ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

We will begin momentarily at 2pm ET

Slides available now! Recordings will be available to ACS members after one week.

www.acs.org/acswebinars

Contact ACS Webinars ® at acswebinars@acs.org

1

Have Questions?

ACS Chemistry for Life®

"Why am I muted?"
Don't worry. Everyone is muted except the presenter and host. Thank you and enjoy the show.

Type them into questions box!

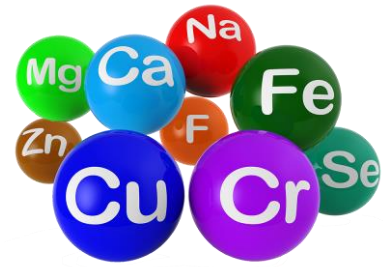
Contact ACS Webinars ® at acswebinars@acs.org

2

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

Have you discovered the missing element?



http://bit.ly/ACSjoin

Find the many benefits of ACS membership!

3

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

Benefits of ACS Membership

C&EN
CHEMICAL & ENGINEERING NEWS

Chemical & Engineering News (C&EN)
The preeminent weekly news source.

ACS Presentations on Demand™
YOUR SOURCE FOR RECORDED MEETING CONTENT

NEW! Free Access to ACS Presentations on Demand®
ACS Member only access to over 1,000 presentation recordings from recent ACS meetings and select events.

NEW! ACS Career Navigator
Your source for leadership development, professional education, career services, and much more.

http://bit.ly/ACSjoin

4

Let's get Social…post, tweet, and link to ACS Webinars during today's broadcast!

ACS Chemistry for Life®

facebook.com/acswebinars

@acswebinars

LinkedIn Search for "acswebinars" and connect!

5

How has ACS Webinars® benefited you?

ACS Chemistry for Life®

"A perfect webinar! Dee Strand was fantastic. *The Chemistry of Hello: Lithium Ion Batteries* was of the clearest and most educational per unit time technical presentations that I have heard in my more than 25 years as a professional scientist."

Fan of the Week

Walter Cicha, Ph.D.,
Industrial Technology Advisor,
Industrial Research Assistance Program,
National Research Council of Canada

Be a featured fan on an upcoming webinar! Write to us @ acswebinars@acs.org

6

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

7

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

Learn from the best and brightest minds in chemistry!
Hundreds of webinars presented by subject matter experts in the chemical enterprise.

Recordings are available to current ACS members one week after the Live broadcast date. **www.acs.org/acswebinars**

Broadcasts of ACS Webinars® continue to be available to the general public LIVE every Thursday at 2pm ET!

8

www.acs.org/acswebinars

Upcoming ACS Webinars®

www.acs.org/acswwebinars

Thursday, April 14, 2016

Creating a Stand Out Professional Development Plan

Dorie Clark, Author and Marketing Strategy Consultant, Clark Strategic Communications, Inc.

John Mihalick, Strategic Accounts Manager, ACS Professional Advancement

Thursday, April 21, 2016

Tackling Toxics: The Chemical Class Approach towards Healthier Products and Materials

Arlene Blum, Executive Director**,** Green Science Policy Institute

Graham Peaslee, Professor of Chemistry, Hope College

Contact ACS Webinars ® at acswebinars@acs.org

2016 Material Science Series

http://bit.ly/2016MaterialScienceSeries

Ever since the Model-T first rolled off the production line in 1908, the world of transportation has never been the same. Join us as we examine the science behind innovations that will drive the world for the next 100 years.

* If you are attending today, you are already signed for all the webinars in the “Chemistry of Go” mini-series so just save the dates of May 5th and June 2nd for the upcoming webinars.

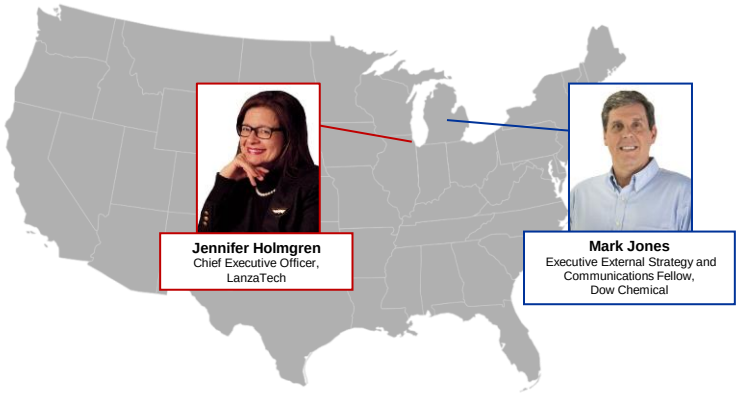
The 2016 Material Science Series is co-produced with ACS Industry Member Programs and C&EN

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

2016 Material Science Series

"Chemistry of Go: Innovations in Alternative Fuels"



Slides available now! Recordings will be available to ACS members after one week

www.acs.org/acswebinars

The 2016 Material Science Series is co-produced with ACS Industry Member Programs and C&EN

11

"The Chemistry of Go:
Innovations in Alternative Fuels"

Jennifer Holmgren, CEO, LanzaTech

LanzaTech
capturing carbon. fueling growth.

