The Biofuel Innovation Tracker

Julie Witcover*, Jeff Kessler‡, Rob Williams*, Arthur Wu*, Heather Liu*, Olivia Natasha*

*Institute of Transportation Studies, University of California, Davis. ‡Currently at California Air Resources Board - *June 2016*

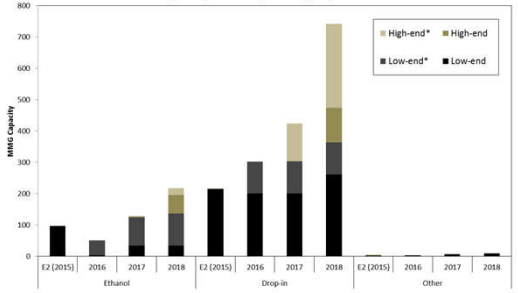
Purpose of Project

This project highlights developments in the advanced biofuel industry aiding in the assessment of near-term biofuel availability. This is follow-on work to the E2 Advanced Biofuel Market Report which was discontinued in 2014. Improvements to data have the potential to meaningfully contribute to regulatory policies that target greenhouse gas emission reductions. Several other market reports exist, including the National Renewable Energy Laboratory's Survey of Non-Starch Ethanol and Renewable Hydrocarbon Biofuels Producers, Biofuels Digest's SuperData, and the Lux Research Alternatives Fuel Supply tracker. The IEA and Genscape also maintain online biofuels facility directories.

Why Biofuels? A Climate Policy Lens

The project focuses on tracking trends in North American production capacity for biofuels with substantial greenhouse gas (GHG) emissions reductions compared to petroleum-based fuels. Of particular interest are biofuels produced through innovative fuel pathways that hold significant promise for meeting long-term GHG emission reduction policy targets. While this definition includes any number of innovations, such as "bolt-on" technologies that affect conventional biofuel processes, research currently follows E2 methods and focuses on companies with a) plans for production facilities in North America, and b) with fuel pathways achieving a 50% reduction in lifecycle fuel carbon intensity compared to conventional fuel (gasoline and diesel), as assessed by the California Air Resources Board (ARB) for its Low Carbon Fuel Standard (LCFS) program.

Capacity Tracking - Company Level Research



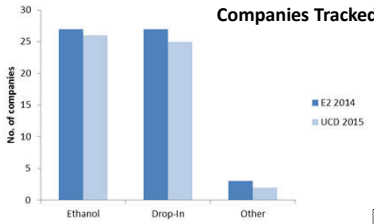
E2 (2015): E2 Advanced Biofuel Market Report 2014 (2015 proj.)

Company Level Tracking of Capacity – Preliminary Results

Methods. We followed methods used by E2 for this follow-on research. Biodiesel was not tracked at company level, as the industry is more developed and technologies more mature. For non-biodiesel companies, we made contact by email with information obtained via independent research and asking for updates, following up with calls as needed and using secondary sources if there was no response. We track *capacity* rather than production, which is in flux due to many other factors and market conditions. We show results in gallons of liquid fuel produced (not gasoline gallon equivalents). We assess capacity that exists or is close to completion or in commissioning as 'low-end'; projections of new technology facilities are classified as 'high-end'. We include demonstration and pilot plants in use for fuels within our scope.

Results. Data for 2016 show lower non-starch ethanol volumes, but higher drop-in volumes than E2 had projected for 2015 (in its 2014 report). Both fuel categories have plans for expansion through 2018. We also found companies switching focus to other bioproducts and away from fuels, or putting plans on hold, citing market conditions. For ethanol, capacity in existing cellulosic facilities may not be fully accessible due to commissioning. More information is needed on commissioning times and factors affecting ramp-up rates. Company activity increased for bolt-on cellulosic corn fiber technology, with cellulosic ethanol now reported in production at two facilities, and other companies licensing the technology. For drop-ins, the dominant fuel was renewable diesel and jet fuel (see next section).

Companies Tracked



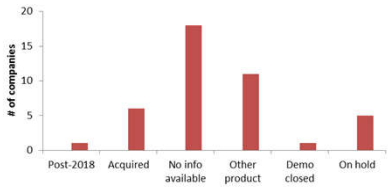
UCD 2015 (non-biodiesel)

Initially tracked: 98 cos.

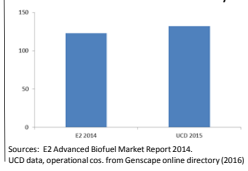
Included: 53 cos.

Out of scope: 45 cos.

