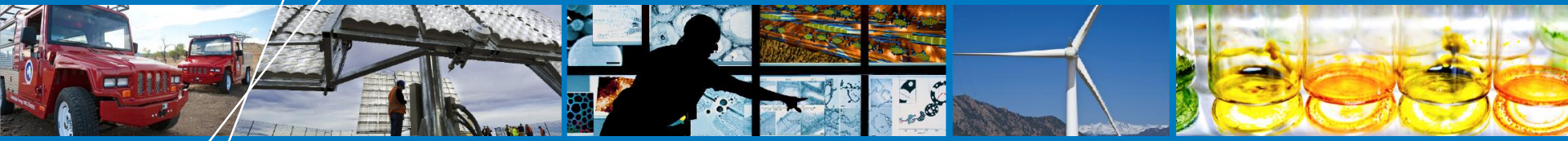
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Systems-Level Analysis & Bioenergy Market Assessment



24 March 2015

BETO Project Peer Review

4.1.2.1 Systems Analysis and Modeling

John Lewis

National Renewable Energy Laboratory

This presentation does not contain any proprietary, confidential, or otherwise restricted information

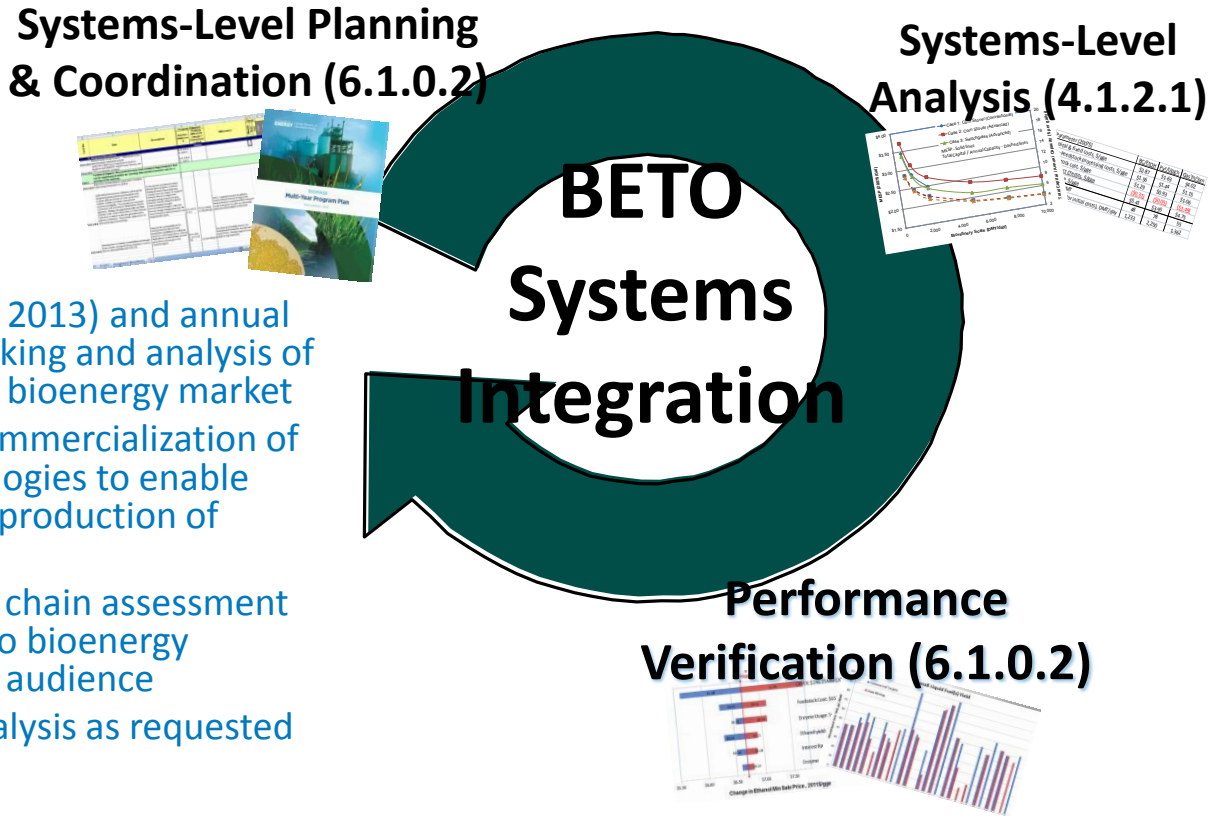
Goals and Project Objective

System Integration:

- Provide BETO with a systems-level perspective and technical support to ensure data-driven decision-making and effective program integration

Systems-Level Analysis

- Maintain core analytical capabilities to facilitate and conduct system-wide and cross-system analyses for BETO that enable the development of a sustainable, commercially-viable national bioenergy industry



Project Objectives

- Provide a baseline (from 2013) and annual updates that enable tracking and analysis of the evolution of the U.S. bioenergy market
- Facilitate tracking the commercialization of viable bioenergy technologies to enable sustainable, nationwide production of biofuels
- Convey results of supply chain assessment (from feedstock supply to bioenergy infrastructure) to a wide audience
- Ad hoc systems-level analysis as requested by BETO

Quad Chart Overview

Timeline

- Systems Analysis: Ongoing Since 2004†
- Market Report
  - Start: October 2013
  - Market Report Finish: September 2017 †
  - 2013 Market Report: 95% Complete

Budget‡

	Total Costs FY10 – FY12	FY13 Costs	FY14 Costs	Total Planned Funding (FY15-Project End Date
DOE Funded – *Systems-Level Analysis*	$614K	$223K	$169K	$450K
DOE Funded – *Market Report*	$0	$0	$343K	$1,050K
Project Cost Share	$0	$0	$0	$0