12

Easter Parade New York City 1900

LanzaTech
capturing carbon. fueling growth.

Easter Parade New York City 1913

Source: George Grantham Bain Collection.

LanzaTech
capturing carbon. fueling growth.

What do we need to "Go"?

Movement requires energy.
Fuels carry energy.

What makes a good fuel?

Energy-dense

Inexpensive

Easy to handle

LanzaTech
capturing carbon. fuelling growth.

15

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT

What percentage of cars in 1900 were electric?

- Less than a quarter
- About a quarter
- Between a quarter and a half
- More than half
- About three-fourths

16

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT

What percentage of cars in 1900 were electric?

- Less than a quarter
- About a quarter
- Between a quarter and a half (37%)
- More than half
- About three-fourths

17

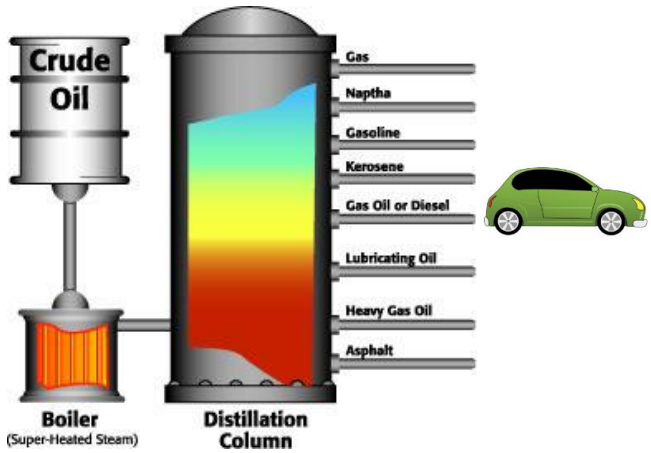
Evolution of Go…Steam, Electricity and Coal

LanzaTech
capturing carbon. fueling growth.

18

And then came Petroleum…

- Reliable
- Practical
- Cheap
- Efficient
- Easier to Control
- Less likely to explode



LanzaTech
capturing carbon. fueling growth.

19

Refinery Output

Crude Oil

Asphalt

Bunker Fuel (Ships)

Refinery Products

Gasoline/Cars

Jet Fuel/Airplanes

Diesel Trucks/ Construction Equipment

Lube Oils

LanzaTech
capturing carbon. fueling growth.

20

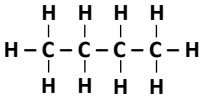
Refinery Overview

- Crude oil is a complex mixture of various lengths and shapes of carbon and hydrogen molecules, with different chemical properties. In addition, crude oil contains significant levels of heteroatoms such as S, N which must be removed before burning fuels.
- A typical US refinery processes 100,000 – 250,000 barrels (~ 4 – 10 million gallons) of crude oil per day.
- Processing unit operations vary by refinery and depend on crude oil used as input as well as desired product slate.

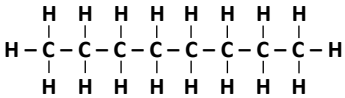
Crude Oil

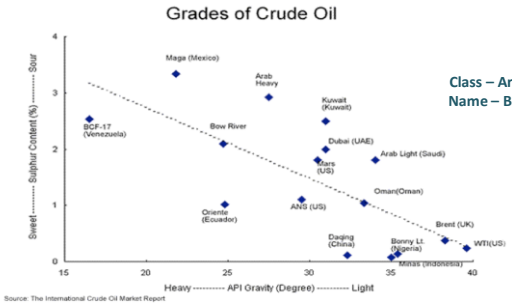
- Crude oil varies in both density and sulfur content depending on its origin around the world.
- This results in differences in cost for purchasing the oil and required technology to refine it into products.

