Commercializing Conventional and Advanced Liquid Biofuels from Biomass

Task 39
IEA Bioenergy

Inside This Issue

From the Task

By Mahmood Ebadian, Susan van Dyk, Jack Saddler and Jim McMillan

Since publishing our last Newsletter, IEA Bioenergy Task 39 has continued its work to advance commercialization of sustainable, lower carbon liquid biofuels for transport.

IEA Bioenergy Task 39 held it first business meeting of 2018 in Beijing, China on April 7-9. This meeting was graciously hosted by Professor Tianwei Tan of the Beijing University of Chemical Technology (BUCT) and organized by Dr Huili Zhang of BUCT. We sincerely thank our Chinese hosts for their generous hospitality and good organization, which were key to us being able to convene a successful Task meeting in Beijing. The IEA Bioenergy Technology Collaboration Program (TCP) and its Task 39 have been trying to recruit China to become a member of IEA Bioenergy and Task 39 for several years, and this meeting afforded the Task as well as several members of the IEA Bioenergy Executive Committee (ExCo) an excellent opportunity to meet face to face with senior government officials from China to promote the work of IEA Bioenergy and show first hand some of the benefits of joining the IEA Bioenergy TCP.

This meeting was a resounding success in advancing IEA Bioenergy's relationship with China. Representatives from all Task 39 participants other than South Africa and Austria attended. In addition, to represent the ExCo and provide a broader view of the IEA Bioenergy TCP, we were fortunate to also have attending ExCo Chair Jim Spaeth (USA; provided overview of IEA Bioenergy TCP), ExCo Vice-chair Paul Bennett (New Zealand; provided overview of Task 34 (Liquefaction)) and Ex-Co member Mark Brown (Australia; provided overview of Task 43 (Feedstocks)). In addition to many observers from China, a representative from Indonesia also attended, ultimately expressing interest in Indonesia joining the TCP. Alas, the Indian delegation we'd expected, were unable to attend.

Task 39 Members - ExCo* and Country Leads+ and Task Representatives

Australia
Mark Brown*
Steve Rogers

Austria
Theodor Zillner*
Dina Bacovsky

Brazil
Miguel Ivan Lacerda de Oliveira*
Antonio Maria Bonomi

Canada
Alex MacLeod*
Jack Saddler
Warren Mabee

Denmark
Ane Katharina Paarup Meyer*
Claus Felby
Michael Persson
Henning Jørgensen

European Commission
Kyriakos Maniatis*
Laura Lonza
Adrian Oconnell

Germany
Birger Kerckow*
Franziska Müller-Langer
Nicolaus Dahmen

Japan
Seiji Morishima*
Shiro Saka
Satoshi Aramaki

Netherlands
Kees Kwant*
Timo Gerlagh
Johan van Doesum

New Zealand
Paul Bennett*
Ian Suckling

South Africa
Thembakazi Mali*
Emile van Zyl

South Korea
Seungchan Chang*
Jin Suk Lee
Kyu Young Kang
Seonghun Park

Sweden
Asa Forsum*
Tomas Ekbom
Leif Jonsson

United States
Jim Spaeth*
Jim McMillan

Image Source: esf.edu.com

Day one of the meeting was devoted to internal Task 39 business and primarily attended by Task 39 members, focussing on review of the Task's ongoing and recently completed work; the Task's budget status; and priorities for the remainer of this triennium. The Task also discussed proposed projects/deliverables for the next triennium to run 2019-2021. Discussions were aided by a presentation highlighting IEA Bioenergy Roadmap findings made by IEA consultant Adam Brown (via Skype).

Day two of the meeting was organized as an open workshop to provide Chinese observers with an overview of the IEA Bioenergy TCP and some of its tasks (e.g., Tasks 33, 34 and 43 in addition to Task 39) to help progress China's consideration to join the IEA Bioenergy TCP.

IEA Bioenergy Task 39 business meeting day two- attendees gathered at BUCT.

During the first day of the meeting, particpants also provided short presentations summarizing biofuels policy developments in their respective countries/jurisdictions, input that collectively will inform the Task's periodically issued Implementation Agendas report, being updated this year. This report compares and contrasts policies and their successes within member countries (and other key countries like China and India).

We welcome your feedback. Please direct your comments to Mahmood Ebadian

Task 39 Management:

Operating Agent (Agency):	**Alex MacLeod** (Natural Resources Canada)
Task Leader (Agency):	**Jim McMillan** (National Renewable Energy Lab)
Co-Task Leader (Agency):	**Jack Saddler** (Univ. of British Columbia)
Subtask Leaders:	
(Biochemical conversion, N. America)	**Jim McMillan (NREL, USA)**
(Biochemical conversion, EU):	
(Link to Advanced Motor Fuels IA):	**Franziska Mueller-Langer** (DBFZ, Germany)
(Policy issues, EU):	**Michael Persson** (Denmark)
Task Coordination:	**Mahmood Ebadian** (Univ. of British Columbia)

The day two worshop featured as guest speakers a number of distinguished experts from academia and industry, and included panel discussions on several topics at the forefront of biofuels development, namely: a) sustainability and life cycle assessment (LCA); b) aviation biofuels development; c) the status of biofuels in China; and d) the broader work of the IEA Bioenergy TCP (i.e., beyond Task 39). Panel presentations on day two were:

- *Sustainability and Life Cycle Assessment (Jim Spaeth moderator)*
  - o Michael Wang (Argonne National Laboratories) - GREET biofuel lifecycle analysis
  - o Mark Staples (Massachusets Institute of Technology) - Life cycle analysis for advanced biofuel
  - o Rolf Hogan (Roundtable on Sustainable Biomaterials) - An approach to sustainability
  - o Nan Li (World Wildlife Federation) - Sustainability of alternative aviation biofuel
  - o Don O'Connor (S&T2 Consultants) (via Skype) – sustianbility of biofuels and life cycle assessment
- *Aviation biofuels development (Elisabeth Martin moderator)*
  - o Elisabeth Martin (Boeing) - Sustainable Aviation Biofuel – Boeing's work in China
  - o Robert Boyd (International Air Transport Association) - The role of biofuels in aviation
  - o Ken Lai (Lanzatech) - Lanzatech technology and progress in commercialisation
  - o Shutong Liu (Motioneco) - The biodiesel industry in China
- *Biofuels in China (Paul Bennett moderator)*
  - o Fan Li (COFCO) - Fuel ethanol industry in China
  - o Hailong Lin (SIDC)- Technical progress of bioethanol in China
  - o Prof Li Chang-Zhu- President of Hunan Branch of Chinese Academy of Forestry- Bioproduction technology of biodiesel and biolubricants from non-edible oil
- *Work of IEA Bioenergy*
  - o Mark Brown (Overview of Task 43 – Sustainable biomass supply)
  - o Timo Gerlagh (Overview of Task 33 – Gasification)
  - o Paul Bennet (Overveiw of Task 34 – Direct thermochemical liquefaction)
- *Other distinguished speakers*
  - o Jim Spaeth – Introduction to IEA and the IEA Bioenergy TCP
  - o Professor Tianwei Tan – Liquid Biofuels in China and the work of his research group at BUCT
  - o Director-General Siqang Wang (China's National Energy Administration) – opening/welcoming speech

On Monday, April 9, attending Task members participated in a study tour to visit China National Cereals, Oils and Foodstuffs Corporation's (COFCO) R&D center and laboratories, followed by a visit to a portion of the Great Wall. COFCO is one of China's state-owned food processing holding companies and the COFCO group is China's largest processor, manufacturer and trader of foods. We were toured through their impressive laboratory facilities where they do research on bioethanol, in addition to other work on food and nutrition.