†Project continuation and direction determined annually by DOE
‡ This is a lab project subject, to zero cost share

- **Barriers Addressed**
  - "Optimization of Supply Chain Interfaces and Cross-System Integration"[MYPP Mt-A]
  - "Analytical Tools and Capabilities for System-Level Analysis" [MYPP At-B]
  - "Data Availability Across the Supply Chain" [MYPP At-C]
- **Partners & Collaborators**
  - No subcontract partners
  - National lab collaborations with INL, ORNL, ANL, PNNL, NREL
  - External collaborations with Federal Aviation Administration (FAA), Commercial Aviation Alternative Fuels Initiative (CAAFI), USDA-Forest Service

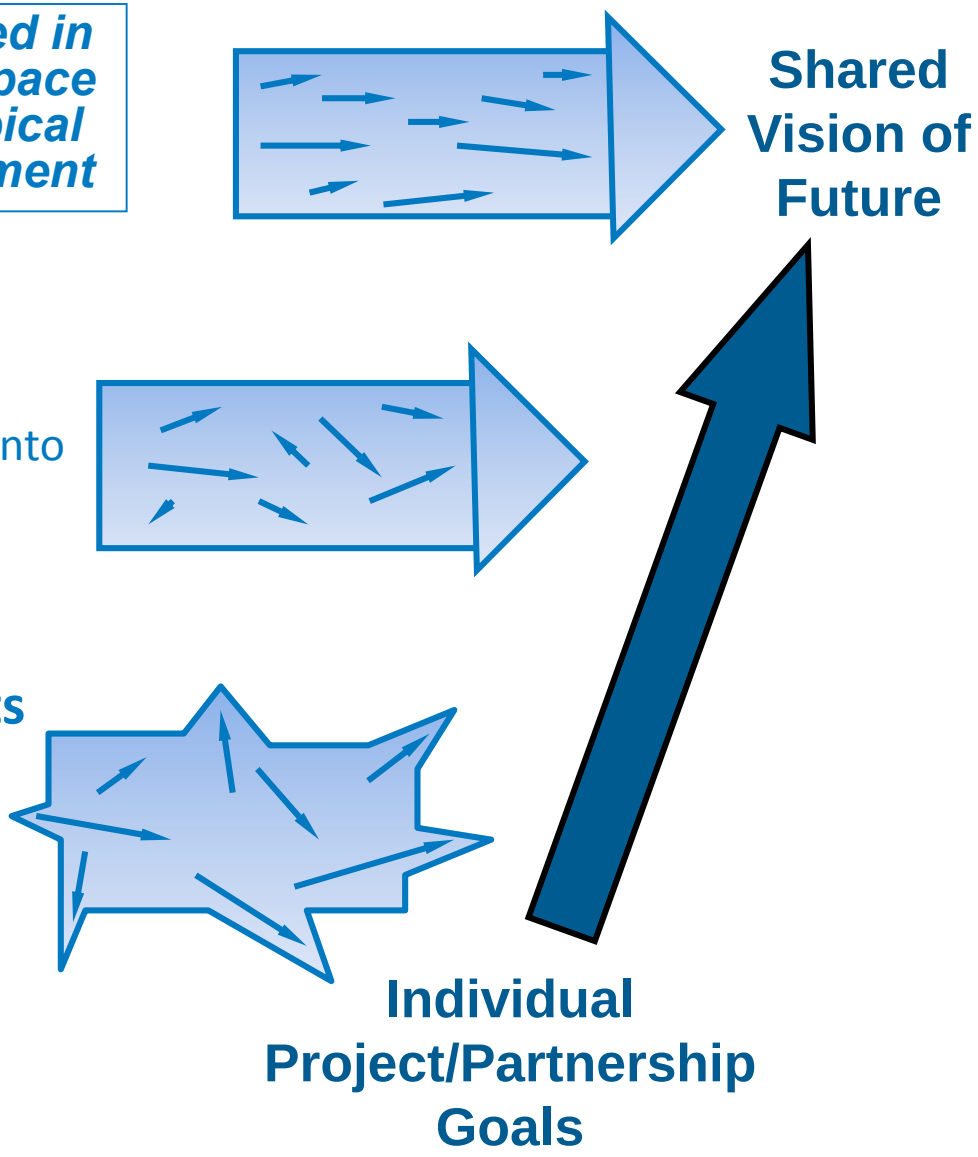
Project Overview

- **Challenge/Objective**
  - Identify emerging areas of opportunity in bioenergy, and conduct systems-level analyses to support BETO decision making
  - Document a baseline understanding of an industry in the early stages of development
  - Track that development over time, and integrate this understanding into other cross-supply-chain analyses
  - Maintain a core analytical capability to support BETO efforts to conduct systems-level analysis in key areas such as biofuels, biopower and bioproducts
- **Products**
  - Survey of non-starch ethanol and renewable hydrocarbon biofuels producers
  - Bioenergy market report
  - Aviation overview report
  - Investigation of thermochemical biorefinery sizing and sustainability – journal article
  - Learning curves analysis - internal report
  - Impact of a billion tons of biomass on the U.S. economy – internal analysis
  - Analytical support for Multi-Year Program Plan
  - Ad hoc analyses for internal BETO purposes

System Integration Focus – Approach (Tech)

BETO Mission could be compared in scope to "create a functioning space industry" rather than a more typical one product aerospace development

