Novel Vertimass Catalyst for Conversion of Ethanol and Other Alcohols into Fungible Gasoline, Jet, and Diesel Fuel Blend Stocks

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DOE Bioenergy Technologies Office (BETO)
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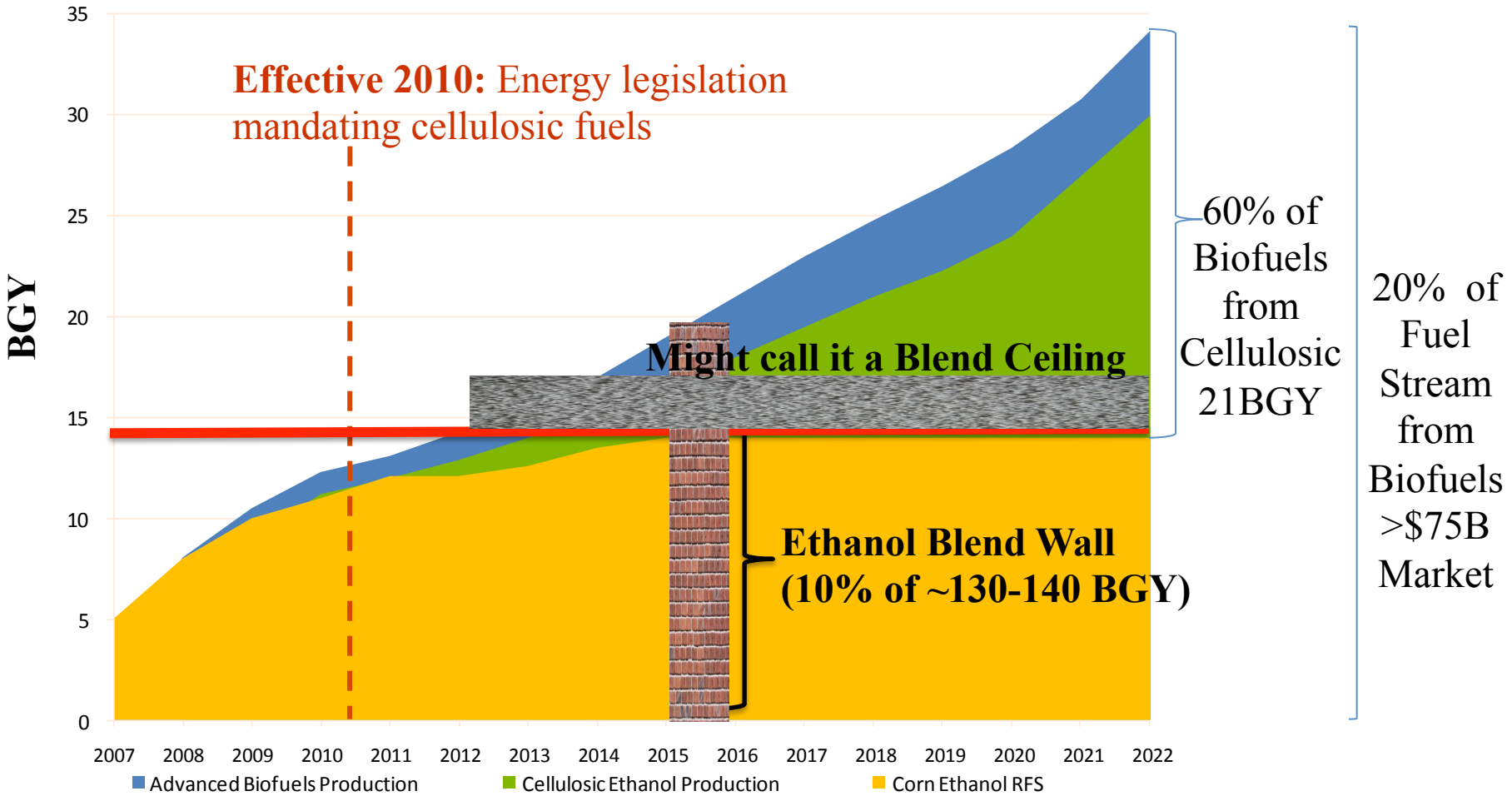
Vertimass Overview

- Vertimass catalyst converts ethanol into gasoline blend stock that eliminates blend wall as obstacle to market growth
- Hydrocarbon products also open up new ethanol markets for diesel and jet fuels and chemicals (e.g., BTX)
- Simple one step bolt-on results in low CAPEX and OPEX
- Advantages include no hydrogen addition, operation at atmospheric pressure and moderate temperatures, near 100% energy yields, minimal light gas production, compatibility with 5-100% ethanol in water, product flexibility, and one hour reaction time
- Exclusive worldwide rights to 2 issued patents, 5 patent applications
- DOE recently selected Vertimass for $2 million award to scale up the technology