The need for greater production and use of advanced liquid biofuels to enable future emissions reduction targets to be reached continues to mount, and international coordination remains key to efficient progress. We are excited about the potential for China (and India and Indonesia) to join the IEA Bioenergy TCP in the near future, buoyed by the positive discussion and interactions we had in Beijing (and previously in Brussels in September, 2017).

This Newsletter's feature article describes biofuels-related developments in the US, which in recent years has been the world's largest producer of liquid biofuels.

As always, we appreciate your readership and are interested in any input or feedback on this newsletter. Please send us by email any ideas or suggestions for increasing its value.

Thanks for reading and participating in the IEA Bioenergy Task 39 network.

Jim, Jack, Susan and Mahmood

Biofuels Production and Consumption in the US: Status, Advances and Challenges

Mahmood Ebadian and James D. McMillan

1. Status of the US Biofuels Industry

The United States (US) economy remains highly dependent on liquid transportation fuels, still primarily derived from petroleum but increasingly including renewable content, to power various transportation fleets. In 2016, the US had about 21% of the world's registered vehicles (268.8 million including passenger cars, motorcycles, trucks, buses, and other vehicles) and used about 20% of the world's oil consumption.[1, 2] The transportation sector represents a primary user of energy in the US, comprising 29% of total US energy use, with 95% of this energy provided by fossil fuels.[3]

The Energy Independence and Security Act (EISA) was enacted in 2007 to enhance domestic production of fuels and spur economic development while reducing reliance on imports and improving the environment (through reducing both the absolute level of fossil fuel use (lowering GHG emissions), and fuel combustion-related pollution such as ground-level ozone and smog). This EISA contains a number of provisions to increase the energy efficiency and the availability and use of renewable energy.[4] One of these provisions amended the original Renewable Fuels Standard (RFS) created under the Energy Policy Act of 2005. The 2007 amended RFS (RFS2) targets the ramping up of domestic biofuel production to 36 billion gallons per year (BGY) by 2022 (over 136 billion liters). As depicted in Figure 1, this comprises 15 BGY of conventional corn starch-based ethanol and 21 BGY of advanced, cellulosic and biodiesel biofuels (i.e., 16 BGY of cellulosic biofuels, 4 BGY of advanced biofuels, and 1 BGY of biomass-based biodiesel).

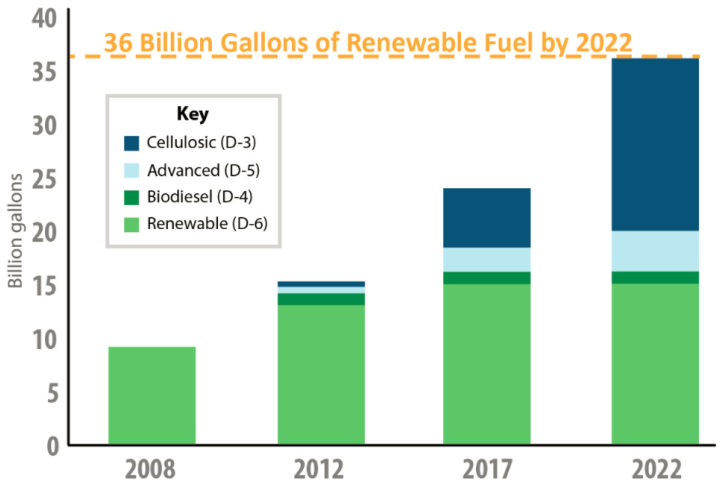

Figure 1. Volume targets for renewable fuels under revised RFS2 as orginally enacted in 2007.[5]

Over the past decade, the RFS2 has effectively propelled increased production and use of biofuels in the US, primarily more conventional ethanol production from corn kernel starch but also conventional fatty acid methyl ester (FAME) biodiesel from oleaginous feedstocks. In recent years, volumes of cellulosic ethanol and renewable diesel (also known as hydrotreated vegetable oil (HVO) or hydroprocessed esters and fatty acids (HEFA)) has also increased. Figure 2 shows how ethanol production has increased under RFS2. In 2017, a total of 15.8 billion gallons (59.8 billion liters) of fuel ethanol was produced in the US. This production came from 199 plants located across 29 states. Considering supply and distribution chains, this production alone accounts for over 270,000 jobs. In 2015, about 0.1 billion gallons of ethanol was imported into the US and the total exported volume was about 0.8 billion gallons.[6] US motor gasoline consumption has grown in the past four years, increasing from 8.7 million b/d in 2012 to 9.3 million b/d in 2016, resulting in an increase of 7% in additional ethanol demand for E10 blending in gasoline that has helped to support the consistent growth in ethanol production over this period. The US remains the largest producer of ethanol in the world (58%), followed by Brazil (26%) and EU (5%).[7, 8]