Class – Paraffin
Name – Butane

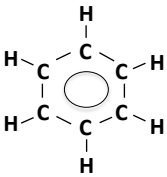


Class – Aromatic
Name – Octane

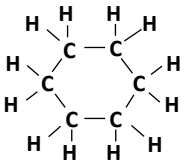




Class – Aromatic
Name – Benzene



Class – Cyclo-paraffin
Name – Cyclohexane



Chemical Conversion: Adding Value

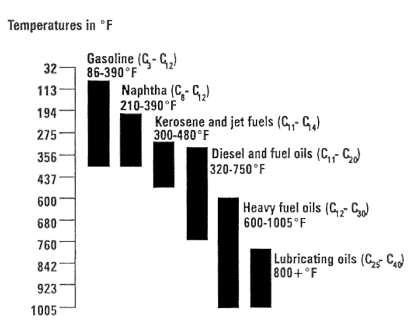
- **Cracking**
  - Converts heavy gas oils and residual to higher value gasoline and diesel components
  - Cracking can be thermal (Coker) or catalytic (Fluidized Catalytic Cracker)
- **Alkylation**
  - Converts shorter-chain molecules to longer-chain molecules
  - Typically C_3/C_4 molecules upgraded to gasoline components
- **Upgrading**
  - Improvement of low-octane fuels to high-octane fuels (Reformer)
  - Dehydrogenation reactions, converting linear hydrocarbons to branched and cyclic hydrocarbons

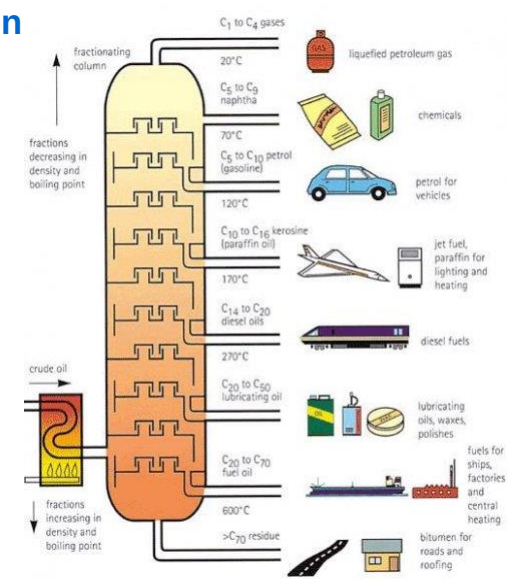
LanzaTech capturing carbon. fueling growth.

23

Boiling Point Separation

- Smaller hydrocarbons are gaseous with low boiling points
- Longer chains are liquids, then waxes and finally solids

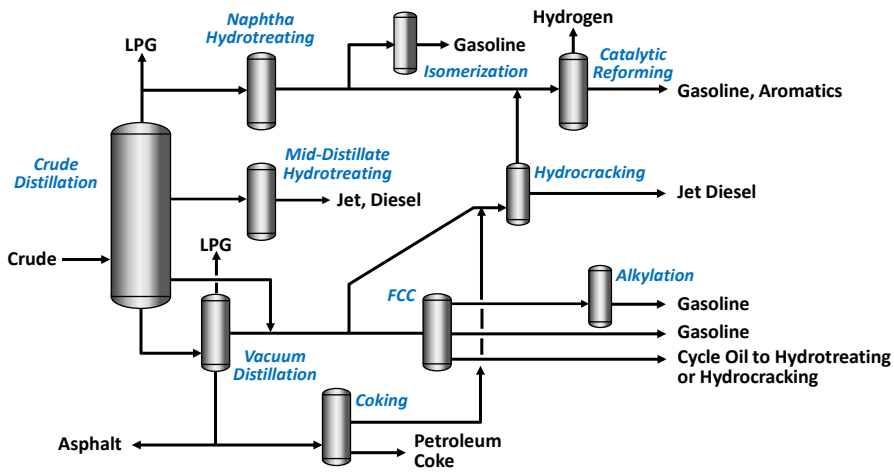




LanzaTech capturing carbon. fueling growth.

24

Generic Refining Flowscheme



Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT

How are the hydrocarbons produced at the top of the column, different from those produced lower down?

- They have longer chains and lower boiling points
- They have shorter chains and lower boiling points
- They have longer chains and higher boiling points
- They have shorter chains and higher boiling points

Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT

How are the hydrocarbons produced at the top of the column, different from those produced lower down?

- They have longer chains and lower boiling points
- They have shorter chains and lower boiling points
- They have longer chains and higher boiling points
- They have shorter chains and higher boiling points

* The longer the chain the higher the boiling temperature.

27

Evolution of "Go"

Vehicles have changed a lot. Their fuel? Not so much

Cars have been tied to gasoline for most of their history, but fuel tech keeps evolving…

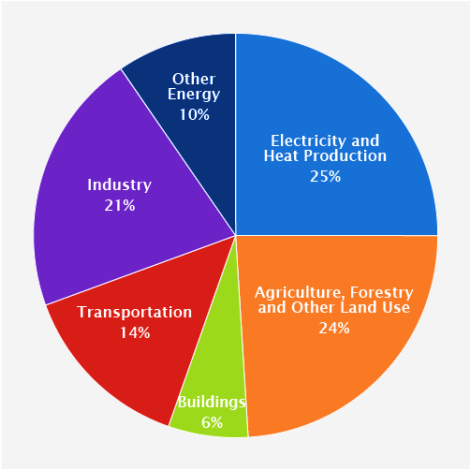
Now more than ever, we need to look at alternative solutions and technologies to make us "GO"

LanzaTech

capturing carbon. fueling growth.

