

U.S. DEPARTMENT OF
ENERGY

Office of
**ENERGY EFFICIENCY &
RENEWABLE ENERGY**

Country Report United States 2023

IEA Bioenergy

Task 42 Biorefining in a Circular Economy

Robert Natelson, Mark Shmorhun
U.S. Department of Energy



Outline

- **BETO Background**
- **U.S. Biorefining Status**
- **BETO Activities**
- **Major National Stakeholders and Partners in Biorefining**

BETO Background

EERE FY 2022 Request Guiding Principles

Accelerate the research, development, demonstration, and deployment (RDD&D) of innovative technologies that will transition Americans to a 100% clean energy economy no later than 2050 and ensure the clean energy economy benefits all Americans.

EERE Mission

Keys to Ensure the Greatest Impact



Environmental
Justice and Equity



Diversity in STEM



Workforce
Development



State and Local
Partnerships

EERE Program Priorities

100% decarbonized
electric grid by
2035

Decarbonize
transportation
across all modes

Decarbonize energy
intensive industries

Reduce the carbon
footprint of
buildings

Enable a net-zero
agricultural sector

Bioenergy Technologies Office (BETO)

Production and Harvesting

Feedstock Technologies

- Lower costs
- Improve quality
- Increase types of feedstock intermediates available for conversion.

Advanced Algal Systems

- Increase algae productivity
- Algal strain improvement and efficient cultivation.

Conversion and Refining

Conversion Technologies

- Reduce costs of deconstructing feedstock into intermediate products
- Upgrade intermediates into liquid biofuels (e.g., SAF), bioproducts, and biopower

Distribution and End Use

Systems Development and Integration

- Systems research to combine tech, operations, subsystems developed by R&D programs into integrated processes.
- Integrated processes tested (pre-pilot to demo scale) to identify R&D needs, readiness for scale-up and commercialization.

Crosscutting

Data, Modeling, and Analysis

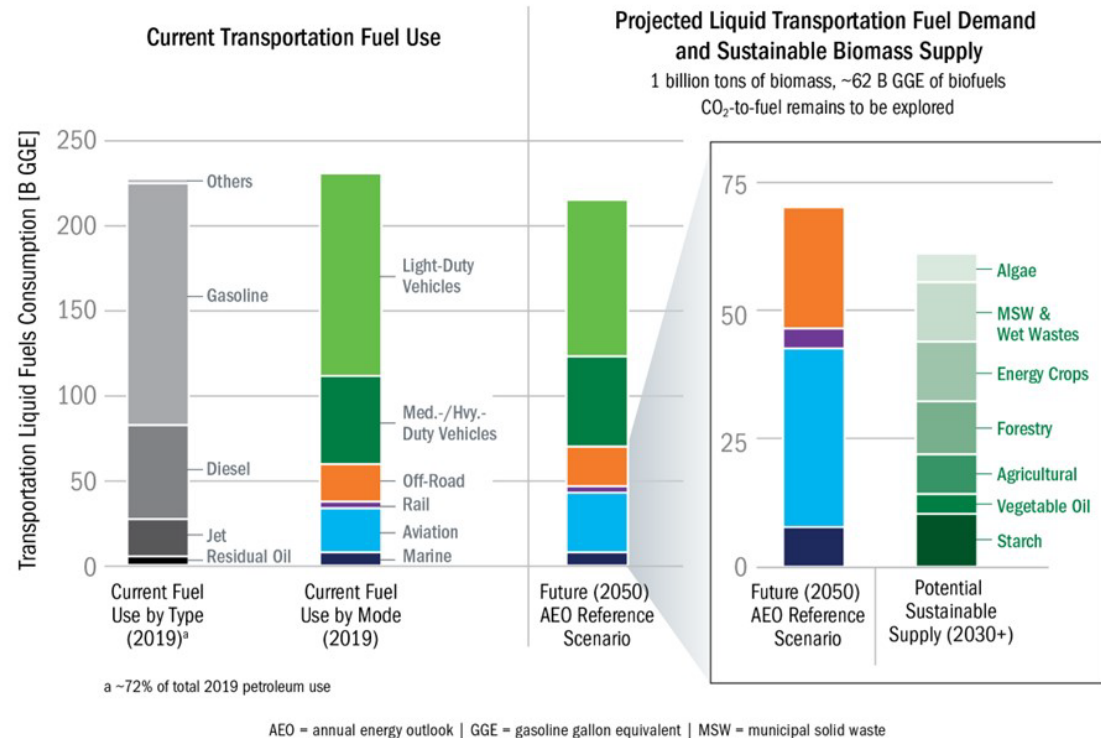
- Track technology progress and identify opportunities and challenges related to economic/environmental impact of advanced bioenergy systems.