2007 RFS and 10% Ethanol Blend Wall



Source: Biofuels for Energy Security and Transportation Act of 2007- U.S. Market

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EPA Slashes Biofuels Targets for 2014, 2015, 2016 under Renewable Fuel Standard*

"**Due to constraints in the fuel market to accommodate increasing volumes of ethanol, along with limits on the availability of non-ethanol renewable fuels, the volume targets specified by Congress in the Clean Air Act for 2014, 2015 and 2016 cannot be achieved.** However, EPA recognizes that the statutory volume targets were intended to be ambitious; Congress set targets that envisioned growth at a pace that far exceeded historical growth rates. Congress clearly intended the RFS program to incentivize changes that would be unlikely to occur absent the RFS program. Thus while EPA is proposing to use the tools provided by Congress to waive the annual volumes below the statutory levels, we are proposing standards that are directionally consistent with Congress' clear goal of increasing renewable fuel production and use over time. The proposed volumes would require significant growth in renewable fuel production and use over historical levels. EPA believes the proposed standards to be ambitious but within reach of a responsive marketplace."**

*Biofuels Digest, May 29, 2015

**EPA-420-F-15-028, May 2015

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Challenges for Fuel Ethanol

- Ethanol is not fully fungible with petroleum fuels for transport via existing pipelines
- Ethanol creates concerns about lower mileage and different solvent properties
- Existing ethanol production of ~14 billion gallons is saturating U.S. 10% gasoline blend market
- Higher level blends require additional infrastructure, engine modifications for lower air-fuel ratios, and auto and oil company acceptance
- Ethanol energy density is too low for jet fuel
- Ethanol cannot be easily run in compression ignition engines for heavy duty vehicles

The Vertimass Bolt-On Solution

5-100% Ethanol

Heat Exchanger

Catalyst

Decanter

Fractionation (if needed)

Chemicals, e.g., BTX

Jet Fuel

Diesel

JP-8

Gasoline

Existing infrastructure

Through the ethanol blend wall and opening up new ethanol markets

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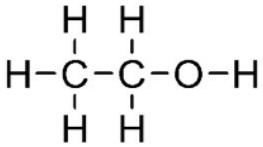
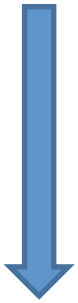
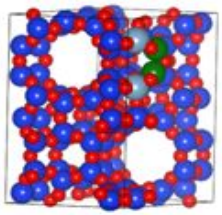
Catalyst Transforms Ethanol into Fungible Blend Stocks in One Step without Adding Hydrogen

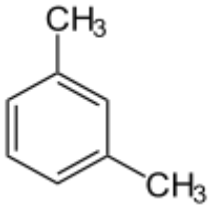


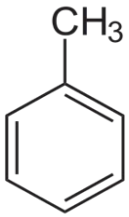
Hydrous ethanol from distillation column





Low-cost metal-exchanged zeolite catalyst



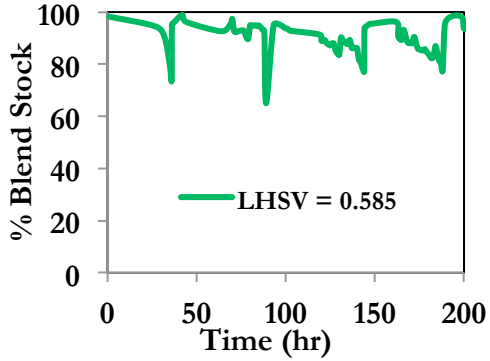


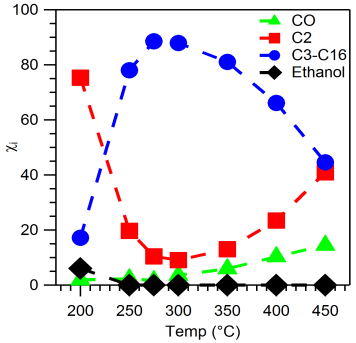
Aromatic and aliphatic HCs typical of blend stocks (C_4-C_{12}) with water and trace ethylene

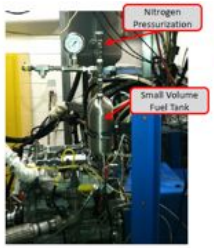
Group	% Volume
Paraffins	3.855
I-Paraffins	9.588
Olefins	5.371
Naphthalenes	1.988
Aromatics	79.198
Oxygenates	0.00
Unidentified	4.203