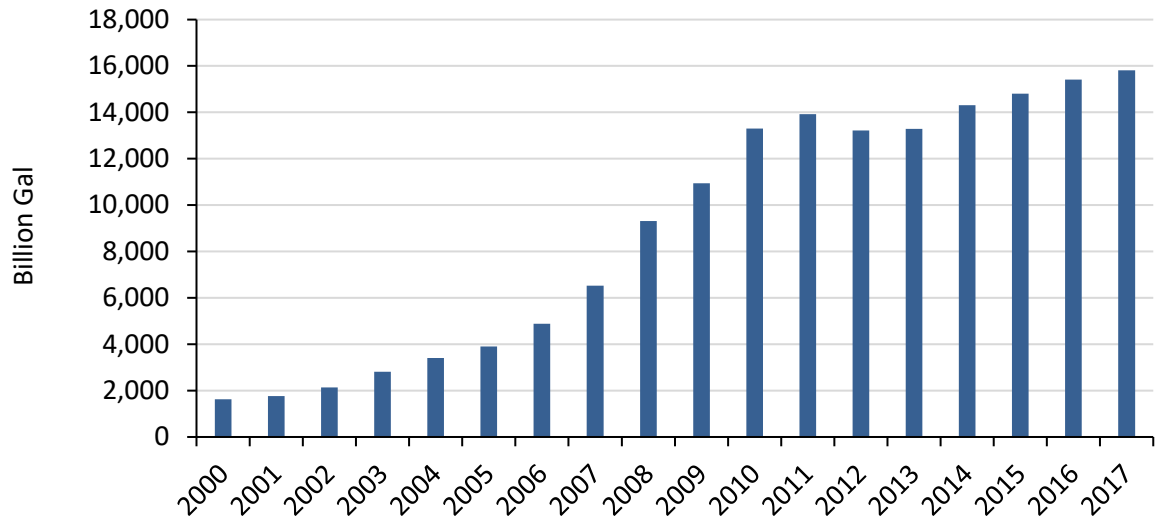

Figure 2. Historical production of ethanol in the US, 2000-2017.[8]

Corn is the primary feedstock for ethanol production in the US, and large corn harvests in recent years have contributed to increased production. The US Department of Agriculture (USDA) estimates that the US produced a record 15.1 billion bushels of corn in the 2016–17 harvest year, 11% more than the 2015–16 harvest. Increased corn yields and relatively stable corn prices help make increased conventional ethanol production from corn kernel starch more profitable. In 2017, about 30% of the total US corn crop – over 4.2 billion bushels of corn – was used to produce fuel ethanol.[7]

Similar to ethanol, the RFS has driven increased production and use of diesel biofuels in the last 10 years, both FAME biodiesel and renewable diesel type. As shown in Figure 3, diesel biofuels production reached about 2.5 billion gallons in 2017 as compared to 215 million gallons in 2010. This production level was achieved by 97 plants operating across 37 states. FAME biodiesel and renewable diesel compete for the same oleaginous feedstocks and the recent trend has been renewable diesel starting to outcompete for the limited feedstock, meaning more renewable diesel (HVO/HEFA) production and less FAME biodiesel production.

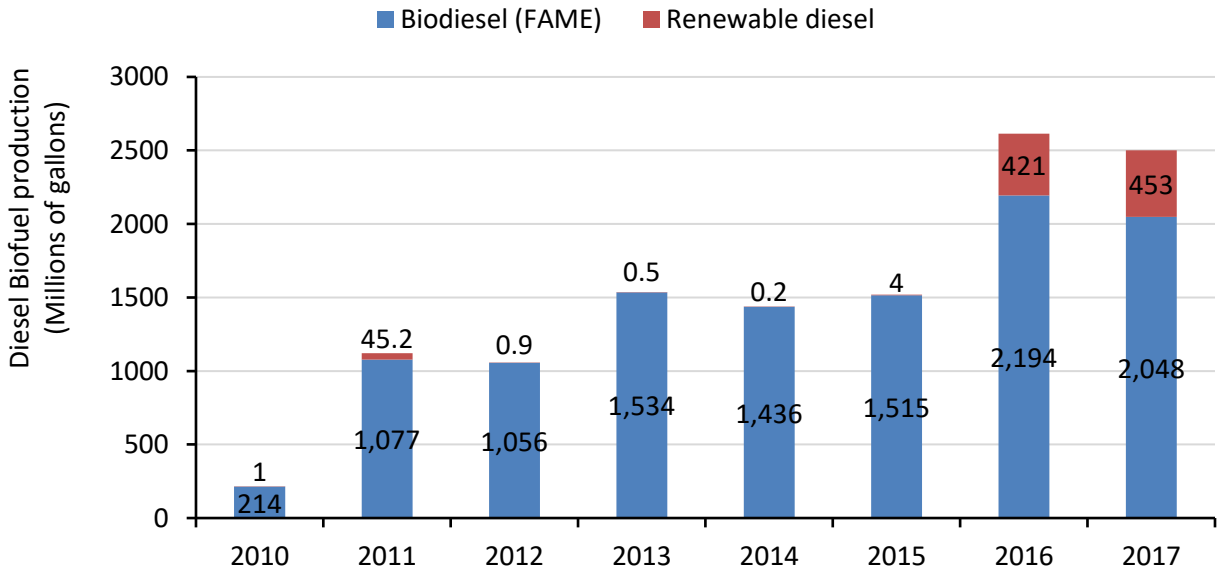

Figure 3. Diesel biofuel production in the US, 2010-2017 (based on EPA RIN data).[9]

Production volumes of diesel-substituting biofuels are limited by the availability of oleaginous feedstocks. In 2016, 11.05 billion pounds (over 5 million metric tons) of such feedstocks were used to produce diesel biofuels, 77% vegetable oils and 23% recycled/used vegetable oils and animal fats. Soybean oil was the largest single feedstock for US

production, using 6.1 billion pounds of soybean oil in 2016, compared to 4.9 billion pounds in 2015, an increase of 24%, and representing approximately 28% of the total 2016 US soybean oil production (22.1 billion pounds (over 10 million metric tons)).[10, 11]

Despite the substantial presence of conventional biofuels (i.e., starch-based ethanol and biodiesels) in the US transportation fuel market, the production of advanced cellulosic feedstock-based biofuels remains relatively small. Advanced biofuels production volumes remain far below original targets (Figure 1) due to slower than expected progress in scale up and deployment of commercial production of cellulosic ethanol and other advanced biofuels. In 2017, total production of renewable diesel, cellulosic biofuels, and biojet was 453, 10, and 1.7 million gallons, respectively (based on EPA RIN data).[9] Future production level increases depend on the ability to export as well as on how fast cellulosic biofuels production can be ramped up.

It is anticipated that biofuels production for the aviation sector will continue to increase, in part due to the anticipated global expansion of commercial aviation and limited alternative options beyond low carbon biofuels to decarbonize this sector. Additionally, the US military previously committed to increase its use of domestically manufactured aviation fuel and biodiesel fuels as part of a national security imperative. However, while the US Secretaries of Agriculture, Energy, and the Navy in 2011 signed a Memorandum of Understanding to commit $510 million ($170 million from each agency) to produce hydrocarbon jet and diesel biofuels[6], the future of this initiative is currently unclear and under discussion. Table 1 lists operational, under construction and planned biojet and renewable diesel production facilities in the US.

