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Performance-advantaged products from biomass: *State of the market and Opportunities for innovative products*

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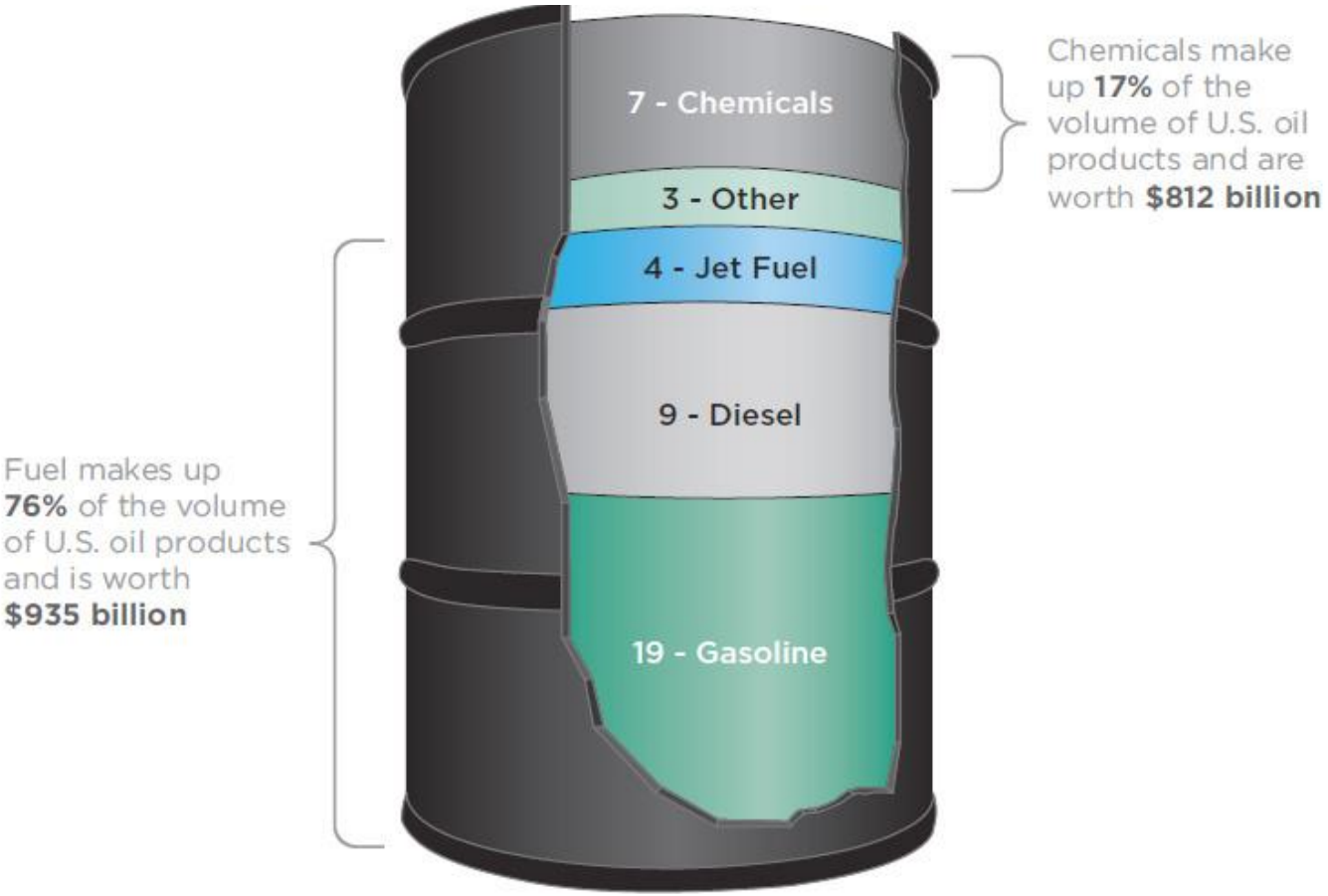
DOE/USDA BRDI TAC Meeting

Motivation for Chemicals From Biomass

- The U.S. Chemical Industry provides over **15% of the world's chemicals** and since 2010 has accounted for about **2% of the US GDP**.[1,2,3]
- In 2013, the overall bio-based products industry supported four million jobs with **a value of $369 billion to the U.S. economy** (USDA).[4]
- 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).[5]

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. 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."
5. IEA. 2013. Technology Roadmap Energy and GHG Reductions in the Chemical Industry via Catalytic Processes. International Energy Agency.