Role of Biomass in Sustainable Transportation

- Transportation accounts for 34% of U.S. greenhouse gas (GHG) emissions.
- Biofuels are part of a sustainable transportation fuel strategy to decarbonize all modes.
- U.S. biomass can meet the needs of “hard to decarbonize” modes, such as aviation, marine and rail.

Focus areas for biofuels:

- Ethanol for passenger cars
- “Drop-in” fuels that can use existing infrastructure such as renewable diesel/sustainable aviation fuels



Resource Evolution

2021-2025

Fats, oils,
and greases
Corn/corn
ethanol



2026-2030

MSW and
wood waste



2030-2040

Ag wastes



2040-2050

Energy crops
and algae



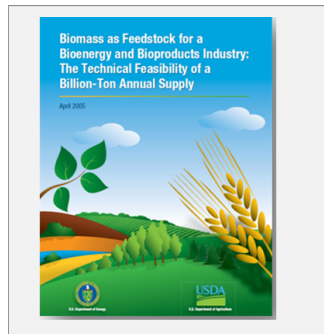
2023 Billion-ton Report, in Preparation

(FI.1 Understand resource markets and availability; PA.2 Conduct techno-economic and production potential analysis)

To inform research, development, and deployment strategies.

- Policy agnostic
- End-use agnostic
- Not predictions
- Not targets

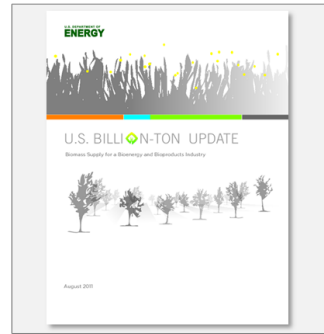
2005



Supply...

Can we displace 30% of the country's petroleum consumption?

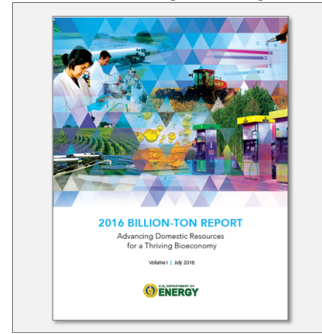
2011



...Cost...

- County-level supplies by cost.
- Economic model of ag+energy crops.

2016 (BT16)



...Sustainability.

- 44 feedstocks w/ modeled crop yields
- Forest model
- Delivered costs
- 2 Volumes + visualization tools