Table 1. Operational and planned jet fuel and renewable diesel production facilities in the US.[6]

Project Name	Location	Feedstock	Technology	Capacity (MG/year)	Operational - year started or anticipated
Fulcrum Sierra Biofuels	Storey County, NV	MSW	Gasification	10	2019
Emerald Biofuels	Gulf Coast	Fats, oils, and greases	HEFA	88	2017
Red Rock Biofuels	Lakeview, OR	Woody biomass	Gasification, micro-channel FT	16	2017
AltAir Fuels	Los Angeles, CA	Fats, oils, and greases	HEFA	40	2016
REG Synthetic Fuels	Geismar, LA	Fats, oils, and greases	HEFA	75	2014
Diamond Green Diesel	Norco, LA	Fats, oils, and greases	HEFA	150	2013
SG Preston	South Point, OH	Fats, oils, and greases	HEFA	120	2020
SG Preston	Logansport, IN	Fats, oils, and greases	HEFA	120	2020

2. Policies driving the production and consumption of biofuels in the US

The RFS is the primary federal policy tool encouraging biofuels use in the United States. The RFS is implemented by the US Environmental Protection Agency (US EPA). EPA implements the revised program (RFS2) in consultation with the USDA and US Department of Energy (USDOE). An overview of the program and its history of development is provided at: https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard.

Besides the already introduced RFS, another strong policy driving increased biofuels production and use is California's Low-Carbon Fuel Standard (LCFS). The main goal of this legislation is to decarbonize the transportation sector by at least 10% by 2020 (from a 2010 baseline) by using low-carbon alternative fuels such as ethanol, biojet and biodiesel as well as cleaner burning fossil fuels such as CNG and LNG. Enacted in 2007, with specific eligibility criteria defined by

the California Air Resources Board (CARB) in April 2009, and first taking effect in January 2011, this legislation was readopted in 2015. California's LCFS works with three other programs to reduce transportation GHG emissions (i.e., its Cap-and-Trade Program, Advanced Clean Car Program, and SB 375 legislation). Other jurisdictions following California include Oregon and Washington in the US and British Columbia in Canada. Together, they have formed a regional initiative called the Pacific Coast Collaborative. Each jurisdiction has its own LCFS in place and a regional low-carbon fuels market is being considered for the future. An overview of California's LCFS program and its history of development is provided at: https://www.arb.ca.gov/fuels/lcfs/lcfs.htm.

The USDA and US DOE and some states also administer a wide variety of programs aimed at encouraging greater production and use of bioproducts and biofuels. USDA's National Institute of Food and Agriculture (NIFA) through its Division of Bioenergy supports research on sustainable production of biomass, genomic improvement of bioenergy feedstocks, as well as other areas of biomass conversion. NIFA has provided financial incentives for feedstock development such as in the Advanced Hardwood Biofuels Northwest and Northeast Woody/Warm-season Biomass Consortium initiatives. A listing of projects facilitating the development of regional bio-based industries producing advanced biofuels, industrial chemicals, and other bio-based products can be found here. In addition, USDA's Agricultural Research Service (ARS) focuses on feedstock development, feedstock production and biorefining.

US DOE has supported related feedstock supply chain development such as Sun Grant/DOE Regional Biomass Feedstock Partnership and Feedstock-Conversion Interface Consortium. Information about US DOE's feedstock development and conversion programs can be found here. The US DOE provides research funding through both its Office of Energy Efficiency and Renewable Energy's (EERE) (primarily via EERE's Bioenergy Technologies Office (BETO)) and its Office of Science (SC) (primarily via SC's Biological and Environmental Research Office (BER)). Funding is directed at advancing biochemical, thermochemical and hybrid biofuels production technologies. The primary focus is on non-food/feed feedstocks such as lignocellulosic biomass, photosynthetic algae and carbonaceous waste streams such as municipal solid waste (MSW) and CO/CO_2 rich gases. Over the past 10 years (2007–2017), three Bioenergy Research Centers (BRCs) supported by the Genomic Science program within DOE's SC BER Office have made significant advances toward the bio-based economy. These centers are the Great Lakes Bioenergy Research Center, the Joint BioEnergy Institute, and the BioEnergy Science Center (now becoming the Center for Bioenergy Innovation). In February, a fourth DOE-funded center also began operating, the Center for Advanced Bioenergy and Bioproducts Innovation. These BRCs are producing multiple breakthroughs in the form of deepened understanding of sustainable biomass production practices, targeted re-engineering of biomass feedstocks, development of new methods for deconstructing feedstocks, and engineering of enzymes, microbes and inorganic catalysts for more effective production of a diverse range of biofuels.

In addition, both USDA and US DOE administer loan guarantee programs intended to buy down the risk of constructing first of a kind scaled up commercial facilities. The USDA's 9003 Biorefinery Assistance Program assists companies in the development, construction, and retrofitting of new and emerging technologies for advanced biofuels, renewable chemicals and bio-based products by providing loan guarantees of up to $250 million for first of a kind commercial facilities. Information on US DOE's Loan Guarantee Program can be found here. Other agencies such as the US EPA and the National Science Foundation (NSF) also provide funding, mostly for research, some directed at biofuels.

There are many other laws and incentives depending upon the fuel type and jurisdiction. The USDOE's Alternative Fuels Data Center provides a good single site for finding/searching these many laws and incentives at both federal and state levels: https://www.afdc.energy.gov/laws.

In addition to federal and state legislations supporting the production and use of biofuels to help decarbonize the US's transportation sector, increasing Corporate Average Fuel Economy (CAFÉ) standards also have been contributing to the decarbonization of the transportation sector by reducing energy consumption through increasing the fuel economy of light duty vehicles (cars and trucks). More information on the US's CAFE standards can be found at: https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy.

3. Advances in biofuels technologies

With the support from US federal and state agencies and many collaborations among universities, national labs and companies, the science and technology for producing lower carbon renewable biofuels keep marching forward with the efficiencies and technology readiness levels of many routes to biofuels continuing to improve. Recent examples of such advances include:

- **Demonstration of commercial-scale cellulosic ethanol production improving:** In 2017, POET-DSM's pioneer cellulosic ethanol production facility in Emmetsburg, Iowa, reported beginning to routinely achieve corn stover conversion yields of 70 gallons ethanol per bone-dry ton of biomass, near this plant's design target, albeit this facility remains in a ramp-up phase for plant throughput. More recently, POET-DSM announced it is going to add on-site enzyme manufacturing to this facility.[12]
- **Ethanol production from corn fiber being implemented in existing corn dry mills:** Ethanol production from corn fiber has become an area of active R&D and commercialization since 2014, when the EPA classified corn kernel fiber as a crop residue, with multiple routes now being commercialized to convert some or most of the corn kernel fiber byproduct present in dry mill ethanol facilities to ethanol. These technologies enable conventional corn ethanol dry mill plants to generate 2% - 10% additional ethanol (cellulosic ethanol) from their captive fibrous residue stream(s). Technologies development companies with patented corn fiber to cellulosic ethanol pathways include D3MAX, Edeniq, ICM and Quad County Corn Processors.[13,14.15] EPA has so far approved seven companies to produce cellulosic ethanol from corn kernel fiber (Table 2).