28

The Status Quo is not an Option

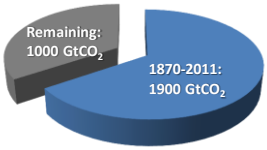


14% of Global CO_2 Emissions come from transportation fuels

LanzaTech
capturing carbon. fueling growth.

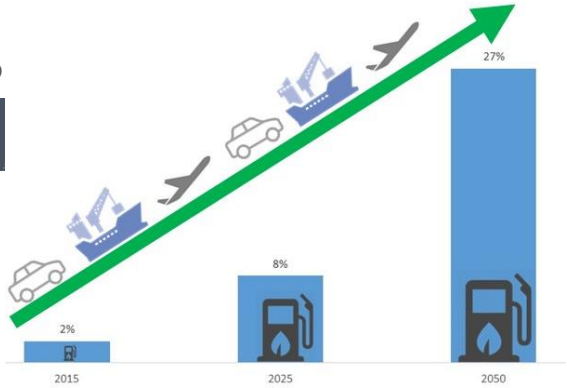
29

A Carbon Smart World



65% of 2°carbon budget: USED

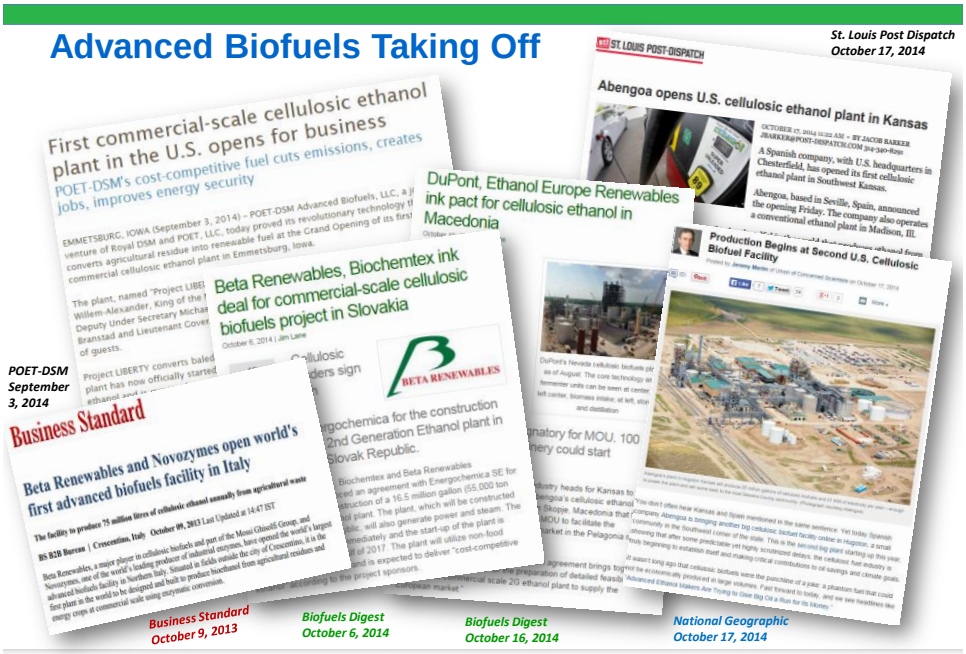
Must stay in the ground



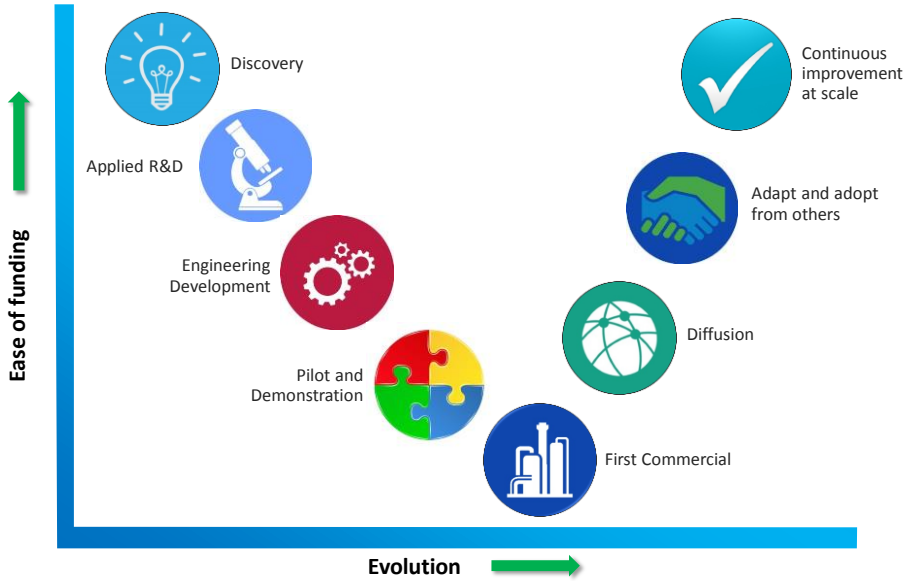
LanzaTech
capturing carbon. fueling growth.