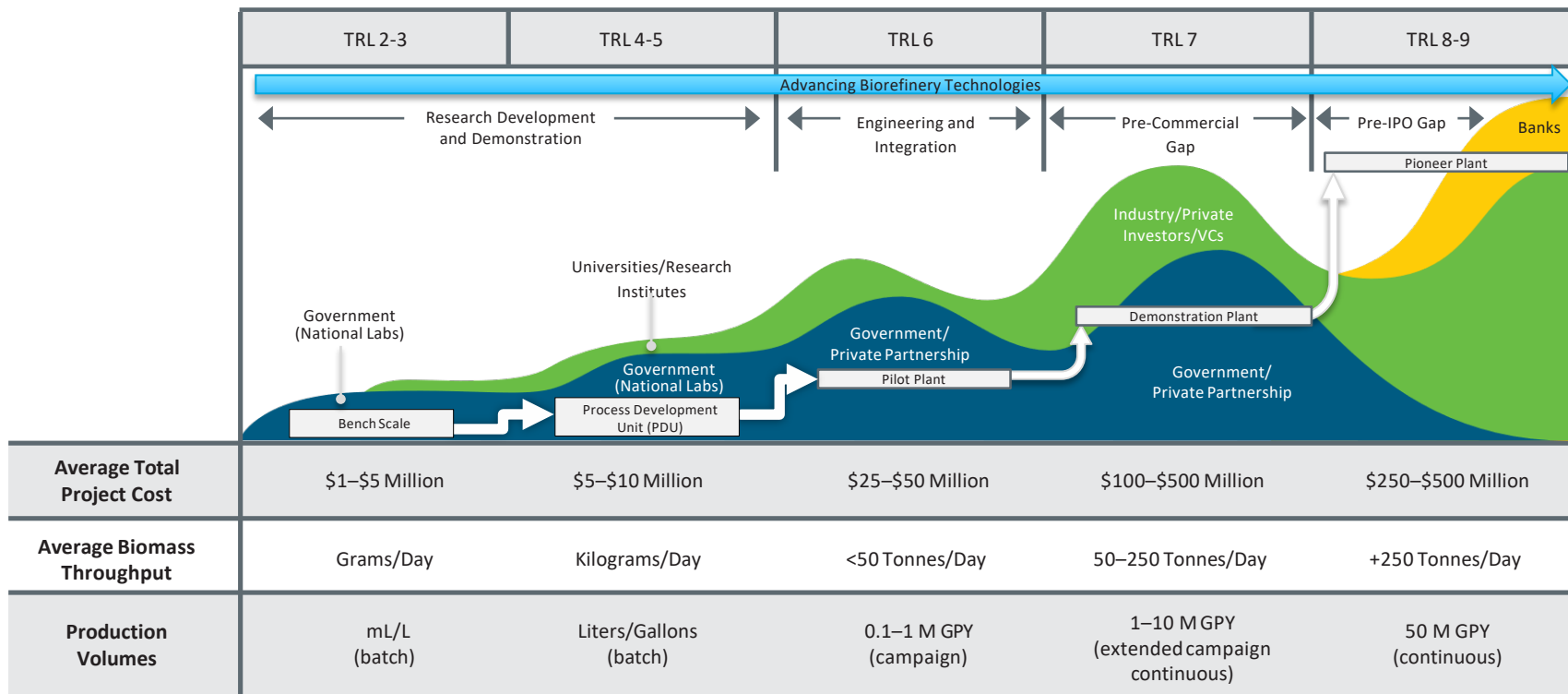


2023 (BT23)



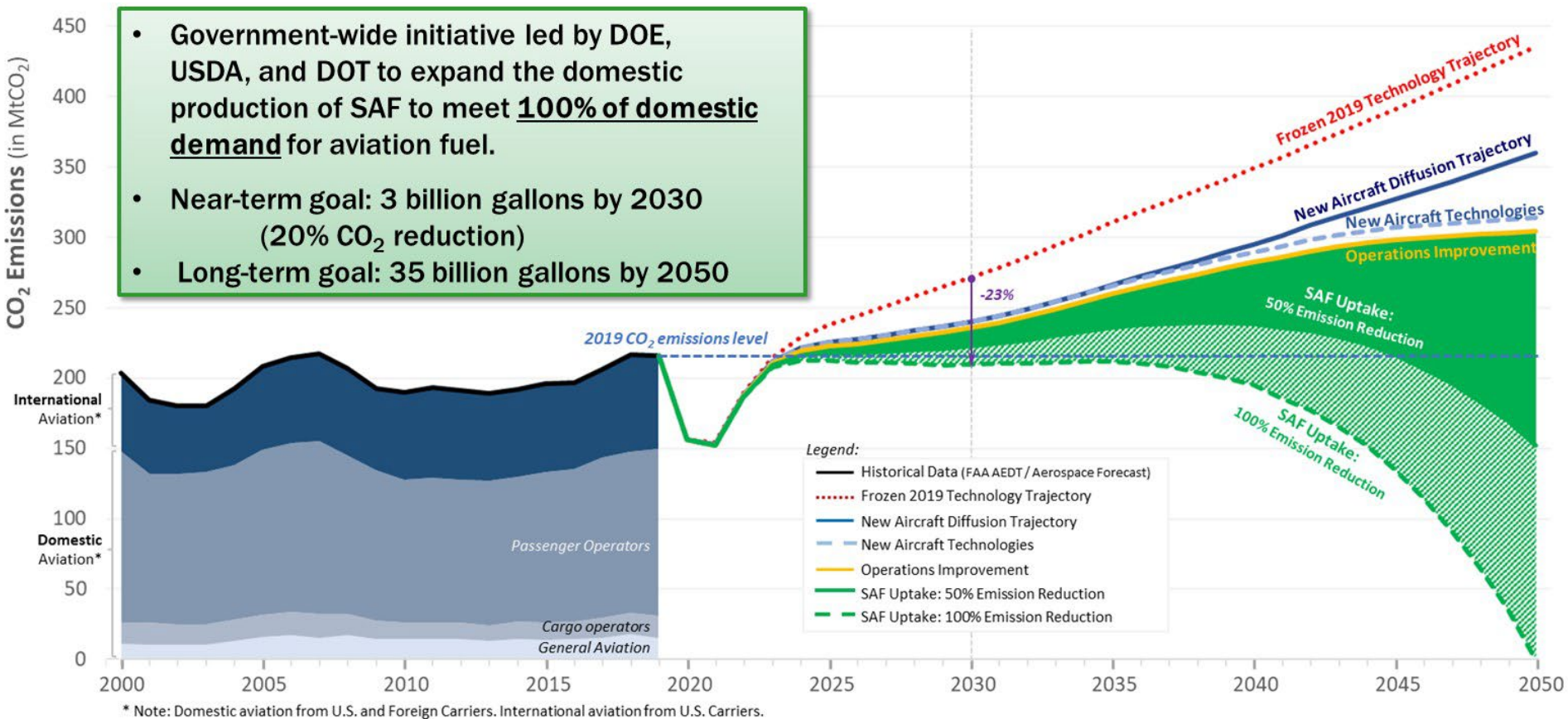
Add new feedstocks
Update waste and algae Refine forest resources