Table 2. List of ethanol plants approved to generate RINs from corn kernel fiber.[14]

Corn Ethanol Plant	Location	Data approved by EPA to generate cellulosic ethanol
Quad County Corn Processors	Galva, IA	October 2014
Pacific Ethanol	Stockton, CA	September 2016
Flint Hills Resources	Shell Rock, IA	December 2016
Little Sioux Corn Processor	Marcus, IA	January 2017
Siouxland Energy & Livestock Cooperative	Sioux Center, IA	June 2017
Flint Hills Resources	Iowa Falls, IA	October 2017
Mid America Agri Products/Wheatland LLC	Madrid, NE	December 2017

The increase in cellulosic ethanol production owing to increasing implementation of corn fiber conversion technology as well as increasing production from the POET-DSM plant discussed above is measurable. Cellulosic ethanol production was more than doubled from 3.8 million gallons in 2016 to 10 million gallons in 2017 (Figure 4), as more corn stover- and corn kernel-based ethanol production came online. EPA RIN data indicate production volumes are continuing to increase during 2018 year to date.[9]

- **Drop-in fuels by co-processing in petroleum refineries advancing:** Co-processing refers to the simultaneous processing of biogenic and fossil (petroleum) feedstocks, especially combined processing in existing petroleum refineries of biomass-derived biocrudes or bio-oils with intermediate petroleum distillates such as vacuum gas oil (VGO). This co-processing approach is of interest because of its potential to use existing fuel refining, distribution and storage infrastructure to produce lower carbon drop-in fuels. Several national labs and universities are active in co-processing R&D, and a few commercial refiners are exploring production at pilot and larger scales. Current research is mostly examining the potential to do such coprocessing using fluid catalytic cracking (FCC) or hydrocracking/hydrotreating units in existing refineries. Research to date suggests that co-processing of up to 20% (by wt.) biogenic oils (e.g., vegetable oils, animal fats) with VGO may be possible in FCC units. The US DOE estimates that more than 8 billion gallons of renewable hydrocarbon fuels (over 30 billion liters) could potentially be produced via co-processing using the 110 FCC units that already exist in the US.[16,17,18]

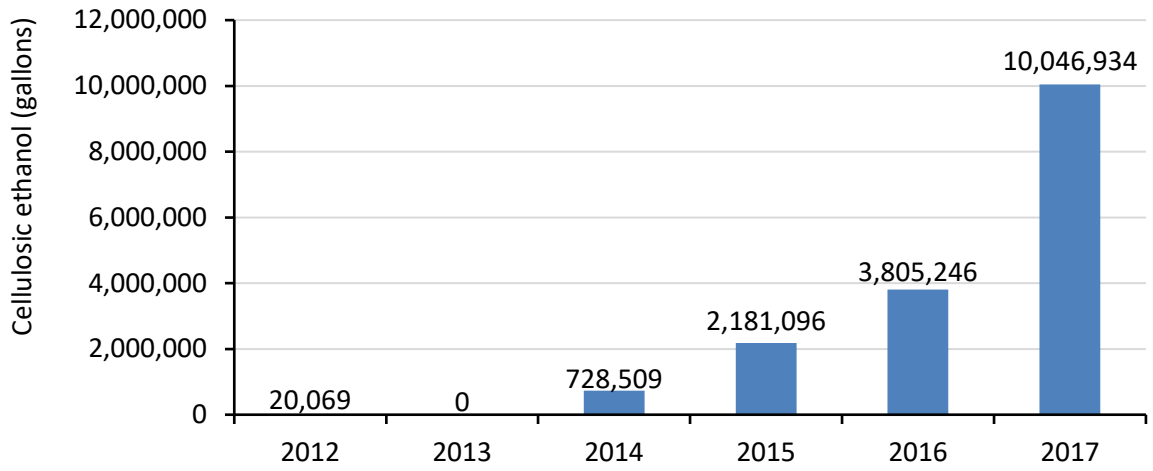

Figure 4. Production of cellulosic ethanol, 2012-2017 (based on EPA RIN data).[9]

- **Commercialization of ethanol from CO/syngas progressing:** LanzaTech's gas fermentation platform enables regional production from local wastes and residues, including gases as varied as industrial flue gas, gasified biomass wastes and residues, biogas, and high-CO_2 stranded natural gas. Originally founded in 2005 in New Zealand, the company relocated its headquarters to the US in 2014. An overview of LanzaTech's progress can be found here.
- **Co-optimization of Fuels and Engines**: The US DOE's crosscutting "Co-Optima" initiative tackles fuel and engine innovation from a systems perspective, with the goal of optimizing overall performance and efficiency. This initiative seeks to improve transportation fuel economy 15%–20% beyond business as usual targets for separate R&D on engines and fuels. This is a large collaboration drawing on the expertise of two DOE research offices, nine national laboratories, and numerous industry and academic partners. Results to date indicate that increasing the efficiency of internal combustion engines through the use of renewable blending components has great potential to increase the efficiency of both conventional and hybrid vehicles. Higher octane gasoline allows for greater fuel efficiencies, but engines must be tuned to optimally run on higher octane blends. By matching high octane fuels to high compression ratio engines, the auto industry can gain an additional 3-4.5% in vehicle efficiency.[19-20] More information on Co-Optima can be found at:https://www.energy.gov/eere/bioenergy/co-optimization-fuels-engines.
- **Algae-based biofuels:** Algae have significant potential to support an advanced biofuels and biorefining industry in the US, and the goal of US DOE BETO's Advanced Algal Systems Program is to develop cost-effective algal biofuels production and logistics systems. Since reviving its algal biofuels program in 2009, BETO has invested in a variety of research, development, and demonstration projects tackling the barriers to economic scale-up of commercial algal biofuels. A recent report, "National Algal Biofuels Technology Review" discusses the current status and remaining challenges to commercialize production of algal-based biofuels and bioproducts in the US.
- **Feedstock development:** Research is also underway to develop improved biomass/bioenergy crops that exhibit more favorable chemical compositions and are easier to convert to targeted biofuels. One example of alternative feedstock development is an effort to transform sugarcane and Miscanthus into better feedstocks for producing biodiesel and biojet fuels by engineering these plants to produce higher levels of oil (lipids) rather than sugar (carbohydrates). In February 2018, the US DOE awarded $10.6 million grant to the so-called Renewable Oil Generated with Ultra-productive Energycane (ROGUE) project, a collaboration by researchers from the University of Illinois, Brookhaven National Laboratory, University of Florida, and Mississippi State University. USDA and US DOE also support a variety of projects to develop cost-efficient and reliable feedstock logistics and supply chains. For example, DOE's High-Tonnage Biomass Logistics Demonstration Projects were focused on developing five improved harvesting technologies to reduce biomass logistics costs while maintaining or improving harvested biomass quality.