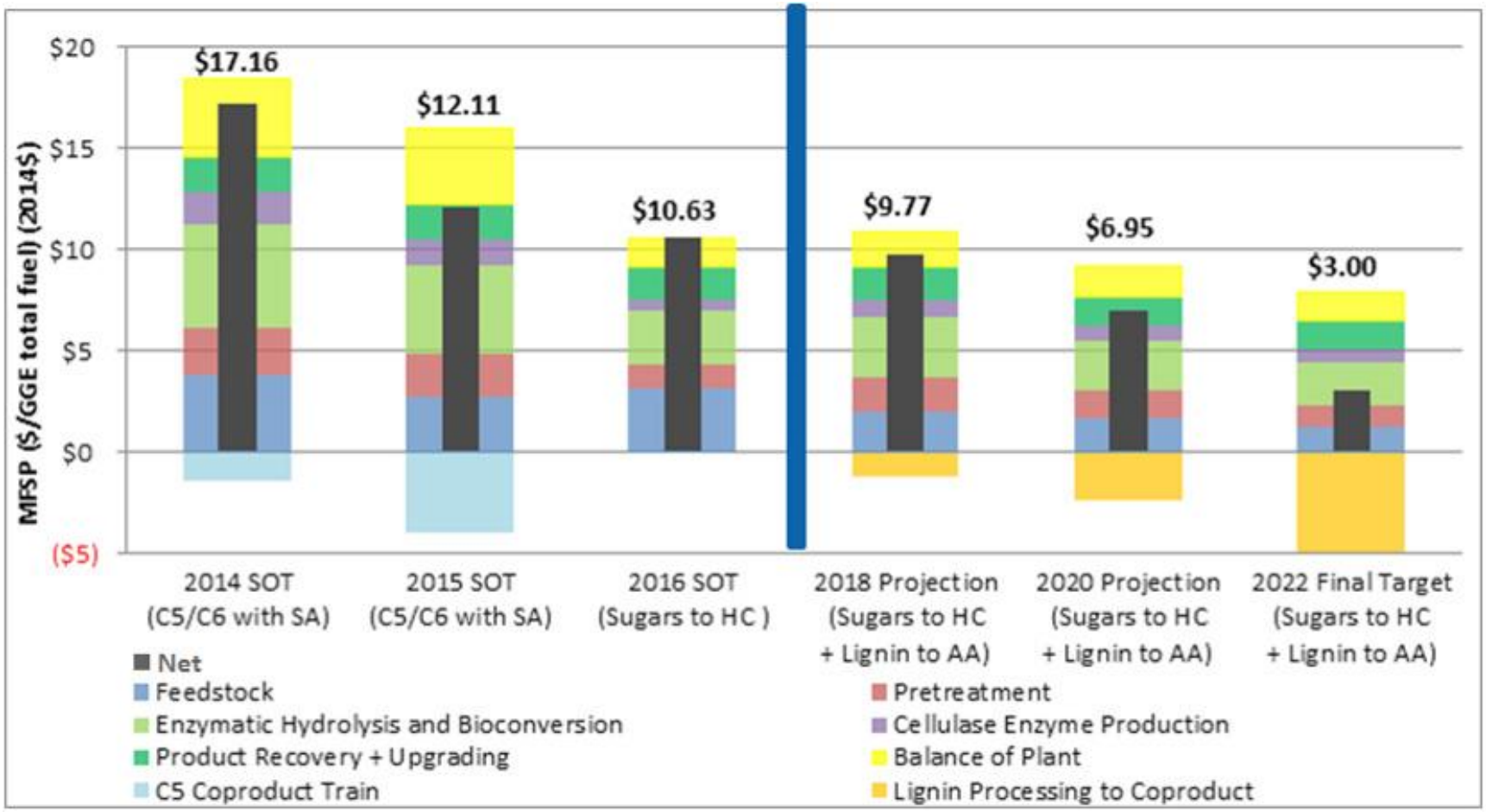
Motivation for Chemicals From Biomass



Supporting DOE BETO Cost Goals – Up to **17% of the entire barrel of oil** goes toward the production of chemical products, while chemical products account for **nearly 50% of the profits**.[1]