BETO Invests from Applied R&D to Large-Scale Demonstration



● Government ● Project Recipients and Partners ● Banks

SAF Grand Challenge



Roadmap Structure



- 26 Workstreams
- 140 Activities
- 2030 & 2030-2050 impact timeframes



SAF GC Roadmap CAAFI Workshop | June 16, 2023

11

Latest Funding Opportunity

Bioenergy Technologies Office

U.S. Department of Energy Announces \$59 Million to Expand Biofuels Production and Decarbonize Transportation Sector

JUNE 1, 2022



Bioenergy Technologies Office

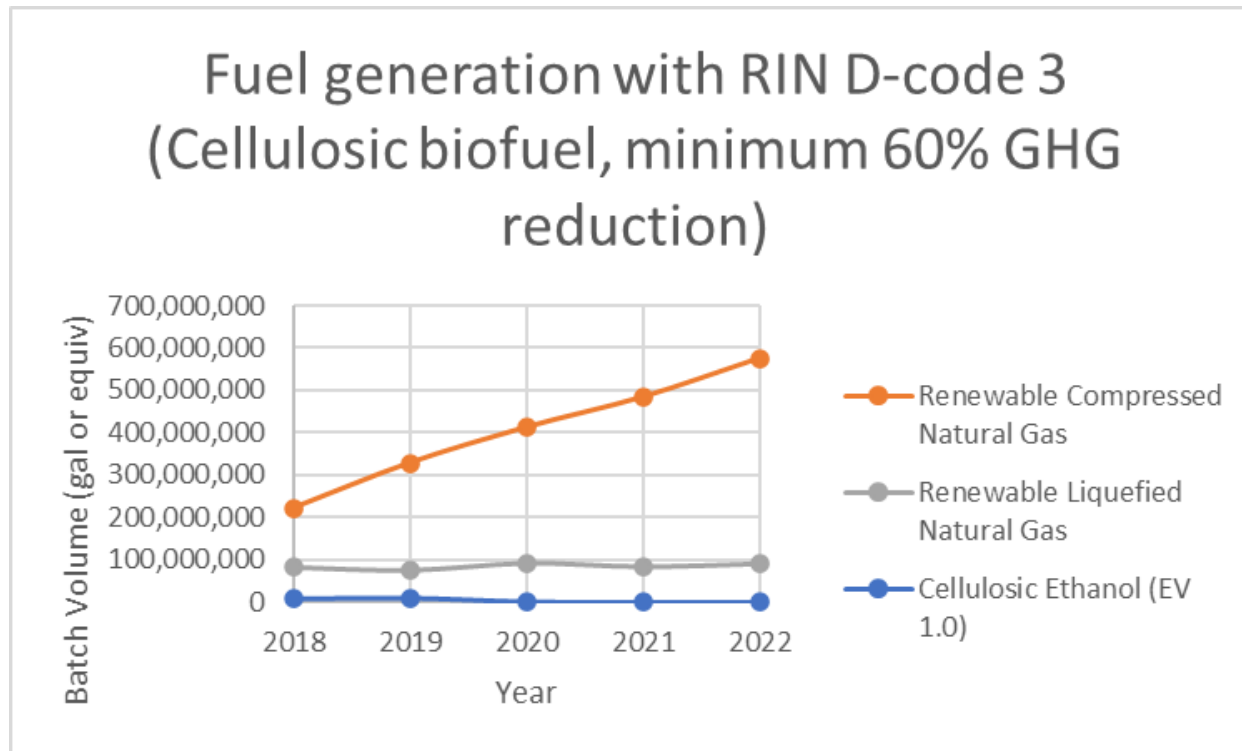
U.S. Department of Energy Awards \$118 Million to Accelerate Domestic Biofuel Production