- **Market Transformation**
  - Paradigm shift in current agricultural sector
  - Requires significant penetration into existing energy markets
  - Program efforts only enable commercialization by the private sector
- **Aligning and Integrating Efforts**
  - 400+ BETO-Funded Projects
    - Government Agencies
    - Universities
    - Industry
- **System Integration Approach**
  - Cross-system analysis
  - Measure baseline and progress



Deliverables & Decision Points – Approach (Mgmt)

Month - Year	Deliverable or Go/No-Go Decision	% Complete
Oct - 2014	**Deliverable:** One briefing and internal report delivered to BETO on insights and results from Deployment and Market Transformation (DMT) planning scenario analysis	100%
Jan - 2015	**Deliverable:** Results of biorefinery survey published as a technical report	100%
Feb - 2015	**Deliverable:** Draft of *2013 Bioenergy Market Report* circulated for external review	100%
Mar - 2015	**Deliverable:** Complete Red Team review of *2013 Bioenergy Market Report,* and deliver document to BETO for final review and publication	95%
Apr - 2015	**Go/No-Go Decision:** Determine scope of FY15 market report, and additional bioproduct market content relative to initial market report	80%
Jun - 2015	**Deliverable:** Deliver draft of *2014 Bioenergy Market Report* for BETO review prior to publication	10%

2013 Survey Results of U.S. Non-Starch Ethanol Biorefineries – Accomplishments

- No U.S. facilities produced cellulosic ethanol during 2013 (measured by RINs assigned by EPA)
- 4 commercial facilities identified in survey scheduled to become operational sometime after 2013
- 25 non-starch ethanol facilities identified utilizing 4 different conversion pathways and 6 different feedstock types

Scale of Facility	Company Name_Facility Location	Planning	Under Construction	Operating	Idle
Commercial	Abengoa_KS		+		
	Beta Renewables_NC		×		
	BlueFire Renewables, Inc._MS	△			
	Canergy, LLC_CA	×			
	DuPont_IA		+		
	Fiberight_IA	◇			
	INEOS New Planet BioEnergy LLC_FL		◇		
	Mascoma_MI	△			
	POET Design & Construction_IA		+		
Demonstration	American Process Inc_MI		△		
	BP_LA			×	
	Coskata_PA				△
	DuPont_TN			+	
	Lignol Innovations_Undisclosed	△			
	Mascoma_NY				△
	RSA d/b/a Old Town Fuel & Fiber_ME	△			
	ZeaChem_OR			△	
Pilot	Algenol Biofuels Inc._FL		□		
	Archer Daniels Midland_IL		+		
	Arkenol_CA				△
	Fiberight_VA				◇
	ICM, Inc._MO			*	
	LanzaTech_GA		△		
	Logos Technologies_CA				+
	POET Design & Construction_SD			○	

Technology Pathway
- Algae Tech
- Biochemical
- Hybrid BC/TC
- Thermochemical Gasification

Feedstock Category
- ○ Not Reported
- □ Algae
- \+ Crop Residues
- × Dedicated Energy Crops
- * Herbaceous Mix
- ◇ Vegetative and Yard Waste
- △ Woody Biomass

2013 Survey Results of U.S. Renewable Hydrocarbon Biorefineries – Accomplishments

- 514,627 gallons of renewable hydrocarbons produced in 2013 (measured by RINs assigned by EPA)
- KiOR facility was only producer in 2013, and this facility was subsequently idled in 2014
- 17 renewable hydrocarbon facilities identified utilizing 4 different conversion pathways and 6 different feedstock types

Scale of Facility	Company Name_Facility Location	Planning	Under Construction	Operating	Idle
Commercial	Cool Planet_LA	△			
	Diamond Green Diesel_LA		◁		
	Dynamic Fuels LLC_LA				◁
	KiOR_MS			△	
	OriginOil_CA	×			
	Sundrop Fuels_LA	△			
Demonstration	Cool Planet_CA			○	
	Envergent Technologies/UOP_HI				△
	REII_OH			△	
	Sapphire Energy, Inc._NM			□	
	Sundrop Fuels_ND				△
Pilot	BioProcess Algae_IA	□			
	ClearFuels/Rentech_CO				△
	Frontline BioEnergy, LLC_TX	▽			
	Haldor Topsoe, Inc._IL				△
	Mercurius Biorefining_MI/IN	+			
	Sundrop Fuels_CO				△

Technology Pathway
- Not Reported
- Algae Tech
- Hydrotreating/Isomerization
- Thermochemical Gasification
- Thermochemical Pyrolysis

Feedstock Category
- ○ Not Reported
- □ Algae
- \+ Crop Residues
- × Dedicated Energy Crops
- ▽ Municipal Solid Waste
- ◁ Vegetable Oils, Fats, and Greases
- △ Woody Biomass

2013 Survey Capacity of U.S. Commercial-Scale Cellulosic Ethanol and Renewable Hydrocarbon Biorefineries – Accomplishments

Company	Project Location	Technology Pathway	Feedstock Category	Capacity [MMGY]	Operational Year (Anticipated)
Abengoa	Hugoton, KS	Biochemical	Crop Residues	24	(2014)
Beta Renewables, Inc.	Clinton, NC	Biochemical	Dedicated Energy Crops	20	(2016)
DuPont	Nevada, IA	Biochemical	Crop Residues	30	(2014)
INEOS New Planet Bioenergy LLC	Vero Beach, FL	Thermochemical Gasification	Vegetative and Yard Wastes	8	2012
POET Design & Construction	Emmetsburg, IA	Biochemical	Crop Residues	22.5	(2014)

U.S. Commercial-Scale Cellulosic Ethanol Capacity (Installed or Under-Construction): 104.5 MMGY

