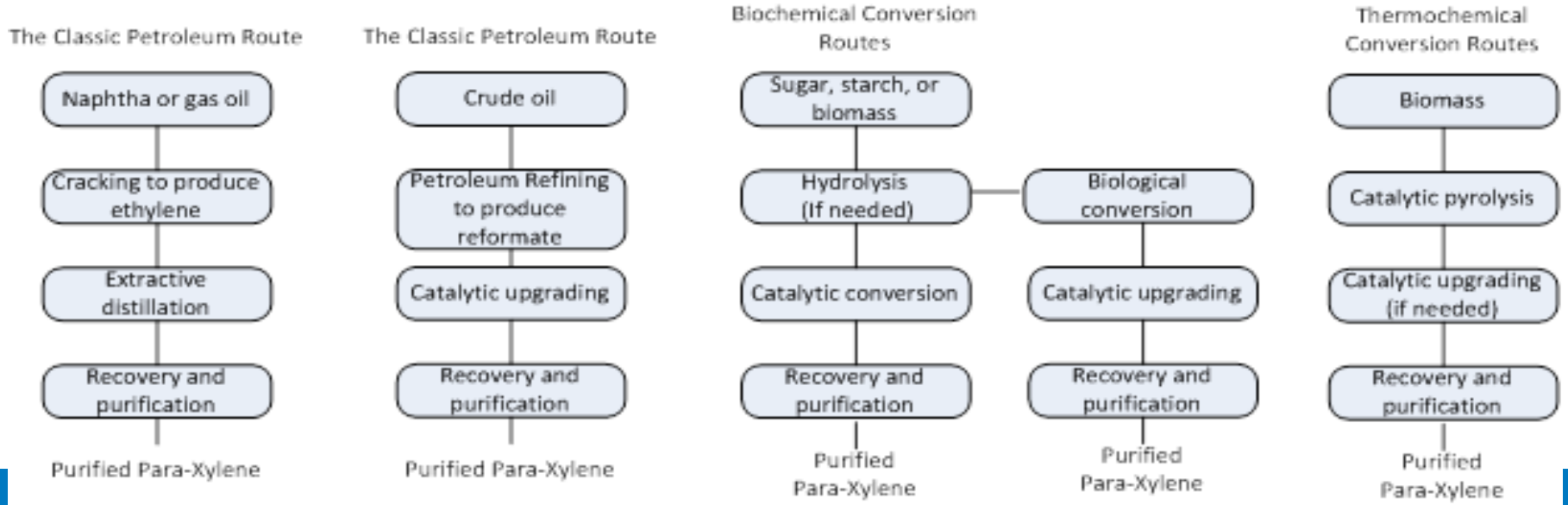


- 45% of BDO => THF => …=> component of spandex, urethane elastomers, and copolyester ethers.
- Two routes from renewable feedstocks:
  - Direct fermentation – *Genomatica*
    - Demonstrated the first commercial production of biologically-derived BDO by making more than 5 million pounds of BDO in a five week campaign (*with Dupont Tate and Lyle*).
    - *BASF and Novamont* licensed this technology.
  - Catalytic upgrading of intermediates – *BioAmber and Myriant* from succinic acid.
- Market champions include *INVISTA* and *Nike.*

Market Driver 2: Consumer demand - para-Xylene



- Fossil-derived either from reformate or py-gas.
- ~97% of pX is used to manufacture polyesters.
  - 65% destined for fibers, 27% for PET bottle resin, and the remaining for films and other polymer uses
- Renewable routes:
  - Fermentation/catalytic upgrading - *Gevo*
  - Thermochemical pyrolysis routes – *Anellotech*
  - Catalytic upgrading of sugars – *Virent*



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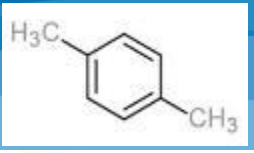

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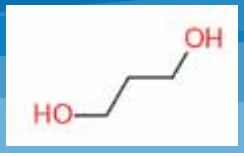
  - Other routes – *Micromidas and Biochemtex*
- Market Champions - *Coca-Cola, Ford, Heinz, Nike, and Procter & Gamble* formed a consortium in 2012 to promote research for developing PET 100% derived from renewable raw materials.
- Also interested in furan dicarboxylic acid (FDCA) to make polyethylene furanoate (PEF) – a replacement to PET.

Market Driver 3: Superior Properties/Lower Cost

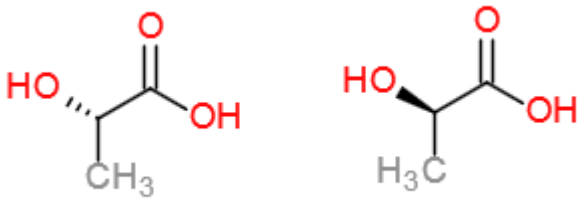
(1,3-) Propanediol



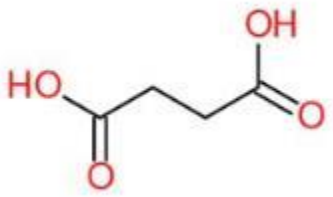
- Biologically-derived is lower cost than fossil-derived.
  - Bio-based PDO uses 40% less energy than the typical petroleum-based route.
- PDO is has desirable properties in making polymers:
  - Polytrimethylene terephthalate (PTT) polymers.
  - PTT for textiles and fibers due to its superior durability and stain resistance compared to nylon.
- Produced via fermentation:
  - *DuPont Tate & Lyle Bio Products* plant in Loudon, Tennessee, has a capacity of 63,500 metric tons per year.
- PTT (PDO) is marketed under the brand name Sorona with one-third renewable material content.
- PDO is also utilized in laundry detergents and cleaners.

Market Driver 3: Superior Properties

- Lactic Acid
  - Primarily produced by microbial fermentation.
  - Diverse applications in food, pharma, and industry.
  - Strong growth expected for PLA market (current scale ~300,000 metric tons/year).
  - Potential to utilize for acrylic acid production.



- Succinic Acid
  - Current petroleum-derived market is small.
  - Platform chemical – possible replacement for butanediol.
  - Possible growth up to 400,000 metric tons/year.
  - Commercial scale processes at *BASF/Corbion Purac, BioAmber, Myriant, and Reverdia (DSM-Roquette)*.
  - Offtake agreements support market expansion.



Summary

- Selection of products based on a number of metrics (*e.g.*, market considerations, TRLs, and LCA).
- Range of drivers for bio-derived products:
  - Supply/demand and market need (fossil replacements).
  - Consumer demand.
  - Superior properties and potential lower costs.
- Majority of scaled processes are focused on commodity feedstocks, however, there is growth in lignocellulosic feedstocks.
- Additional products reviewed in the report include:
  - Ethyl lactate, fatty alcohols, furfural, glycerol, and propylene glycol
- Expansion and utilization of work in a number of other projects:

http://www.manufacturingcleanenergy.org/

  - AGILE BioFoundry **http://agilebio.lbl.gov/**

- Report is published at:
  http://www.nrel.gov/docs/fy16osti/65509.pdf

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Thank you!

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