JANUARY 26, 2023



US Biorefining Status

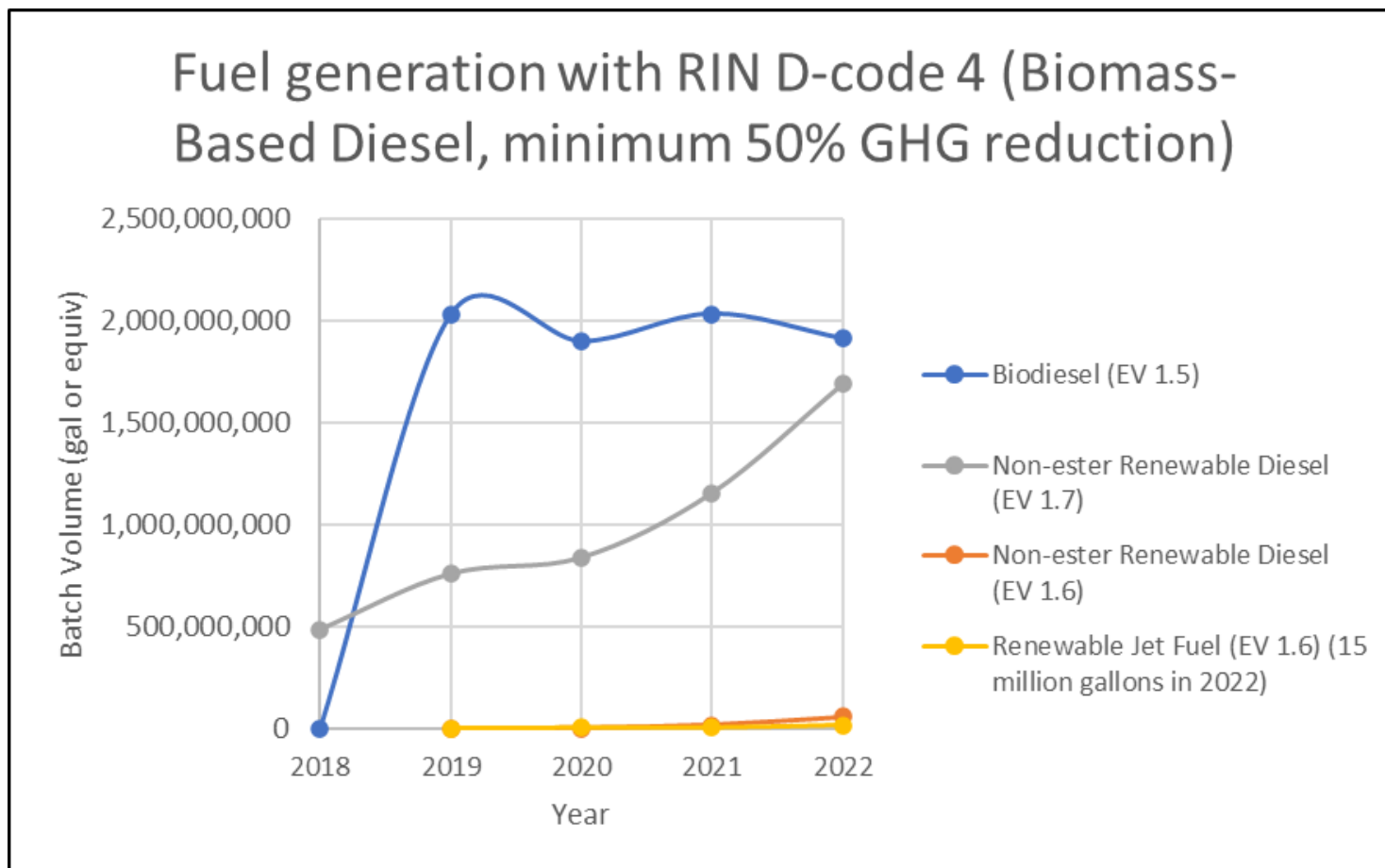
Biofuels Production tallied by RIN Generation