Company	Project Location	Technology Pathway	Feedstock Category	Capacity [MMGY]	Operational Year (Anticipated)
Diamond Green Diesel	Norco, LA	Hydrotreating/ Isomerization	Vegetable Oils, Fats, and Greases	136	(2014)
Dynamic Fuels LLC	Geismar, LA	Hydrotreating/ Isomerization	Vegetable Oils, Fats, and Greases	75	2010 [Idled in 2013]
KiOR	Columbus, MS	Thermochemical Pyrolysis	Woody Biomass	13	2013 [Idled in 2014]

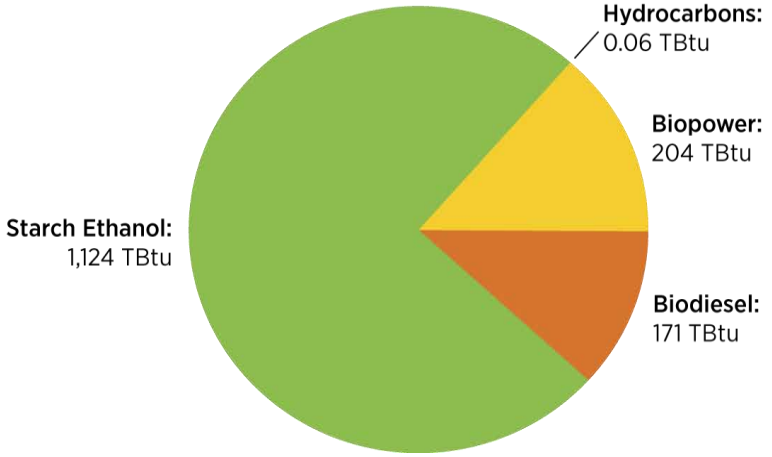
U.S. Commercial-Scale Renewable Hydrocarbon Capacity (Installed or Under-Construction): 224 MMGY

Published Report: http://www.nrel.gov/docs/fy15osti/63389.pdf

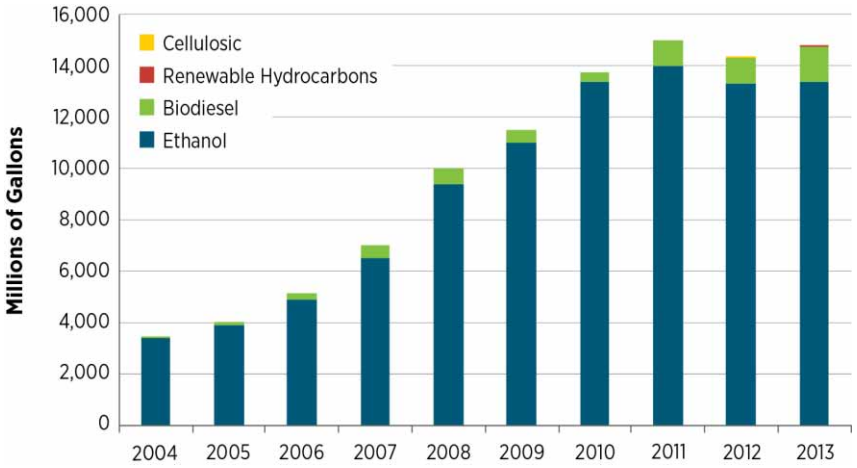
MMGY = Million Gallons per Year

Bioenergy Market Report – Accomplishments

- In 2013, U.S. bioenergy production reached nearly 1,500 trillion Btu from ethanol, biodiesel, renewable hydrocarbons, and biopower
- Biofuels make up the largest portion (86%) of the current bioenergy market
- Biofuels production is dominated by conventional starch ethanol, which accounts for 75% of total bioenergy production
- Renewable fuels production has grown steadily in the U.S. over the past decade
- Biopower accounts for 11% of all renewable energy produced in the U.S., and about 1.5% of total electricity generation.



2013 U.S. bioenergy production (1,500 TBtu total)



2012: cellulosic ethanol: 20,069 gallons; Renewable hydrocarbons: 1,024 gallons
2013: cellulosic ethanol: 0 gallons; renewable hydrocarbon: 514,627 gallons

U.S. renewable fuels production

[Sources: EIA Annual Energy Review and EPA 2013 RFS2 Data]

Documenting An Evolving Cellulosic Feedstock Market – Accomplishments

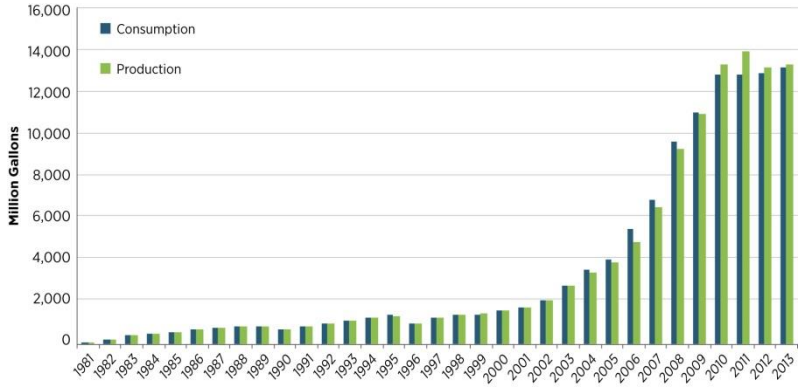
- **Annual estimated U.S. cellulosic biomass resource of approximately 400 million dry tons**
- **Woody forest resources represent more than 50% of annual cellulosic biomass resources**
- **Cellulosic biomass resources used to generate electricity, power and various biofuels such as cellulosic ethanol and renewable hydrocarbon biofuels**