1. Bioenergy Technologies Office. 2018. Moving Beyond Drop-In Replacements Performance-Advantaged Biobased Chemicals Workshop Summary Report. edited by Department of Energy. Washington, DC

Motivation for Chemicals From Biomass



Supporting DOE BETO Cost Goals – Developing biorefineries that maximize the value of ALL of the biomass can further drive down costs for biofuels while maximizing fuel yields.[1]

1. Bioenergy Technologies Office. 2018. Moving Beyond Drop-In Replacements Performance-Advantaged Biobased Chemicals Workshop Summary Report. edited by Department of Energy. Washington, DC

Chemicals from Biomass Report

Building from Prior Work

- 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.
- Assesses ways in which chemicals production can be leveraged to expand and accelerate the growth of biofuels.

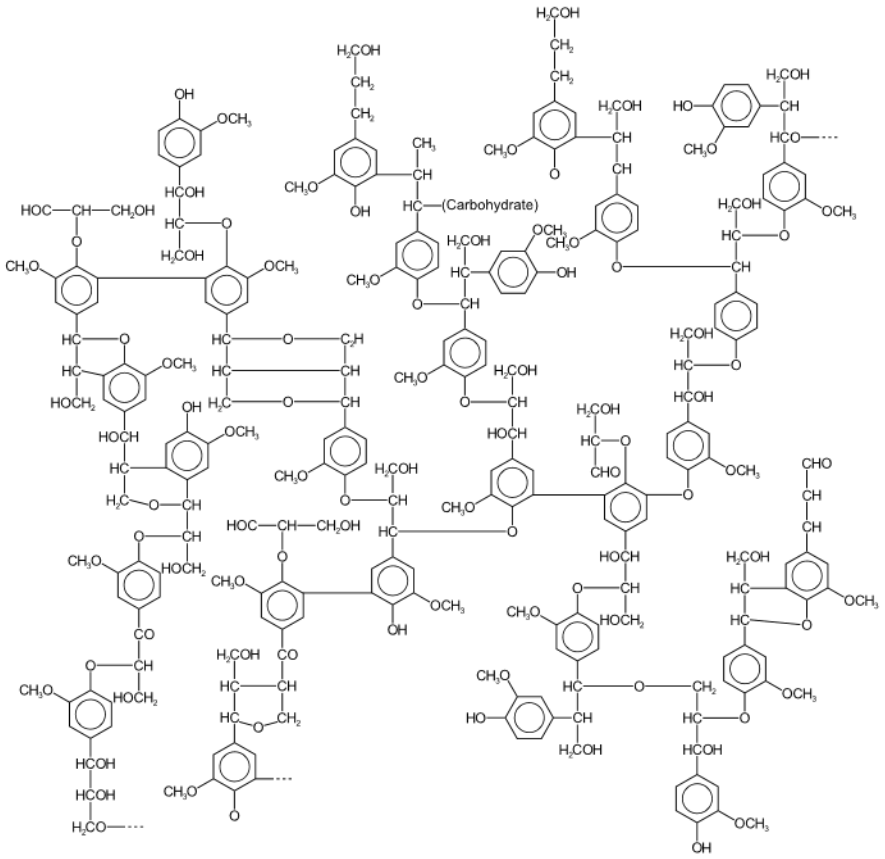
Range of drivers for bio-derived products:

- Supply/demand and market need (fossil replacements).
- Consumer demand.
- Superior properties and potential lower costs.

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

What is a performance-advantaged molecule?

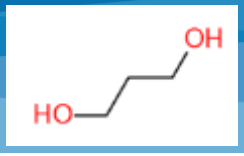
- Renewable chemical that is not traditionally produced from fossil feedstocks.
- Has unique properties/ performance attributes that are an advantage compared to traditional products such as:
  - Biodegradability
  - Low/High glass transition
  - Stain resistance
  - Barrier properties
  - Low VOCs
  - Produced in non-toxic process strategy
- Such products have the opportunity to benefit from the unique heterogenous nature of biomass.