Response rate : 31%

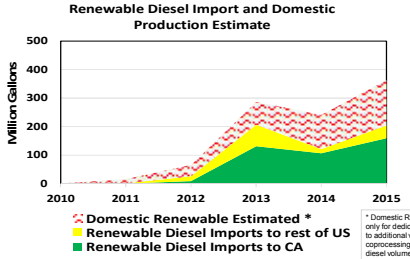


Biodiesel: tracked with 2ndary data



Sources: E2 Advanced Biofuel Market Report 2014.
UCD data, operational cos. from Genscape online directory (2016)

Renewable Diesel Import and Domestic Production Estimate



* Domestic RD estimated production accounts only for dedicated facilities. RFS RIN data point to additional volumes that may be from coprocessing or other facilities (renewable diesel volumes in the program total just over 500mg in 2015).

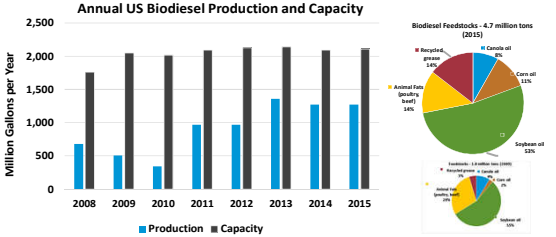
Renewable Diesel

Renewable diesel is a biomass-derived liquid hydrocarbon that meets petroleum diesel fuel specifications (i.e., ASTM D975). As such, it is a "drop-in" fuel functionally equivalent to petroleum diesel. Current commercial renewable diesel is produced by hydroprocessing lipid feedstocks (the product fuel is called HEFA [hydrogenated esters and fatty esters] or HVO [hydrotreated vegetable oil]).

Global renewable diesel production capacity is about 1.2 billion gallons per year (gpy), and projected to 1.9 – 2.5 billion gpy by 2020 (Thurmond, 2016 & GREENEA, 2015). There are approximately 15 facilities worldwide producing renewable diesel with the lion's share from Neste Oil (EIA, 2015 & Lane, 2016). There are six dedicated renewable diesel and one renewable jet fuel facilities in the United States (US capacity is approximately 300 million gpy). Coprocessing at petroleum refineries is a second mode of production.

Some 200 million gallons of renewable diesel was imported to the US in 2015 with 80% to the California market (EIA, 2016). Domestic renewable diesel production estimate is based on dedicated facilities (Geismar Facility commissioning in late 2010 with operation until 2012 and the 160 mgy Diamond Green commissioning and reaching capacity in late 2013). EPA data record an additional 100-200 mg of renewable diesel under the RFS2, which may be domestic or imported coprocessed production.

Annual US Biodiesel Production and Capacity



Biodiesel capacity and production

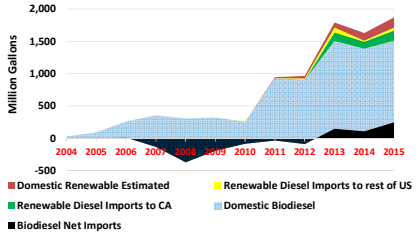
Biodiesel, sometimes called FAME or FAAE biodiesel, refers to mono-alkyl esters of long chain fatty acids derived from vegetable oils and animal fats (ASTM D 6751 fuel). U.S. biodiesel capacity is over 3 billion gpy from 170 EPA registered facilities (NBB, 2015). About 100 facilities, with combined capacity of 2 billion gpy produced some 1.3 billion gallons in 2015 (EIA, 2016b). There is considerable idle capacity in the biodiesel industry. Roughly 40% of existing facilities, representing one-third of the built capacity (1 billion gallons), did not produce commercial biodiesel in 2015. A major driver of domestic production is the RFS2 biomass-based fuel mandate, which provides a market for a certain amount of the fuel each year, although mandate levels have been uncertain and imported biodiesel is also eligible.

Biodiesel Feedstocks

The feedstocks used for biodiesel are of policy interest because they can make a substantial difference in fuel carbon intensity (relevant for California's LCFS and Oregon's CFS policies).

In 2015, raw vegetable oil dominated the 4.7 million tons of feedstocks used in domestic biodiesel production (primarily soybean oil), with animal byproduct fat and recycled grease accounting for a combined 28% (EIA, 2016b). The practice of corn oil extraction during corn ethanol production for use as biodiesel feedstock has diffused through much of the industry.