Annual Cellulosic Biomass Resources (2012)

Biomass Resource	Annual Generation (million BDT)
Total agricultural crop residues	***150***
Harvesting crop residues[12]	138
Processing crop residues[13]	12
Total forest resources	***235***
Logging residues[14]	32
Other removals[14]	11
Primary mill residues[15]	60
Urban wood[16]	45
Secondary mill residues[17]	10
Standing dead timber[18]	9
Thinnings from pinyon-juniper woodland[19]	8
Conventionally sourced wood (pulpwood)[20]	15
Black liquor[21]	45
Total other herbaceous	***15***
Yard trimmings[22]	15
Total cellulosic biomass	***400***

Notes: BDT = Bone Dry Ton. Table shows the total biomass generated in 2012, NOT the biomass resource available for conversion to bioenergy, and does include some materials that are currently already utilized (namely primary mill residues and black liquor). References available in *2013 Bioenergy Market Report.*

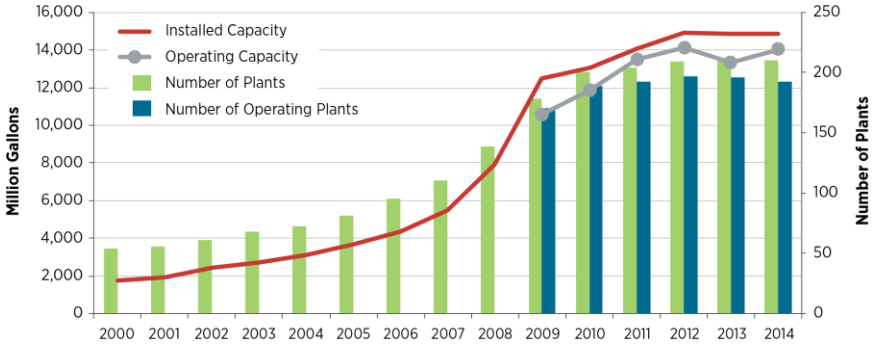
Biofuels Market – Conventional Ethanol – Accomplishments



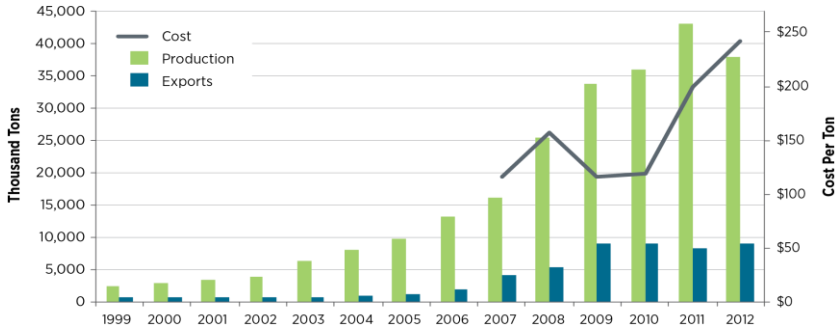
Historical ethanol production and consumption
Source: EIA Annual Energy Review

Ethanol has demonstrated tremendous growth in capacity, production, and consumption since 2000. The past year saw production plateau as the blend wall was essentially reached and markets for blends above E10 were limited.

As of January 2014, there were 210 fuel ethanol plants in 28 states with installed capacity of 14.9 billion gallons producing 13.3 billion gallons.



Historical ethanol plants
Source: RFA Ethanol Industry Outlooks' 2000-2014:
http://www.ethanolrfa.org/pages/annual-industry-outlook

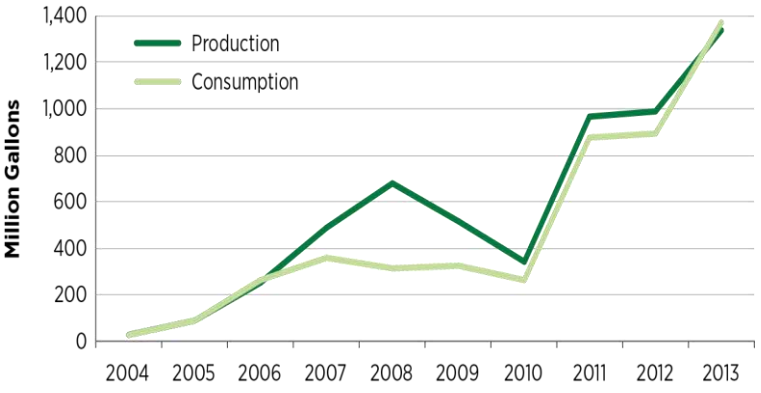


Starch ethanol co-products production, trade, and price

Co-product contribution to revenues has increased in recent years—largely due to corn oil—going from an average of 16.5% of revenue contribution in 2008 to 23% in the first half of 2012.

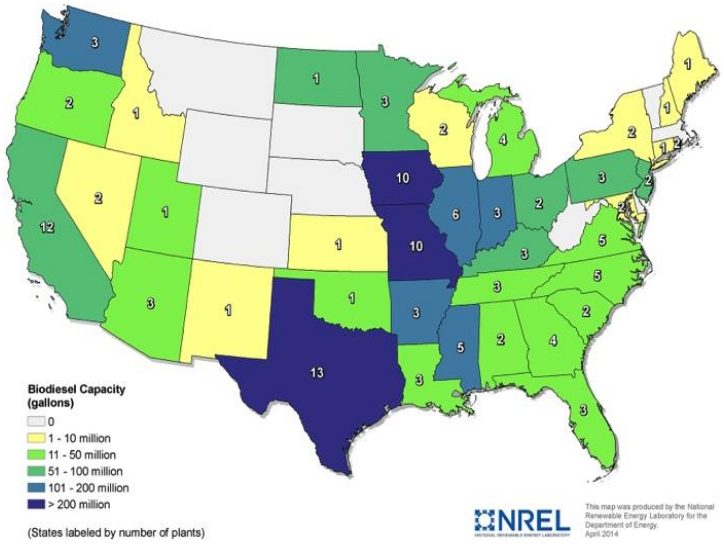
Biofuels Market – Biodiesel – Accomplishments

2013 biodiesel production was 1.334 billion gallons. Approximately 155 biodiesel plants have a total production capacity of more than 2.2 billion gallons across 41 states.