Snapshot of lignin molecular structure

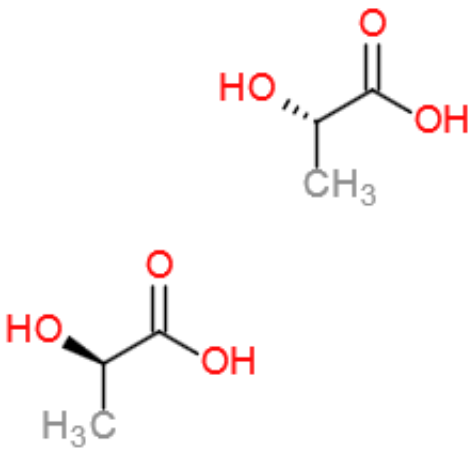
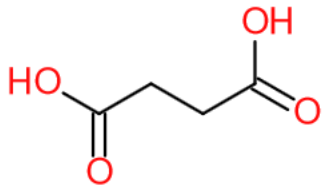
Market Driver : Superior Properties/Lower Cost

(1,3-) Propanediol

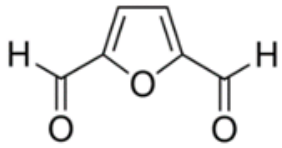
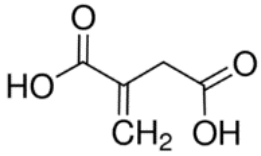


- Biologically-derived is lower cost than fossil-derived.
  - Bio-based PDO uses 40% less energy than the typical petroleum-based route.
- PDO has desirable properties in making polymers:
  - Polytrimethylene terephthalate (PTT) polymers.
  - PTT for textiles and fibers due to its superior durability 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.

PDO is just one example

Performance- Advantaged Product	Use	Desirable properties
Lactic Acid 	Primarily utilized for polymeric applications (PLA). Used in products with short lifetimes such as disposable or biodegradable utensils, food packaging, trash bags, and other consumer products. PLA is also used in high-value medical applications like sutures and tissue scaffolds due to its biocompatibility and biodegradability. ***Current production capacity:*** 400,000 metric tons	Biodegradability Biocompatibility When D and L Limited use in long lifetime applications for food storage due to barrier limitations. For 3-D printing applications: higher printer speed, no harmful fumes, can be used in food applications.
Levulinic Acid 	A range of different applications including personal care, solvents, polymers and plasticizers, resins and coatings, pharmaceuticals, agro-chemicals. ***Current production capacity:*** Commercial facility coming online in Italy in 2018.	Biodegradability. Solvents: Ketals and ester levulinates shown to have excellent degreasing/stain removal, ability to remove baked on polymers, stability in concentrated formulations without clouding, safe toxicology profile for workers. Resins: Can be used in waterborne coatings to facilitate the crosslinking process.

PDO is just one example

Performance- Advantaged Product	Use	Desirable properties
2,5-Furandicarboxaldehyde 	A number of polymeric applications including polyesters, polyamides, and polyurethanes. Potential to replace PET in producing plastic bottles. Due to unique nature, opens opportunity for new applications in packaging and light-weight materials. ***Current production capacity:*** At pilot scale.	Improved barrier permeability properties compared to PET including up to 10x higher for O_2, up to 6x for CO_2, and 2x for H_2O. Moduli that are 1.6x higher than PET which can allow for lighter bottles. Higher T_g which allows for hot fill applications. Lower T_m which can allow for energy reduction in processing.
Itaconic Acid 	Most utilized for polymeric applications. Utilized as cross-linking agent in production of superabsorbent polymers. Poly itaconic acid has the potential to replace sodium tripolyphosphate in detergents. Also utilized in UV-curable coatings in electronics industry. ***Current production capacity:*** 50,000 metric tons. [El-Imam 2014, Transparent Market Research 2015]	Readily biodegrades in soil. Unique structure allows molecule to take part in addition polymerization.