30

Advanced Biofuels Taking Off



Getting a New Process to Scale



RTP™ History

1984:
Foundation

1989-1998
Commercialization & Scale-up US - $20+M sale for Chemicals

1998-2005
Petroleum Business Development & sale for US$100 MM

2006-Present
Renewable Liquid Fuels: Key alliances & Project execution

*** Since 1996, Ensyn has returned to shareholders 2x the amount it has raised in equity funding**

ENSYN

33

Commercial Isobutanol/Ethanol Plant in Luverne, MN

gevo

Agri-Energy

Statistics

- First commercial scale renewable isobutanol plant in the world
- Purchased in 2010 & 100% owned by Gevo
- World-scale chemicals plant

Commissioning timeline

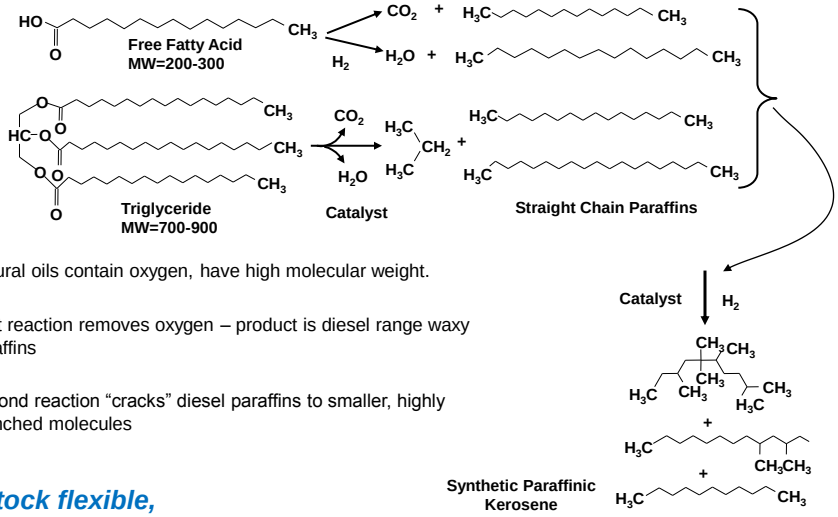
Date	Event
September 2010	Purchased Luverne plant
May-Sep. 2012	Encountered unexpected levels of contamination
Sep.-May 2013	Revamped plant and procedures to address contamination issues
May – Sep. 2013	Tested new systems and procedures Made minor system and hardware upgrades
Oct.– April 2014	Encountered operability issues related to water recycling and solids handling
May 2014 – Present	Running in side-by-side mode to better handle water and solids. Improves operability of plant, and simplifies IBA production. WORKS WELL

	gevo Luverne Facility	Typical Specialty Chemical Plant
Feedstock	Carbohydrates-based	Petroleum-based
Expected Production	100 MM lbs per year of Isobutanol/Ethanol 100 MM lbs per of year of animal feed	50-175 MM lbs per year[1]

(1) Derived from a sample of 10 operating specialty chemical plants producing chemicals such as Methyl Amines, Dimethyl Formamide, EPVC, Phenol Acetone, Formaldehyde, Polyamides and Methanol
Source: International Process Plants, EIA

34

Hydro-Processed Esters and Fatty Acids (HEFA) and Green Diesel



- Natural oils contain oxygen, have high molecular weight.
- First reaction removes oxygen – product is diesel range waxy paraffins
- Second reaction "cracks" diesel paraffins to smaller, highly branched molecules