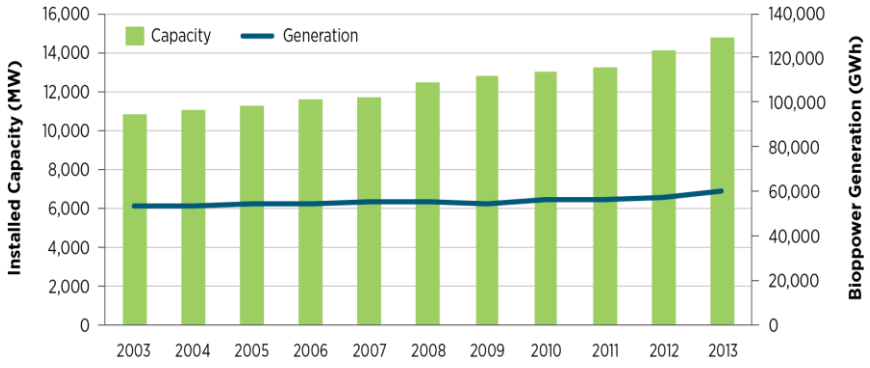
Biodiesel production and consumption
Source: EIA Annual Energy Review, Table 10.4.

Between 2007 and 2009 production exceeded domestic consumption and exports to European nations were common due to higher prices. That opportunity declined in 2010 due to European protectionist legislation. Current and future production could be impacted by an EPA proposal to lower the RFS advanced biofuels volume.



Biodiesel plants by state (as of April 2014)
Source: Biodiesel Magazine Plant List. Last accessed 5/1/2014.

Biopower Market – Accomplishments



U.S. biopower capacity and generation
Source: EIA 2014

Biomass electricity generation currently accounts for 11% of all renewable energy generated in the Unites States and about 1.5% of total electricity generation.

Today, most biopower is generated from woody biomass (namely low-quality wood, residues, and by-products) in dedicated or cogeneration plants (such as pulp and paper mills or sawmills).

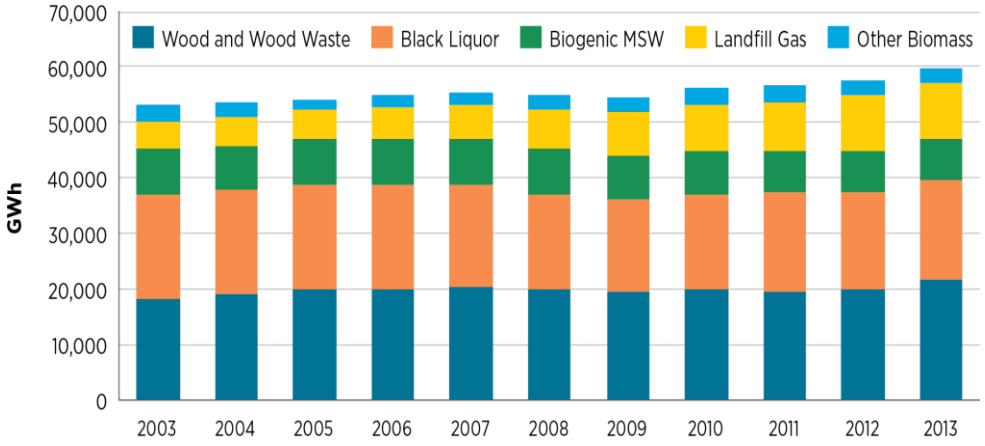


Figure 40. U.S. biopower generation sources
Source: EIA 2014 Other biomass includes other biomass solids, other biomass gases, agricultural crop residues, sludge waste, wood-waste liquids, and other biomass liquids.

Relevance to BETO Goals and Larger Bioenergy Community

Element	MYPP Goal	Project Contribution
Strategic Analysis	Provide the analytical basis for planning and assessment of progress [p. 2-117]	Survey and market report track the progress of biorefinery commercialization, and provide citable references for bioenergy community
Strategic Analysis	Reviews and evaluates external analyses and studies [p. 2-117]	Market report compiles and evaluates information from publically available datasets for use by bioenergy industry analysts
Demonstration and Market Transformation	Prove techno-economic viability and enable commercial production facilities [p. 2-91]	Briefing and internal report of investment effects on the growth of the biofuels industry for BETO
Feedstock Supply	Provide a sustainable, secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry [p. 2-7]	Market report presents a historic and current resource overview for use by the bioenergy community
Risk Assessment	Provide risk assessments and incorporate those assessments into TEAs/LCA. [p. 2-19]	A methodology will be developed for incorporating elements of risk assessment into analytical tools for BETO
Strategic Communi-cations	Convey the results of analytical activities to a wide audience [p. 2-118]	Publication of reports benefit bioenergy community by informing policy-makers, technology developers, and investors