The impact of cheap fossil feedstocks

BioAmber files for Bankruptcy

POSTED BY DORIS DE GUZMAN · MAY 4, 2018 · 1 COMMENT

FILED UNDER BANKRUPTCY, BDO, CELLULOSIC SUGAR, SUCCINIC ACID

Unfortunately, the force is not that strong for BioAmber today as the company announced its filing for Chapter 11 Bankruptcy in the US, while its two Canadian subsidiaries – BioAmber Sarnia Inc. and BioAmber Canada

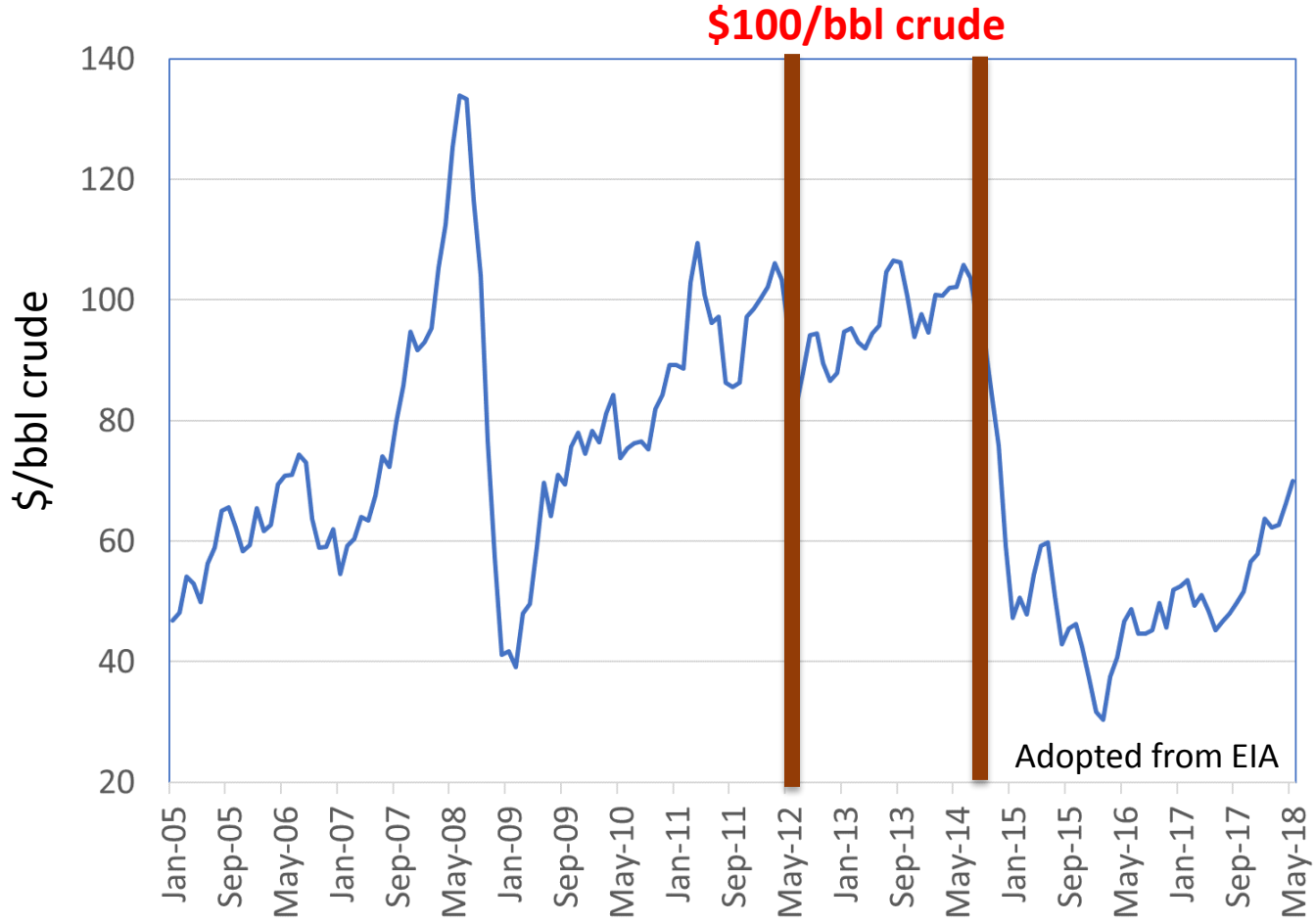
Rennovia's demise, the Triple Rule, and the pursuit of sustainable nylon in a world of low oil prices