4. Challenges to further production and use of biofuels in the US

Despite on-going advances in conventional and advanced biofuels technologies and large potential to further increase biofuels production and use in the US, the biofuels industry faces challenges. Petroleum prices remain modest and future policies for renewable fuels (and vehicle efficiency standards) remain highly uncertain, the subject of contentious debate within government and stakeholders. Before US domestic petroleum production increased due to fracking, petroleum imports into the US accounted for over 60% of total consumption and the level of imports was continuing to grow. In recent years, due to the fracking revolution, this trend has impressively been reversed: In 2017, US net imports of petroleum accounted for only 19% of US petroleum consumption, the lowest level since 1967 (EIA, 2018). As shown in Figure 5, in 2017 total net energy imports into the US fell to 7.3 quadrillion British thermal units (quads), a 35% decrease from 2016 and the lowest level since 1982. In 2017, the US also substantially increased its fossil fuel exports over 2016 levels, with larger exports of crude oil (89% higher), petroleum products (11%), natural gas (36%), and coal (61%). Petroleum products including gasoline, distillate fuel, propane, and other fuels currently comprise the majority (54%) of US energy exports.[21]

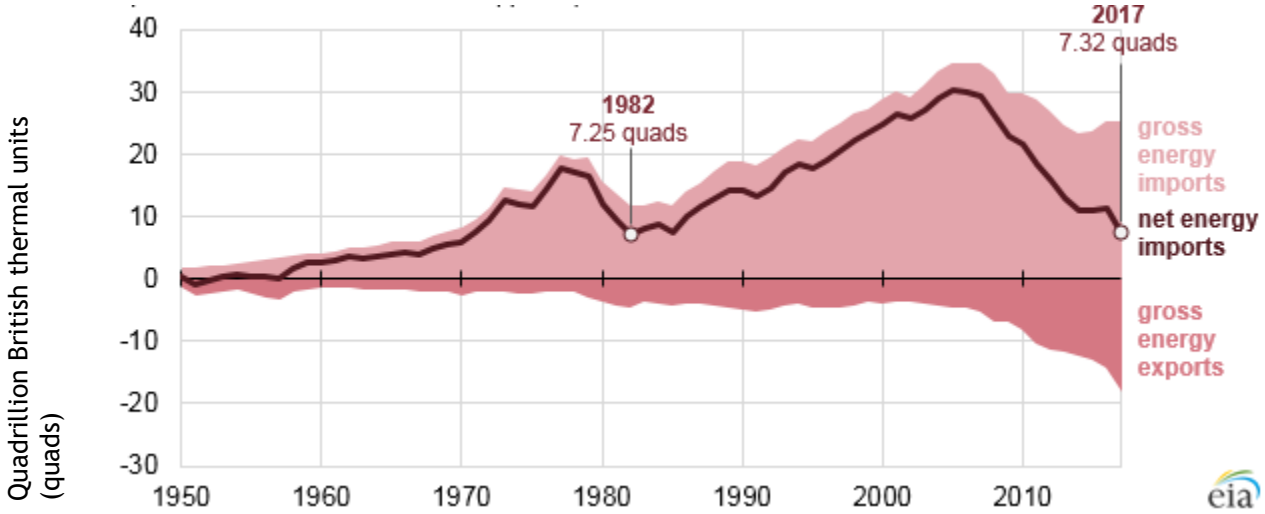

Figure 5. US gross and net energy trade (1950-2017). [21]

In addition to the significant increase in the domestic production of fossil fuels, continuing relatively low petroleum prices and an unclear carbon policy landscape are hindering further investment in conventional and especially advanced liquid biofuels. This situation won't likely change until the future of both the federal renewable fuel standard (RFS2) and the corporate average fuel economy (CAFÉ) vehicle efficiency standards are better understood. These policies remain under discussion for revision, and policy changes are anticipated, however it remains unclear what they will be.

The high policy uncertainly coupled with low profit margin potential of advanced biofuels in the current market environment has prompted many companies such as Amyris to redirect their RD&D and business strategies towards renewable chemicals. Advanced biofuels producers have not been able to ramp up their production levels as quickly as originally expected and as a result, advanced biofuels production substantially lags RFS2 targets. The obligated volumes specified in RFS2 have been revised down in recent years to reflect actual production. In addition, the level of RD&D funding and commercial investments in biofuels has decreased compared to the last five years and it is unknown how soon they will pick up again.

5. Conclusions

Policies such as the federal level RFS and CAFÉ standards, as well as state policies, most notably California's LCFS, and many initiatives and financial supports provided by USDA, US DOE, states and cities, have propelled substantial production and use of biofuels in the US. These policies have helped to make the US, the largest biofuels producer in the world.

However, recent changes in the federal government's perceived commitment to environmental protection – most demonstrably evidenced by the US's announced intention to withdraw from the Paris climate agreement – coupled with the rapid rise in domestic petroleum production and persisting relatively low petroleum prices, present challenges to further progress. Moreover, slower-than-anticipated progress commercializing cellulosic ethanol and other advanced biofuels technologies have led to lowered expectations for how quickly the biofuels industry will be able to scale up advanced biofuels to meet the ambitious targets specified in the original RFS2.

Despite of these obstacles, research and development is under way to tackle technical and commercialization challenges. Government funding for advanced biofuels continues, however the future funding levels and priorities for R&D remain unclear. Despite uncertainty about future policy, the biofuels industry continues to strive to ramp up the production of cellulosic and other advanced biofuels. High levels of ethanol production (≥15 BGY (60 billion liters per year) are expected to continue in the US's roughly 200 corn dry mills, mostly conventionally from corn grain starch but increasing also from "generation 2" corn stover and "generation 1.5" corn kernel fiber to also produce cellulosic ethanol. While the large-scale POET-DSM dedicated cellulosic ethanol plant will continue to increase its production level, if current trends continue, new volumes of cellulosic ethanol produced in this facility will become eclipsed by conversion of corn fiber to ethanol in existing dry mills as deployment of corn fiber conversion technology proceeds. Production of conventional and advanced biodiesels (i.e., FAME and HVO/HEFA) and biojet fuels from oleaginous feedstocks is also anticipated to remain strong, with absolute production levels continuing to be constrained by feedstock availability and price.

References

[1] Statista (2016). Number of vehicles in use worldwide and the U.S. https://www.statista.com/statistics/183505/number-of-vehicles-in-the-united-states-since-1990/

[2] BP (2016). Statistical Review of World Energy June 2016. 65th Edition.