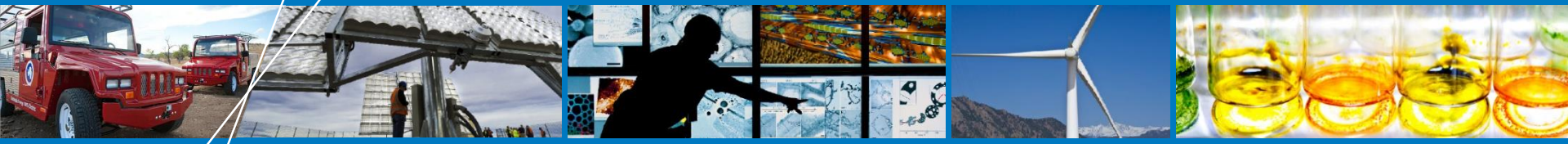
Future Work

- **Update biorefinery survey with 2014 data and increase coverage of facilities with plans to commercially produce bioproducts**
- **Update market report with 2014 data and explore in more depth:**
  - Products and intermediates
  - Greenhouse gas and other emission assessments
  - International bioenergy markets and trade
- **Develop a methodology to identify and quantify uncertainty and risk along the bioenergy supply chain**
- **Learning curves analysis for new conversion pathways (as data becomes available)**

Summary

- **Goal:** *Provide a baseline (from 2013) and annual updates that enable tracking and analysis of the evolution of the U.S. bioenergy market*
  - Biorefinery survey and bioenergy market report facilitated tracking the commercialization of viable bioenergy technologies to enable sustainable, nationwide production of biofuels
- **Methodologies:** *Establish consistent reporting methodologies*
  - Developed a survey methodology to identify and evaluate commercial biofuels producers, and investigated a wide range of biofuels facilities
  - Developed a market report architecture that documents the growth of the bioenergy market to date, with flexibility for future market growth
- **Products:** *Convey results of systems-level analysis to a wide audience*
  - *Investigation of Thermochemical Biorefinery Sizing and Environmental Sustainability Impacts for Conventional Supply System and Distributed Preprocessing Supply System Designs* published as a journal article
  - *An Overview of Aviation Fuel Markets for Biofuels Stakeholders* published as a technical report
  - *2013 Survey of Non-Starch Ethanol and Renewable Hydrocarbon Biofuels Producers* published as a technical report
  - *2013 Bioenergy Market Report* will be forthcoming

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



Additional Slides

Responses to Previous Reviewers' Comments

- **Since this is the first time this project is being reviewed, there are no previous reviewers' comments to address.**

Publications

Internal Reports

- Lewis, J.; Stright, D.; Vimmerstedt, L.; Bush, B. (2014). *2014 Update: Demonstration Investment Effects on the Growth of the Biofuels Industry.* Golden, CO: National Renewable Energy Laboratory. (Internal only).

Technical Reports

- Davidson, C.; Newes, E.; Schwab, A.; Vimmerstedt, L. (2014). *An Overview of Aviation Fuel Markets for Biofuels Stakeholders*. NREL/TP-6A20-60254, Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy14osti/60254.pdf.
- Schwab, A.; Geiger, J.; Lewis, J. (2015). *2013 Survey of Non-Starch Ethanol and Renewable Hydrocarbon Biofuels Producers*. NREL/TP-6A10-63389, Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy15osti/63389.pdf.
- Milbrandt, A.; Moriarty, K.; Schwab, A.; Lewis, J. (Forthcoming). *2013 Bioenergy Market Report.* Golden, CO: National Renewable Energy Laboratory. (Intend to publish as DOE report).