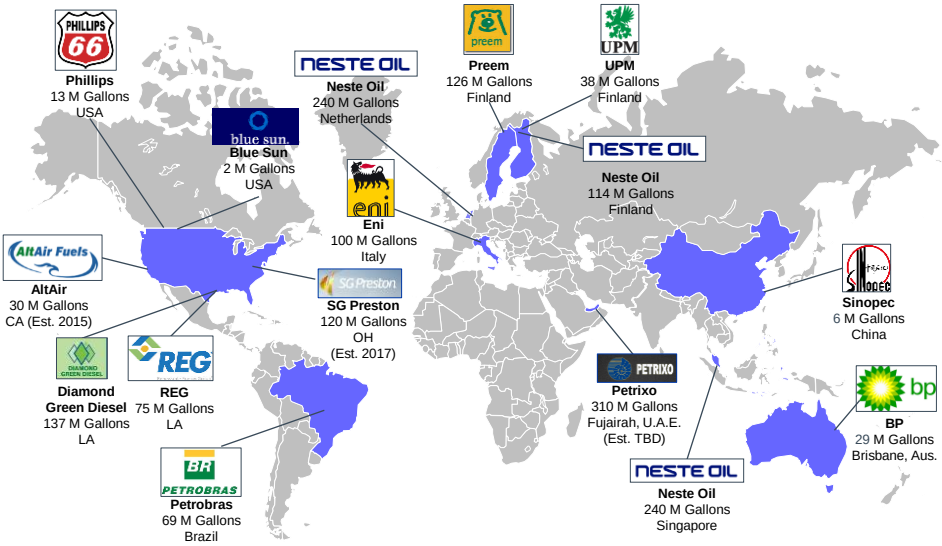
Feedstock flexible,

but with consistent product properties

Source: Dr. James Kinder, Boeing

35

Global green diesel & HEFA production



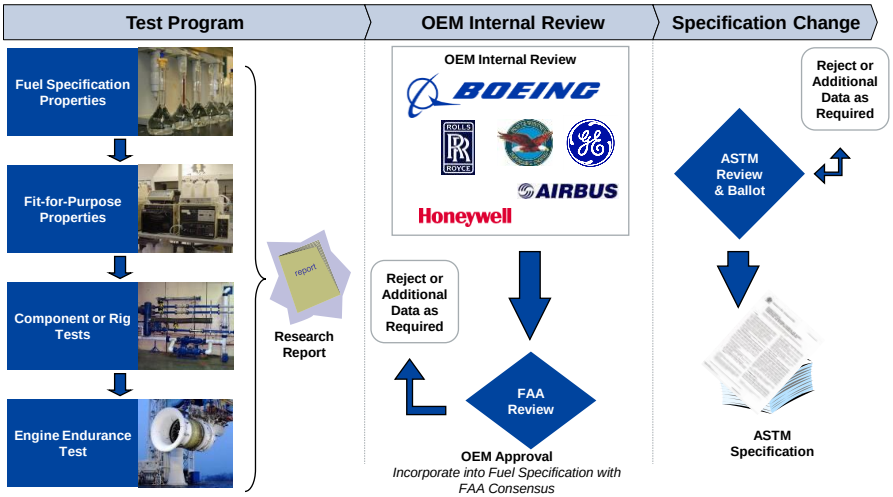
Supply available to address significant aviation markets

Source: Dr. James Kinder, Boeing

36

The Boeing Company

ASTM Fuel Approval Process- ASTM D4054



In depth, multiparty review

Source: Dr. James Kinder, Boeing

Great Progress on Certification for Flight

Certification

"Less than a decade ago, the prospect of flying commercial aircraft on sustainable aviation fuels (SAF) seemed unrealistic due to the associated technical and safety challenges, the developments have been impressive!" IATA Roadmap

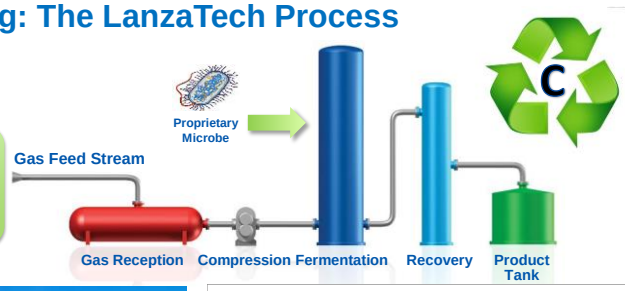
Type	ASTM approval	When
Fischer Tropsch (FT) (*or BtL*)	Max 50% blend	2009
Hydrotreated Esters and Fatty Acids (HEFA)	Max 50% blend	2011
Renewable Synthesized Iso-Paraffinic (SIP)	Max 10% blend	2014
Butanol to Jet Fuel (ATJ)	Max 30% blend	2016

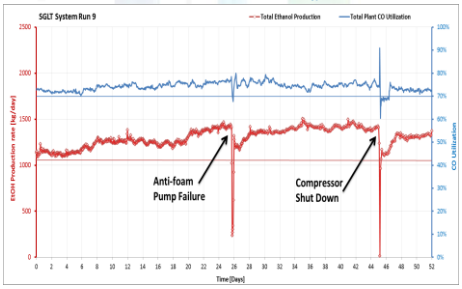
***Pipeline**: Green Diesel, Ethanol to Jet (EtJ), pyrolysis and catalytic cracking (Hydroprocessed Depolymerized Cellulosic Jet), catalytic hydrothermolysis and catalytic conversion of sugars.*

LanzaTech capturing carbon. fueling growth.