March 9, 2018 | Jim Lane

M&G files for bankruptcy protection including Biochemtex and Beta Renewables

November 1, 2017 | Meghan Sapp

The impact of cheap fossil feedstocks

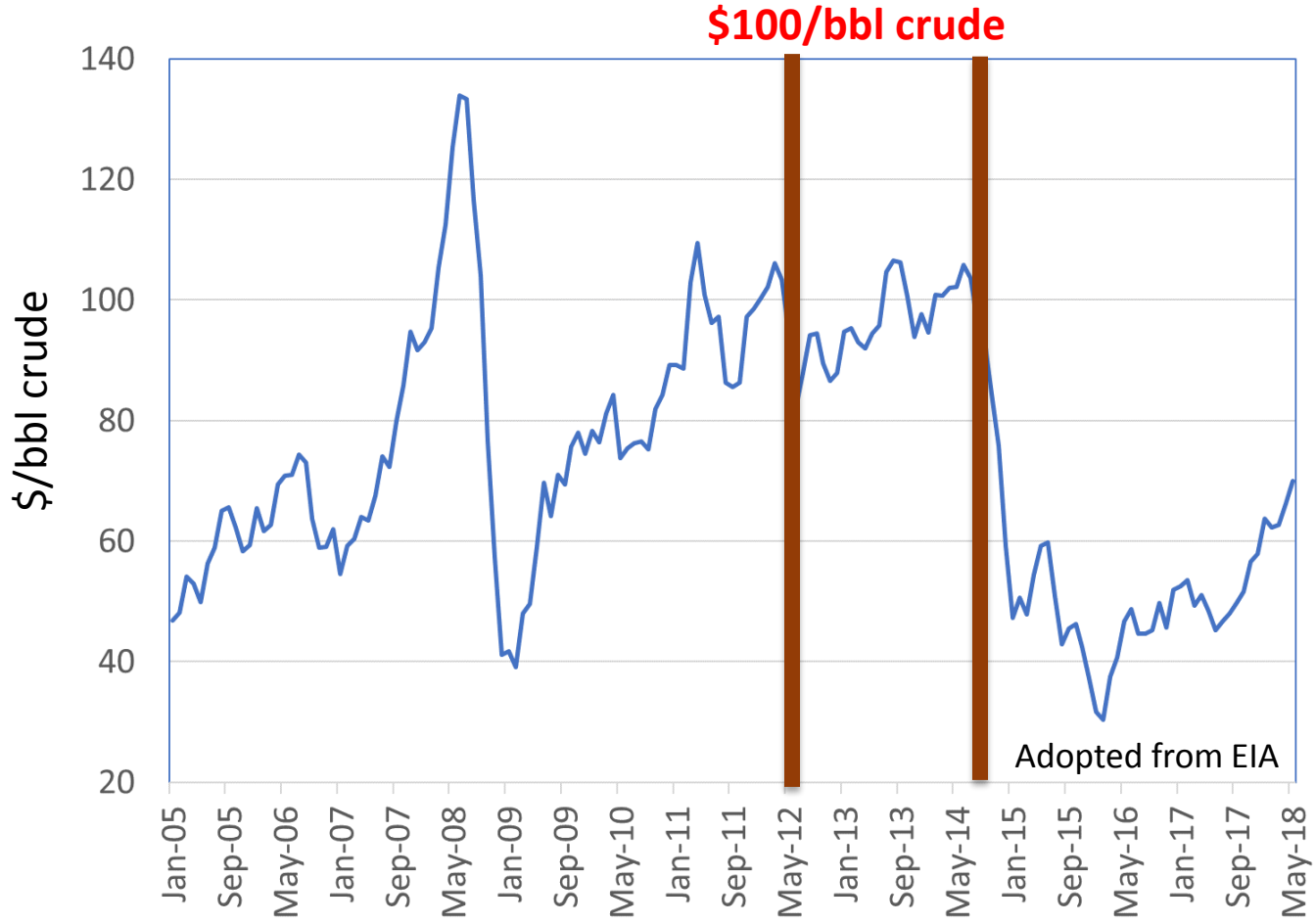


Lux reports that low oil prices are driving VC to shift their focus to biobased chemicals that offer improved performance.