Journal Articles

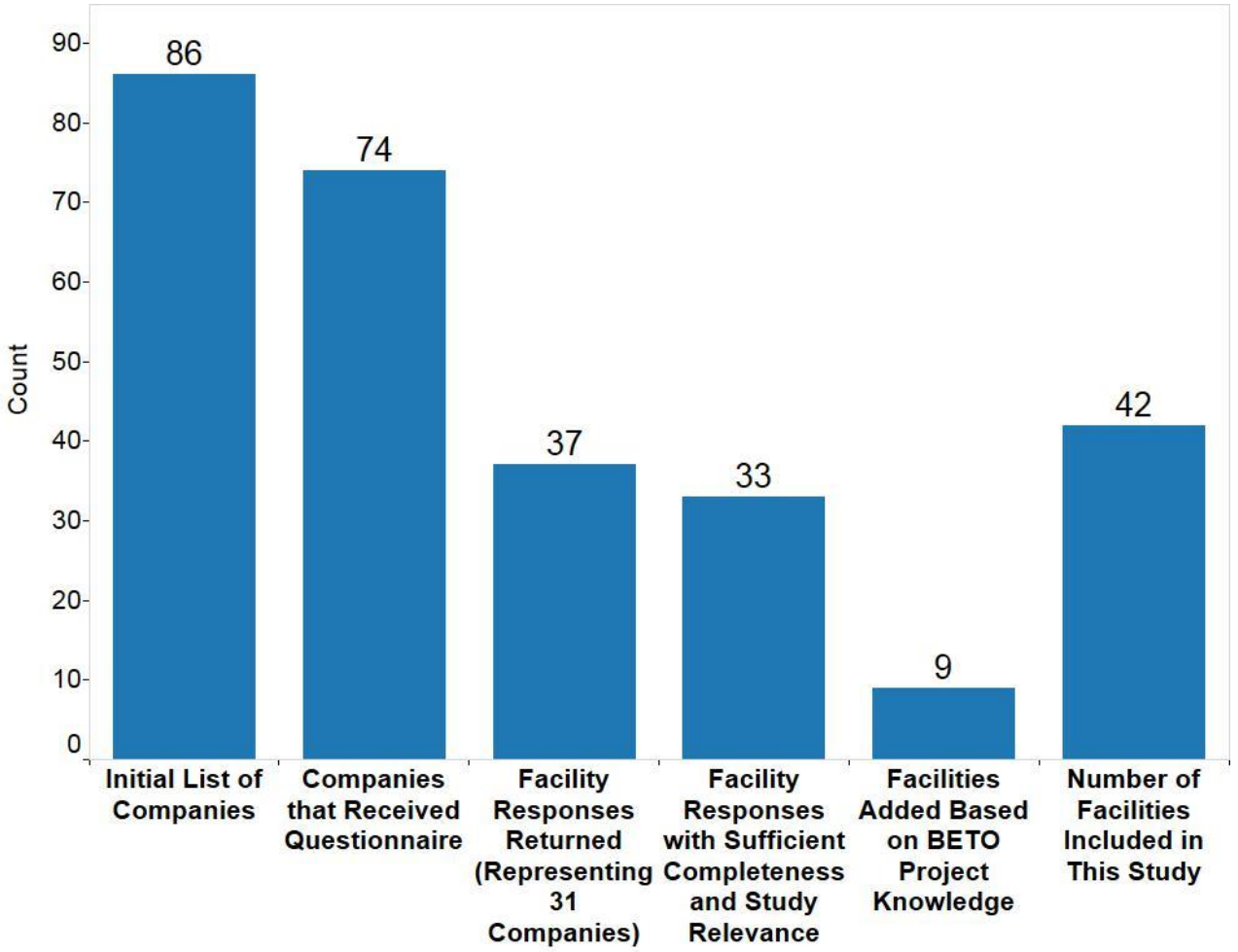
- Muth, D.; Langholtz, M.; Tan, E; Jacobson, J.; Schwab, A.; Wu, M.; Argo, A.; Brandt, C.; Cafferty, K.; Chiu, Y.; Dutta, A.; Eaton, L.; Searcy, E. (2014). *Investigation of Thermochemical Biorefinery Sizing and Environmental Sustainability Impacts for Conventional Supply System and Distributed Preprocessing Supply System Designs.* Biofuels, Bioproducts and Bioefining Vol 8, Issue 4, p545.

Market Analysis Methodology – Approach

Survey Methodology: Identify biorefinery facilities located in the United States, with active plans to commercially produce advanced biofuels. 42% survey response rate.

Market Report Methodology: Document existing bioenergy market. Leveraged existing, publically available datasets, and performed market research. Results vetted by bioenergy market experts.

Survey Process Used to Collect Biorefinery Information



Survey Definitions for Stage of Facility Development

Category	Response Selections— Definitions
Stage of Development	**Planning:** Ground has not been broken for construction. However, one or more of the following activities has occurred: a facility location has been selected, project financing negotiations have started, and/or permits have been obtained for a specific site. **Under Construction:** Ground breaking at the selected site has occurred, and the facility is under construction. This includes facilities undergoing startup and commissioning. **Operational:** The facility is currently producing fuel and/or conducting development work on a regular basis. **Idle:** The facility is no longer producing fuels, but was producing at one point. Possible reasons for an idle facility include unfavorable market conditions, completion of a development period, or project bankruptcy.

Survey Definitions for Scale of Facility

Category	Response Selections— Definitions
Scale of Facility	**Pilot:** Small-scale facility with unit operations integrated; primarily used for research and development work. **Demonstration:** Small-scale, fully integrated facility used for determining design specifications for a larger facility. **Commercial:** First-of-a-kind or subsequent full-scale facility for commercial production of fuel products.

Survey Definitions for Type of Technology Pathway

Category	Response Selections— Definitions
Type of Technology Pathway	**Algae Tech:** Broad category of technology pathways that involve using algae to a produce a fuel product. **Biochemical:** Chemical or enzymatic conversion of biomass to cellulose, which is then fermented or reacted to a fuel product. **Hybrid BC/TC:** Using a combination of the biochemical and thermochemical technology pathways to produce a fuel product. **Hydrotreating/Isomerization:** Conversion of organic material using hydrogen at elevated temperature and pressure levels often in the presence of a catalyst. **Thermochemical – Gasification:** The thermal conversion of organic material to a syngas that is catalytically converted into a fuel product. **Thermochemical – Pyrolysis:** The thermal conversion of organic material to an intermediate oil that is further refined into a fuel product.

Survey Definitions for Feedstock Categories

Category	Response Selections— Definitions
Feedstock Category	**Algae:** A large, aquatic group of simple plant-like photosynthetic organisms—from microscopic cyanobacteria to giant seaweed. **Crop Residues:** Crop residues are divided into two sub-categories: harvesting crop residues and processing crop residues. Harvesting crop residues are materials such as leaves, stalks, and straw left on the field after crop harvesting. Processing crop residues remain after the crop has been processed into a primary product and include materials such as husks and bagasse. **Dedicated Energy Crops:** Dedicated energy crops are specifically grown for bioenergy production and include herbaceous and woody resources. **Herbaceous Mix:** A mixture of herbaceous resources. **Municipal Solid Waste (MSW):** The term refers to solid wastes from residential and business sources that are then converted to produce biofuels and/or electricity. **Vegetable Oils, Fats, and Greases:** Lipid-based feedstock that has historically been used to produce biodiesel, but is emerging as a feedstock for renewable hydrocarbon fuels production. **Vegetative and Yard Waste:** Yard trimmings are a subcategory of MSW and include grass clippings, leaves, and tree/brush trimmings. **Woody Biomass:** A broad category capturing forest logging residues, mill residues, and other woody waste sources.