Carbon Recycling: The LanzaTech Process

Gas fermentation technology converts C-rich gases to fuels and chemicals





Performance milestones achieved and exceeded for >1000 hours

LanzaTech capturing carbon. fueling growth.

39

ArcelorMittal, Gent

Ground Works Started October 2015

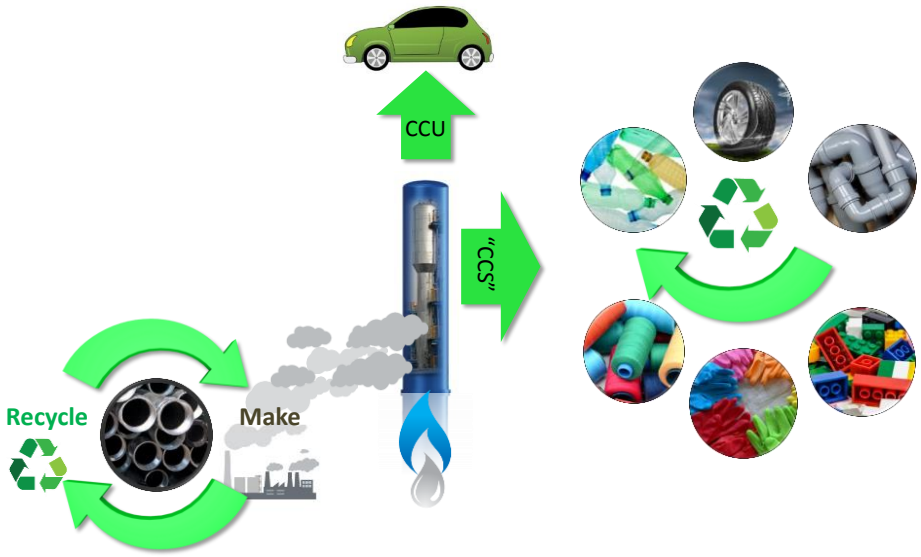
Gas Testing Station Produces Ethanol January 2016

Connection to Steel Mill Gas Lines March 2016

LanzaTech capturing carbon. fueling growth.

40

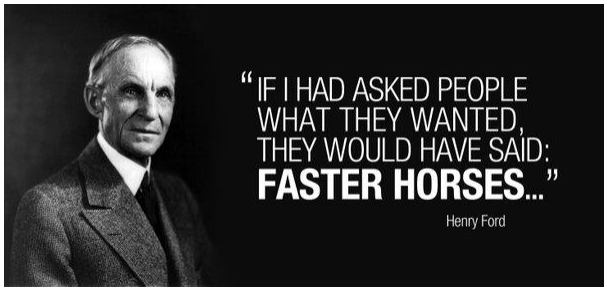
Embrace the Circular Economy: Recycle Everything



LanzaTech
capturing carbon. fueling growth.

41

All Solutions Must Succeed…
Even Those We Don't Yet Know.



LanzaTech
capturing carbon. fueling growth.

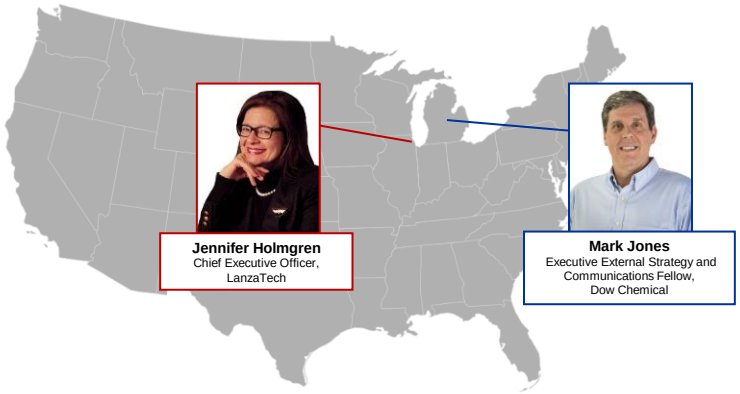
42

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

2016 Material Science Series

"Chemistry of Go: Innovations in Alternative Fuels"



Slides available now! Recordings will be available to ACS members after one week

www.acs.org/acswebinars

The 2016 Material Science Series is co-produced with ACS Industry Member Programs and C&EN 43

2016 Material Science Series

http://bit.ly/2016MaterialScienceSeries

ACS Chemistry for Life®

Ever since the Model-T first rolled off the production line in 1908, the world of transportation has never been the same. Join us as we examine the science behind the innovations that will drive the world for the next 100 years.