Catalyst Developed by Oak Ridge National Laboratory (ORNL)

- Processed up to 2 gals/day ethanol to hydrocarbon fuels
- Catalyst regenerated repeatedly with air over long lifetime
- Achieves high liquid fuel yields with high energy efficiency
- Performed well in small scale engine tests
  - (RON+MON)/2 = 100
  - RVP = 5.1







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Catalyst Advantages

- Single step conversion of ethanol and other alcohols into hydrocarbon blend stocks with high yields
- No hydrogen addition
- High yields of targeted products with minimal light gases
- Mild (atmospheric pressure and 275-350^{o}C) operating conditions
- Robust catalyst
- Ability to process 5 to 100% ethanol concentrations
  - Avoids mole sieve and could displace rectification as well
- Could allow increased ethanol production in given plant
- Product flexibility to respond to changing market demands
- Minimal disruption to existing biofuels production
- Simplicity results in Low CAPEX and OPEX

Funding for Development of Transformative Catalyst

Department of Energy BioEnergy Technology Office (BETO)

Following proof-of-concept through support by:

BioEnergy Science Center (BESC) supported by U.S. DOE Office of Biological and Environmental Research in the Office of Science

Oak Ridge National Laboratory Laboratory Directed Research and Development funds

*Catalyst research and development was sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, BioEnergy Technologies Office under contract DE-AC05-00OR22725 with UT-Battelle, LLC.
Initial proof of concept funding was by the BioEnergy Science Center (BESC) which is supported by the U.S. DOE Office of Biological and Environmental Research in the Office and by the Oak Ridge National Laboratory Laboratory Directed Research and Development funds of Science.

Why Ethanol as a Platform?

- Large scale ethanol production in place
  - U.S. ~13.4 billion gals/year mostly from corn starch
  - Brazil ~6.3 billion gals/year from cane sugar
  - Rest of world ~2.8 billion gals/year
- Cellulosic ethanol production starting to ramp up
  - Includes Abengoa, American Process, DuPont, Enerkem, Ineos, M&G/Beta-Renewables, and POET
  - USDA and DOE estimate up to ~1.4 billion dry tons/year of biomass could be available to produce ~100 billion gallons of gasoline equivalent

Huge Game Changer Potential

2012 U.S. and World Transportation Fuel Sales

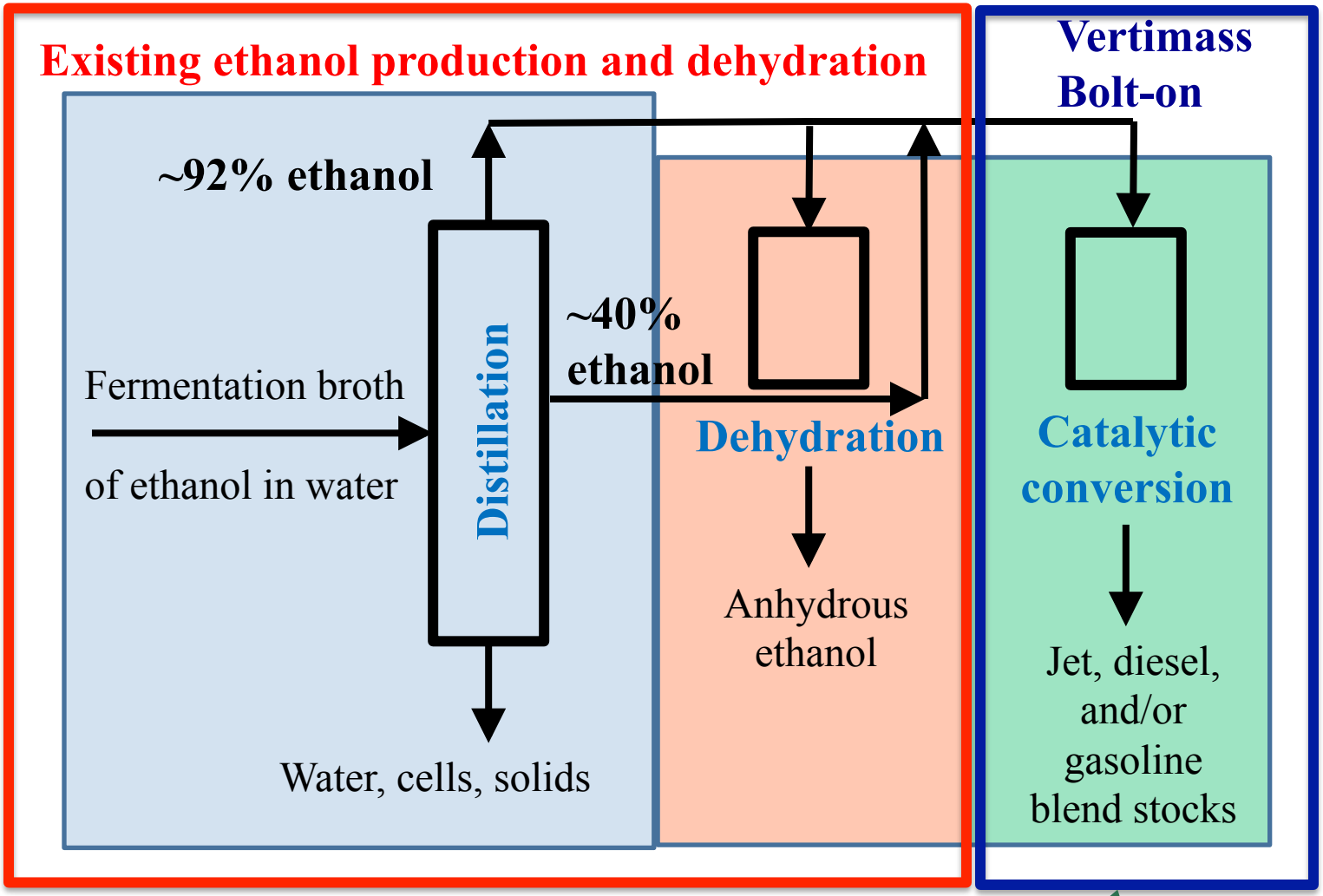
Fuel type	U.S.	World
	billion gallons/year	
Gasoline	133	346
Jet fuel	21	83
Diesel fuel (distillate oil)	57	404
Total of above	211	833
Ethanol	13.4	22.5