[3] EIA (2016). US primary energy consumption by source and sector, https://www.eia.gov/petroleum/ethanolcapacity/index.cfm.

[4] U.S. Sustainability Alliance (2014). The renewable Fuel Standard and Biofuels Policy, https://thesustainabilityalliance.us/biofuels/.

[5] EPA (2017).Renewable Fuel Standard Program: Overview for Renewable Fuel Standard. https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard.

[6] Golden, J.S., Handfield, R., Pascual-Gonzalez, J., Agsten B., Brennan T., Khan L., True E., (2018). Indicators of the U.S. Biobased Economy. USDA, Office of the Chief Economist.

[7] EIA (2017). U.S. fuel ethanol production continues to grow in 2017. https://www.eia.gov/todayinenergy/detail.php?id=32152

[8] Renewable Fuels Association (2018). Annual US Fuel Ethanol Production. http://www.ethanolrfa.org/resources/industry/statistics/#1454099788442-e48b2782-ea53.

[9] EPA (2018). Public Data for the Renewable Fuel Standard: https://www.epa.gov/fuels-registration-reporting-and-compliance-help/public-data-renewable-fuel-standard

[10] EIA (2017). U.S. Inputs to biodiesel production: https://www.eia.gov/biofuels/biodiesel/production/table3.pdf

[11] USDA Economic Research Service (2017). Oil Crops Outlook: February 2017. https://www.ers.usda.gov/publications/pub-details/?pubid=82415

[12] POET-DSM Advanced Biofuels (2017):http://poetdsm.com/pr/poet-dsm-achieves-cellulosic-biofuel-breakthrough

[13] Cagle, K., (Novozmes) (2017). Bioeconomy 2017 conference, session 1E: Drawing a Roadmap to Cellulosic Biofuel Deployment, July 11, 2017.

[14] Brent, E., (2018). A Rising Tide of Cellulosic Ethanol Production. Industrial Biotechnology, Vol. 14, No. 2.

[15] Environmental and Energy Study Institute (2017).1.5 Gen" Technologies Could Boost Cellulosic Ethanol Production by Nearly 2 Billion Gallons: http://www.eesi.org/articles/view/1.5-gen-technologies-could-boost-cellulosic-ethanol-production-by-nearly-2-

[16] California Air Resources Board (2017). Co-processing of biogenic feedstocks in petroleum refineries, Draft Staff Discussion Paper.

[17] Fogassy, Gabriella, et al. (2010). Biomass derived feedstock co-processing with vacuum gas oil for second generation fuel production in FCC units." *Applied Catalysis B: Environmental* 96.3 (2010): 476-485.

[18] DOE (2016). New Pilot Plant Demonstrates the Potential to Co-Process Biomass Streams with Petroleum. https://www.energy.gov/eere/bioenergy/articles/new-pilot-plant-demonstrates-potential-co-process-biomass-streams-petroleum

[19] Environmental and Energy Study Institute (2018). http://www.eesi.org/articles/view/auto-exec-raise-the-octane-rating-of-u.s.-gasoline-for-bump-in-fuel-efficie

[20] Speth et al., (2014). Economic and Environmental Benefits of Higher-Octane Gasoline. Jounral of Environ. Sci. Technol., 48 (12), pp 6561–6568.

[21] EIA (2017). U.S. net energy imports in 2017 fall to their lowest levels since 1982. https://www.eia.gov/todayinenergy/detail.php?id=35532

In the News

Reports and Research

April 18 - USDOE EERE's Bioenergy Technologies Office (BETO) released its Co-Optima Initiative's FY17 accomplishments report (read more). Co-Optima research is exploring ways to co-optimize fuels and engines, looking at the science and engineering needed to create engines and fuels that work more effectively together. Co-Optima researchers are considering blendstocks that can be produced from a wide variety of renewable and fossil resources, with a focus on options that can be sourced from domestic cellulosic biomass and similar renewable, non-food, and under utilized resources.

April 17 - Researchers at MIT and the National Renewable Energy Laboratory (NREL) completed an extensive analysis of several proposals, concluding that putting a price on carbon, in the form of a fee or tax on the use of fossil fuels, coupled with returning the generated revenue to the public in one form or another, can be an effective way to curb emissions of greenhouse gases (read more).

March 27- A new report by the International Transport Forum, "Decarbonising maritime transport pathways to zero-carbon shipping by 2035," reviews pathways to zero-carbon shipping. This study examines four different decarbonization pathways that have the potential to reduce international shipping's CO_2 emissions between 82% and 95% below the level currently projected for 2035. This reduction equals the annual emissions of 185 coal-fired power plants. The pathways include alternative fuels and renewable energy, technological measures to improve the energy efficiency of ships and operational improvements such as slower ship speeds and smoother ship-port co-ordination.

March 22 - In an article published by Biofuels Digest, Jim Lane discusses the current status of the ethanol market in the US and its possible future directions. Advanced Biofuels US's plan for the future of ethanol industry is also outlined (read more).

March 12 - The Iowa State University Research Foundation reports achieving a pyrolysis breakthrough that could cut drop-in biofuels cost from $3.27 per gallon to $2.58 per gallon. They call the process "autothermal pyrolysis." (read more).

February 25 - The last week of February was the 10th anniversary of the first demonstration flight on biofuel, which was performed by Virgin Atlantic. Biofuels Digest has a feature article on the progress made in the last 10 years and the aviation industry's challenges to reliably obtaining sufficient sustainable and affordable feedstock to enable greatly expanded production (read more).

February 25 - Scion carried out a Biofuels Roadmap study to inform and stimulate debate on large-scale production and use of liquid biofuels in New Zealand. The report, "New Zealand Biofuels Roadmap: Growing a biofuelled New Zealand," outlines the thinking that has gone into this study, considerations around technologies and investment requirements, and the practical requirements of establishing an entirely new way to sustainably provide a large proportion of the country's liquid transport fuels.

Policy and Regulatory Developments

April 18 - Several international organizations met in Brussels over April 10-11 to discuss the need and the ways to scale up low carbon fuels in transport. The international conference, "The role of low carbon fuels in decarbonising transport: the emerging consensus from international initiatives," was a collaboration between the Biofuture Platform, the European Comission, IRENA, below50 and ART Fuels Forum, with the participation of IEA and FAO. The Conference produced key messages about the vital role of sustainable biofuels and ways to promote them. Among these are that massive scaleup of bioenergy is needed to help combat climate change, renewable feedstocks are available to meet the bioenergy need sustainably, conversion technologies are also available to meet the need, however stable policy

support and international collaboration will be required to ensure investment in bioenergy scaleup, and an evidence-based approach is needed to ensure sustainability goals are being achieved (read more).