~80% of VC investments in 2016 as compared to 46% from 2010 to 2015.

From: https://www.paint.org/article/interest-biobased-raw-materials-alive-well-despite-lower-petchem-prices/

The impact of cheap fossil feedstocks



"Biobased chemicals are most commonly used today in high-value, low-volume specialty applications and finding success if they are needed to meet regulatory requirements or offer competitive or better performance and/or novel properties," Doris de Guzman (Tecnon OrbiChem)

Companies must also ensure that any biobased raw materials they use do not interfere with the food supply.

From: https://www.paint.org/article/interest-biobased-raw-materials-alive-well-despite-lower-petchem-prices/

Opportunities for new products – Growing sectors

Consumable Goods

Transportation Applications

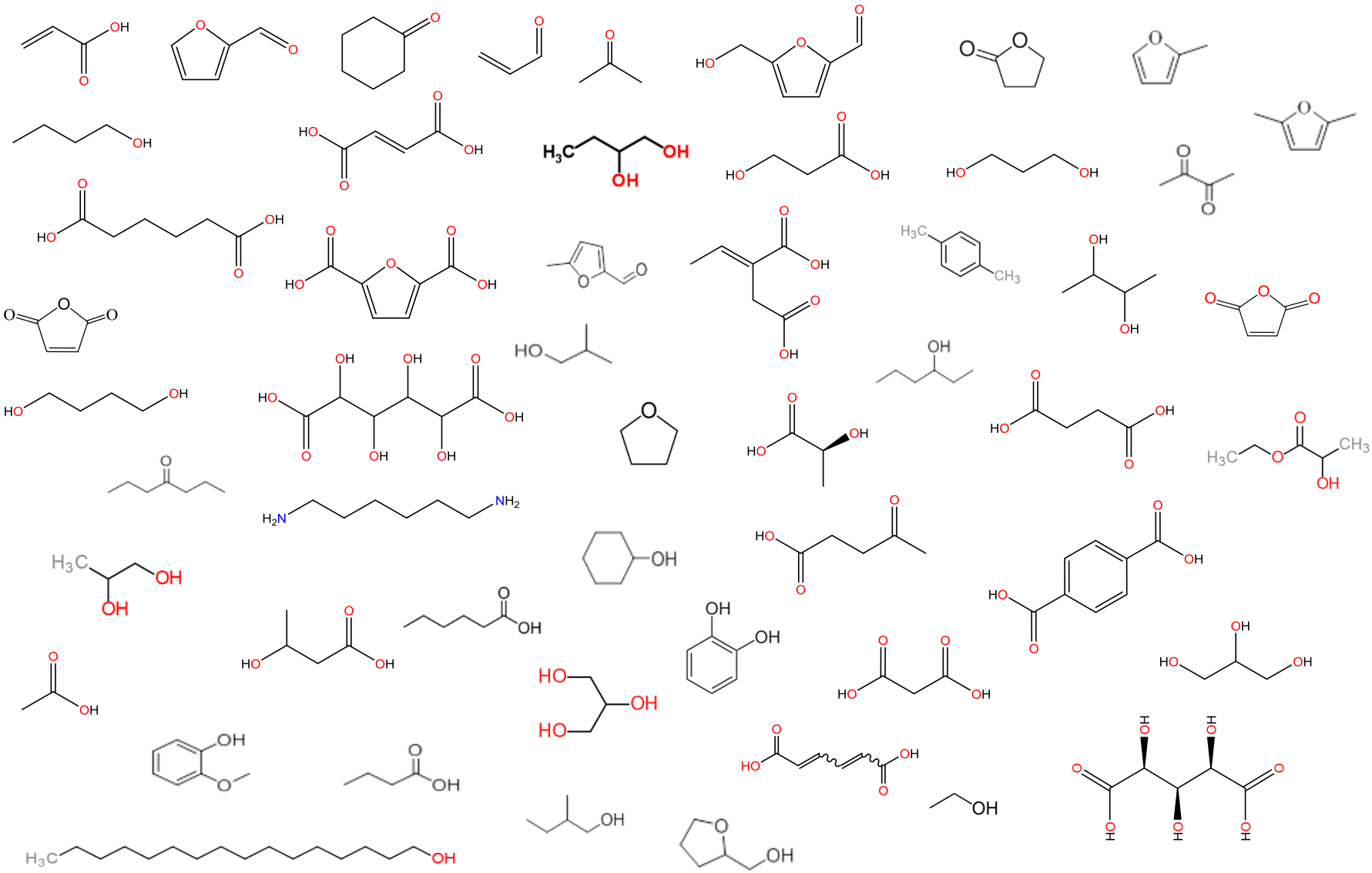
Personal Care Products

Household Cleaners

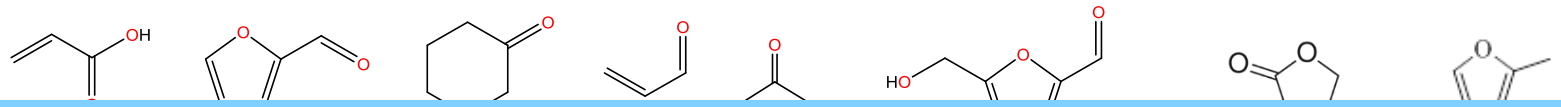
Textiles

Household Goods

Continued development of functional replacements



Continued development of functional replacements

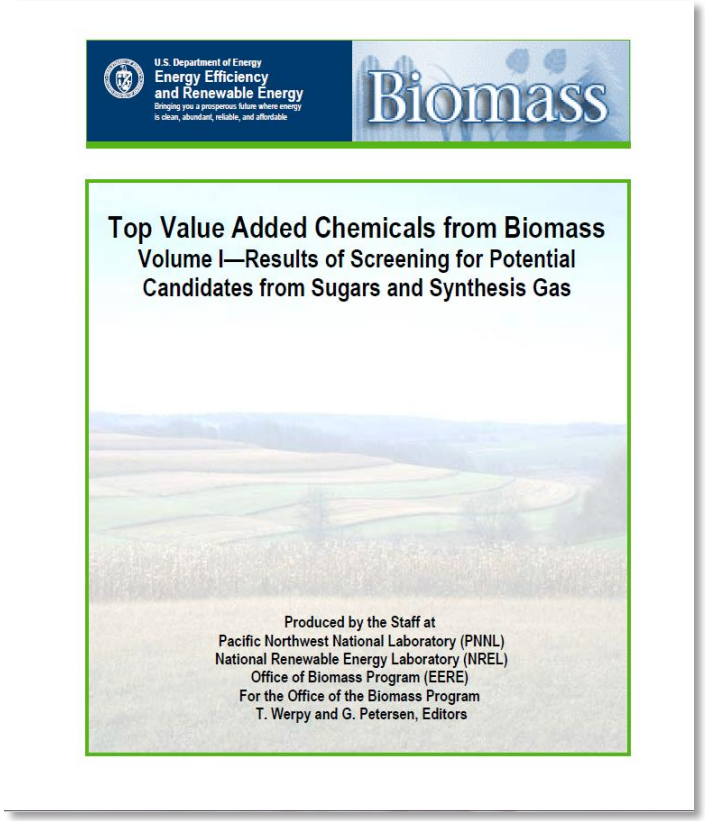


The need and opportunity for research and development

- Need to further explore the desirable properties, performance needs, and potential areas of growth for these bio-derived materials.
- Prior work tends to be either case studies, or focused on producing chemicals and identifying conversion pathways.
- Utilize informed rational design approach towards new and novel chemistries:
  - Systematic approach to understand how the basic, unique molecular structures available from biomass-derived chemicals (such as functionalized oxygen-containing molecules) can translate to performance-advantaged characteristics.
  - Link fundamental modeling with basic R&D for developing conversion pathways.
- Alongside the rational design of these new products, there must be an understanding of what the market will accept and will pay for such novel products.
- Detailed sustainability assessments to ensure that these products and processes are following the principles of green chemistry and to ensure no unintended consequences due the use of these new products.

Next steps in analysis

- Perspective paper on key drivers supporting the development of performance-advantaged products.
- On-going effort to develop a new “Top Ten” report focused on performance-advantaged chemicals from biomass.



https://www.nrel.gov/docs/fy04osti/35523.pdf

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