* If you are attending today, you are already signed for all the webinars in the "Chemistry of Go" mini-series so just save the dates of May 5th and June 2nd for the upcoming webinars.

The 2016 Material Science Series is co-produced with ACS Industry Member Programs and C&EN 44

Upcoming ACS Webinars®

www.acs.org/acswebinars

ACS Chemistry for Life®

Thursday, April 14, 2016

Creating a Stand Out Professional Development Plan

Dorie Clark, Author and Marketing Strategy Consultant, Clark Strategic Communications, Inc.

John Mihalick, Strategic Accounts Manager, ACS Professional Advancement

Thursday, April 21, 2016

Tackling Toxics: The Chemical Class Approach towards Healthier Products and Materials

Arlene Blum, Executive Director**,** Green Science Policy Institute

Graham Peaslee, Professor of Chemistry, Hope College

Contact ACS Webinars ® at acswebinars@acs.org

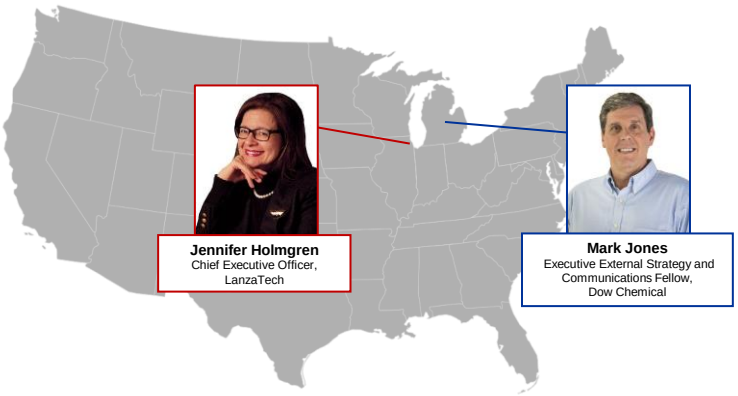
45

ACS Webinars®
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

2016 Material Science Series

"Chemistry of Go: Innovations in Alternative Fuels"



Slides available now! Recordings will be available to ACS members after one week

www.acs.org/acswebinars

The 2016 Material Science Series is co-produced with ACS Industry Member Programs and C&EN

46

How has ACS Webinars® benefited you?

ACS Chemistry for Life®

"A perfect webinar! Dee Strand was fantastic. *The Chemistry of Hello: Lithium Ion Batteries* was of the clearest and most educational per unit time technical presentations that I have heard in my more than 25 years as a professional scientist."

Fan of the Week

Walter Cicha, Ph.D.,
Industrial Technology Advisor,
Industrial Research Assistance Program,
National Research Council of Canada

Be a featured fan on an upcoming webinar! Write to us @ acswebinars@acs.org

47

ACS Webinars®
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

48

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

Benefits of ACS Membership

C&EN
CHEMICAL & ENGINEERING NEWS

Chemical & Engineering News (C&EN)
The preeminent weekly news source.

ACS Presentations on Demand™
YOUR SOURCE FOR RECORDED MEETING CONTENT

NEW! Free Access to ACS Presentations on Demand®
ACS Member only access to over 1,000 presentation recordings from recent ACS meetings and select events.

NEW! ACS Career Navigator
Your source for leadership development, professional education, career services, and much more.

http://bit.ly/ACSjoin

49

ACS Webinars
CLICK • WATCH • LEARN • DISCUSS

ACS Chemistry for Life®

ACS Webinars® does not endorse any products or services. The views expressed in this presentation are those of the presenter and do not necessarily reflect the views or policies of the American Chemical Society.

Contact ACS Webinars ® at acswebinars@acs.org

50

Upcoming ACS Webinars®

www.acs.org/acswwebinars

Thursday, April 14, 2016

Creating a Stand Out Professional Development Plan

Dorie Clark, Author and Marketing Strategy Consultant, Clark Strategic Communications, Inc.

John Mihalick, Strategic Accounts Manager, ACS Professional Advancement

Thursday, April 21, 2016

Tackling Toxics: The Chemical Class Approach towards Healthier Products and Materials

Arlene Blum, Executive Director**,** Green Science Policy Institute

Graham Peaslee, Professor of Chemistry, Hope College

Contact ACS Webinars ® at acswebinars@acs.org

51