Source: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=79&pid=80&aid=1&cid=US,&syid=2008&eyid=2012&unit=TBPD

How is Vertimass Technology Unique?

- Discontinuous:
  - Makes entirely different product from existing platform without need for entire production process
- Defensible:
  - 2 patents issued
  - 5 other patent applications filed
  - Very positive freedom to operate analysis
- Disruptive:
  - Overcomes blend wall for light duty vehicles
  - Opens up jet and diesel fuel markets to ethanol

More Product Flexibility or Displace Mole Sieves or Mole Sieves Plus Rectification



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Next Step: Position to Scale-Up in 2 Years

- Engaged major engineering firm to start scale up to commercial operations within 2 years
  - Worldwide operations
  - Project management, EPC for the energy and chemicals industries
  - Conceptual studies, Basic Engineering Packages (BEPs), EPC, commissioning, startup, and validation
  - Existing catalyst piloting facilities with 40 years experience in catalyst testing and process development
  - Scale-up catalytic processes by up to 10^6 times
- DOE Bioenergy Technology Office (BETO) selected Vertimass for $2 million award to accelerate scale-up

The Vertimass Team – Synergistic Expertise

- Chairman – William A. Shopoff
- President and CEO – Charles Wyman, Ph.D.
- COO – John Hannon, Ph.D.
- EVP – Tom Mullen
- CFO – Sandra Sciutto, CPA
- Board Member– Martin Keller, Ph.D.
- Technology Development Engineer – Brian Davison, Ph.D.
- Catalyst Development Scientist – Chaitanya Narula, Ph.D.
- Team of consultants with extensive experience in:
  - Biofuels development and commercialization
  - Catalyst research and development
  - Catalyst scale-up
  - Ethanol technology and markets
  - Petroleum refining and markets

Vertimass Take Home Messages

- Disruptive Vertimass technology:
  - Built on established low cost ethanol production
  - Eliminates Blend Wall that threatens ethanol market growth
  - Opens up air travel and heavy duty vehicle markets to ethanol
- Catalyst offers numerous operational advantages
- Low CAPEX and OPEX for simple one step Vertimass Bolt-On
- Secure worldwide position through exclusive rights to 2 issued patents, 5 applications, and strong freedom to operate analysis
- Prosaic catalyst for ethanol/water vapor conversion can be scaled up after 2 years through piloting by major engineering firm
- DOE BETO selection of Vertimass for $2 million award accelerates commercialization of catalytic ethanol conversion to fungible fuels
- Vertimass is seeking strategic partners and investors to ready the process for commercialization within 3 years

Business: Develop and License Technology for Ethanol Conversion into Fungible Hydrocarbon Fuel Blend Stocks