April 9 - In Minnesota, effective May 1, all diesel sold in Minnesota must contain at least 20% biodiesel as the state officially implements the B-20 mandate passed in 2008. Once implemented, the B-20 mandate will be in effect during the state's "summer months" of April through September. October through March, the biodiesel requirement will remain at 5% (read more).

April 8 - In Washington, an ASTM International Sub-Committee voted in favor of revising specification D7566 (Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons) to include ethanol in addition to isobutanol; and to increase the approved blend levels from 30% to 50% — that is, the percentage of alcohol-to-jet fuel allowed when blended with petro-based jet fuel. These revisions to the D7566 specification now go to the full ASTM International for final approval, which is expected to occur later this year (read more).

March 15- Biofuels Digest published a Visual Guide to the economics and policies of renewable energy in the US. This Visual Guide clearly shows the significant role of federal and state policies in encouraging the increased production of cellulosic ethanol in the US (read more).

March 14 -, Canada's Minister of Environment and Climate Change, Catherine McKenna, launched an over-$500-million "Low Carbon Economy Challenge" that will consider projects to reduce Canada's greenhouse gas emissions and contribute to Canada's 2030 emission reduction target of 30% below 2005.

January 17 - The European Parliament voted in favor of the RED II (Renewable Energy Directive) proposal, and also to remove biodiesel made from palm oil from its list of biofuels that can count towards the EU's renewables target from 2021. It also voted that, "biomass fuels consumed in transport, if produced from food or feed crops, shall be no more than the contribution from those to the gross final consumption of energy from renewable energy sources in 2017 in that Member State, with a maximum of 7% of gross final consumption in road and rail transport." (read more)

Sustainability

March 25 - In 2013, the Coordinating Research Council, Inc. (CRC) commissioned a study (CRC Project E-102) to better quantify sources of uncertainty and variability in selected LCA models that are being used to regulate fuels by conducting an in-depth evaluation of model inputs, and the uncertainties around these inputs, for several specific fuel pathways. Validation of the inputs and resulting outputs from the models was discussed, and pathway variability and overall model uncertainty for the different pathways were assessed. An update report was published by CRC to better support the uncertainty analysis undertaken in this project, with supporting data from published literature provided. The objective was to find a range of values and/or parameter distributions outside of the default values for a specific pathway in GREET 2014, GHGenius, and BioGrace. Unlike project E102, which looked at the well to wheel emissions of the vehicle and fuel pathways, this work considers the well to tank portion of the pathways (with the exception of heavy duty natural gas vehicles).

Industry News

May 8 - The Pasadena Fire Department (Pasadena is a California city northeast of Los Angeles) has switched much of its fleet of apparatus from operating on petroleum diesel to using Neste MY Renewable Diesel. The department currently operates one truck, four engines and four rescue ambulances on renewable diesel and plans to transition all remaining apparatus to renewable diesel by 2019 (read more).

April 17 - In the Netherlands and England, Shell released its most definitive statement yet on its low-carbon future, committing to 50% lower emissions in its operations and emissions from its fuels by 2050 and net zero by 2070. Biofuels Digest provides a summary of Shell's report here.

March 22 - Enerkem reports producing a new high-performance biofuel that it claims could improve the octane rating of fuels sold on the market as well as reduce their carbon footprint. This innovation has been achieved in collaboration with the National Renewable Energy Laboratory (NREL, US). The Canadian waste-to-biofuels and chemicals producer announced this latest development at the 255th American Chemical Society national meeting held in New Orleans, US (read more).

March 19 - Advanced renewable fuels and chemicals company Aemetis has announced that its Indian subsidiary has completed constructing an advanced biodiesel pre-treatment unit to supply biodiesel to oil giant BP. Constructed by Universal Biofuels, Aemetis' Indian subsidiary, this new facility will process low-cost feedstocks supplied to it under a BP Singapore supply agreement into 'low carbon high-quality distilled biodiesel'. According to a statement from Aemetis, the new pre-treatment unit allows the use of high quality free fatty acid waste feedstocks while also meeting international fuel standards (read more).

March 19 - World Energy has acquired for $72 million renewable jet and diesel producer AltAir Paramount, and its Paramount Petroleum refinery assets, both co-located in Paramount, California, as well an adjacent tank farm and most of Delek's California pipeline assets, from Delek US Holdings. World Energy is one of the largest and longest serving advanced biofuel suppliers in North America. This purchase includes a 63-acre complex consisting of a 45 million gallon per year renewable jet/renewable diesel production facility, 1.7 million barrels of product storage, a truck rack with a 28,000 barrels per day throughput capacity, rail storage for up to 70 rail cars, and pipelines stretching over 71 miles connecting the facility to major southern California distribution hubs including Long Beach (read more).

March 8 - Aemetis embarks on $158 million cellulosic ethanol project, to be built in Riverbank, California, in partnership with LanzaTech. The high market price of cellulosic ethanol sold in California has made this state attractive for production of cellulosic ethanol. Aemetis completed its operation of an integrated demonstration unit for more than 120 days of continuous operations with 94% uptime to meet requirements for a federal USDA 9003 Biorefinery Assistance Program guaranteed loan (read more).

Upcoming Meetings & Conferences

2018

May

- EU Sustainable Energy Week, May 4-8, Brussels, Belgium
- 26th European Biomass Conference and Exhibition (EUBCE), May 14-17, 2018, Copenhagen, Denmark
- International Conference on Negative CO2 Emissions, May 22-24, 2018, Gothenburg, Sweden
- 14th International Conference on Renewable Resources and Biorefineries (RRB-14), May 30- June 1, 2018, Ghent, Belgium

June

- Oleofuels 2018, June 6-7, Helsinki - Finland
- International Fuel Ethanol Workshop & Expo, June 11-13, 2018

July

- 11th World Bioenergy Congress and Expo, July 2-4, 2018, Berlin, Germany

August

- 7th Asia-Pacific Biomass Energy Technology & Equipment Exhibition (APBE), August 16-18, Guangzhou, China

- 2nd International Conference on Renewable Energy and Resources, August 27-28, 2018 (World Energy Congress), Boston, Massachusetts, USA
- 5th World congress on Chemical Engineering and Catalysis, August 28-30, 2018, Paris, France

October

- Bioenergy Australia Conference, Driving Commercial Outcomes, October 16-18, Brisbane, Australia

IEA Bioenergy Task 39 Meetings

The following is an abbreviated schedule of Task 39 events and meetings planned over the next 9 months. Please contact us for more detailed information:

- The next IEA Bioenergy Task 39 meeting will be 5-6 November 2018 in San Francisco, held in conjunction with the IEA Bioenergy ExCo82 end of triennium meeting and Advanced Bioeconomy Leadership Conference GLOBAL ("ABLC GLOBAL") being held 7-9 November.