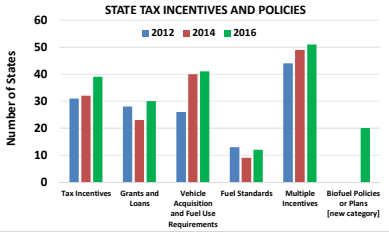
US Biomass-based Diesel - Quantities Available



US Biomass-based Diesel Market

Domestic and (net) imported biodiesel totaled 1.5 billion gallons in 2015 (EIA, 2016c). With renewable diesel quantities described above, US biomass-based diesel available quantities totaled nearly 1.9 billion gallons in 2015.

STATE TAX INCENTIVES AND POLICIES

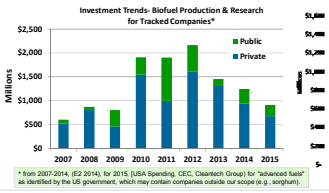


State Tax Incentives and Policies

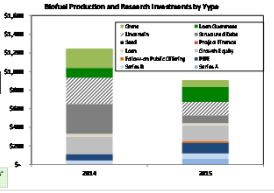
The number of states with biofuel related policies or financial incentives has grown since 2012 with all states plus the District of Columbia now represented (US DOE, 2016).

Support types include the following categories:

- **Tax Incentives**: Tax credits, tax exemptions, or favorable tax rates applying to production or investments in biofuels.
- **Grants and Loans**: Public funds that help buy down capital cost or promote research (grants) or provide attractive interest rates or guarantee loans.
- **Vehicle Acquisition and Fuel Use Requirements**: Requirements for government vehicle fleets to contain alternative fuel vehicles, or biofuel blending requirements for fleet fueling.
- **Fuel Standards:** Renewable fuel blend requirements and low carbon fuel standards.
- **Biofuel Policies or Plans**: Biofuel policy, plan, study or recommendation (state or local) [new category for 2016].



* from 2007-2014, (E2 2014), for 2015, (USA Spending, CEC, Cleantech Group) for "advanced fuels" as identified by the US government, which may contain companies outside our scope (e.g., sorghum).



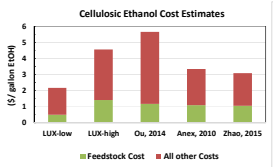
Investment

There has been a marked decrease in both private and public investment in biofuel production facilities and research from levels reached in the 2010-2012 period. The investment picture aligns with the decline in North American production capacity estimates compared to those in E2's 2014 market report.

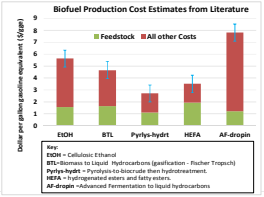
Fuel Production Cost Estimates

Cellulosic ethanol production cost is estimated between $2.17 and $5.50 per gallon ($3.30-$8.30 per gallon gasoline equivalent [gge]) with feedstock costs comprising up to 40% of the total (Lux Research, Ou, 2014, Anex, 2010 & Zhao, 2015). From a review of techno-economic literature on biofuel innovations, production cost estimates range from ~ $2.80/gge for pyrolysis & hydrotreatment fuel to about $8/gge for hydrocarbons via advanced fermentation (fermentation of cellulosic-derived monomer sugars direct to hydrocarbon). Note that estimates refer to non-pioneer facilities. More information is needed on cost estimates per gallon taking into account start-up activity (both capital expenses and curtailed production).

Cellulosic Ethanol Cost Estimates



Biofuel Production Cost Estimates from Literature



Key Findings & Key Issues

We tracked non-starch ethanol and drop-in biofuel companies. Drop-in capacity expansion plans are greatest, due to renewable diesel. 'Bolt-on' production using corn fiber at existing corn ethanol facilities emerged as more important in the projections. Many companies previously tracked had moved out of scope due to changed product focus, industry consolidation, delay of plans, or no visible business activity. Biodiesel capacity remained well above production levels (which have grown largely in response US renewable fuels policy), but the feedstock mix has shifted. Both private and public investment in biofuels declined from 2014. State-level initiatives grew more prevalent.

Key issues from the research include: need to define "effective capacity" (which may differ from nameplate during commissioning or when idle or repurposed); importance of the 'bioproduct landscape' to biofuel innovation; how to define "innovation" (what level of emissions improvement warrants attention? does location of production matter?) . Finally, amid carbon accounting uncertainty, sustainability safeguards are criticial, especially if biofuel volumes or other bio-based products do scale up in a way that increase competition for land (and sparks emissions).

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Contacting the Authors: *Julie Witcover (jwitcover@ucdavis.edu), Rob Williams (rbwilliams@ucdavis.edu), Arthur Wu (acwu@ucdavis.edu)*