EV = energy value, e.g., if EV = 1.6, then RIN = 1.6 * gallon

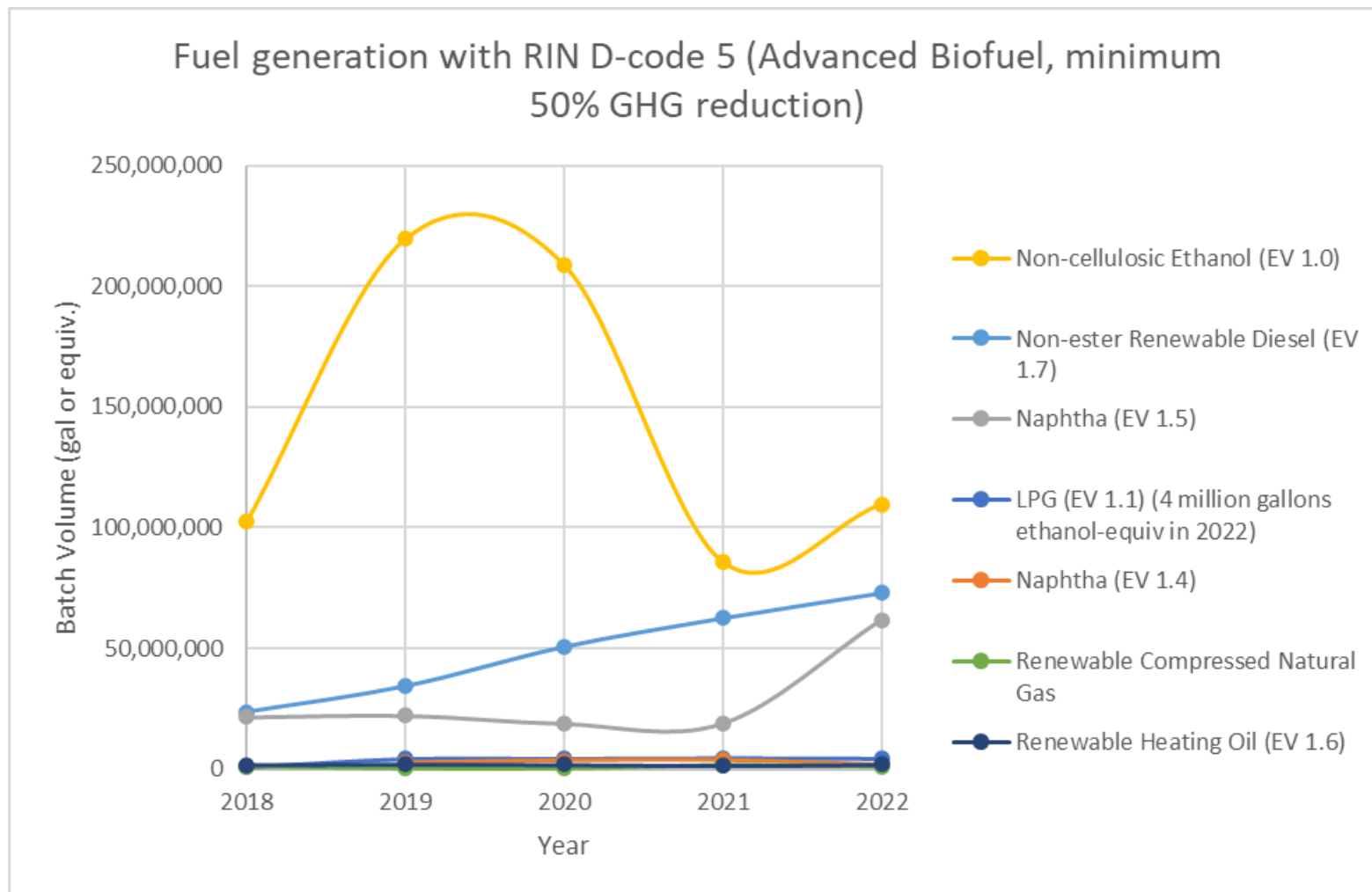
Source: <https://www.epa.gov/fuels-registration-reporting-and-compliance-help/spreadsheet-rin-generation-and-renewable-fuel>

Biofuels Production tallied by RIN Generation



EV = energy value, e.g., if EV = 1.7, then RIN = 1.7 * gallon

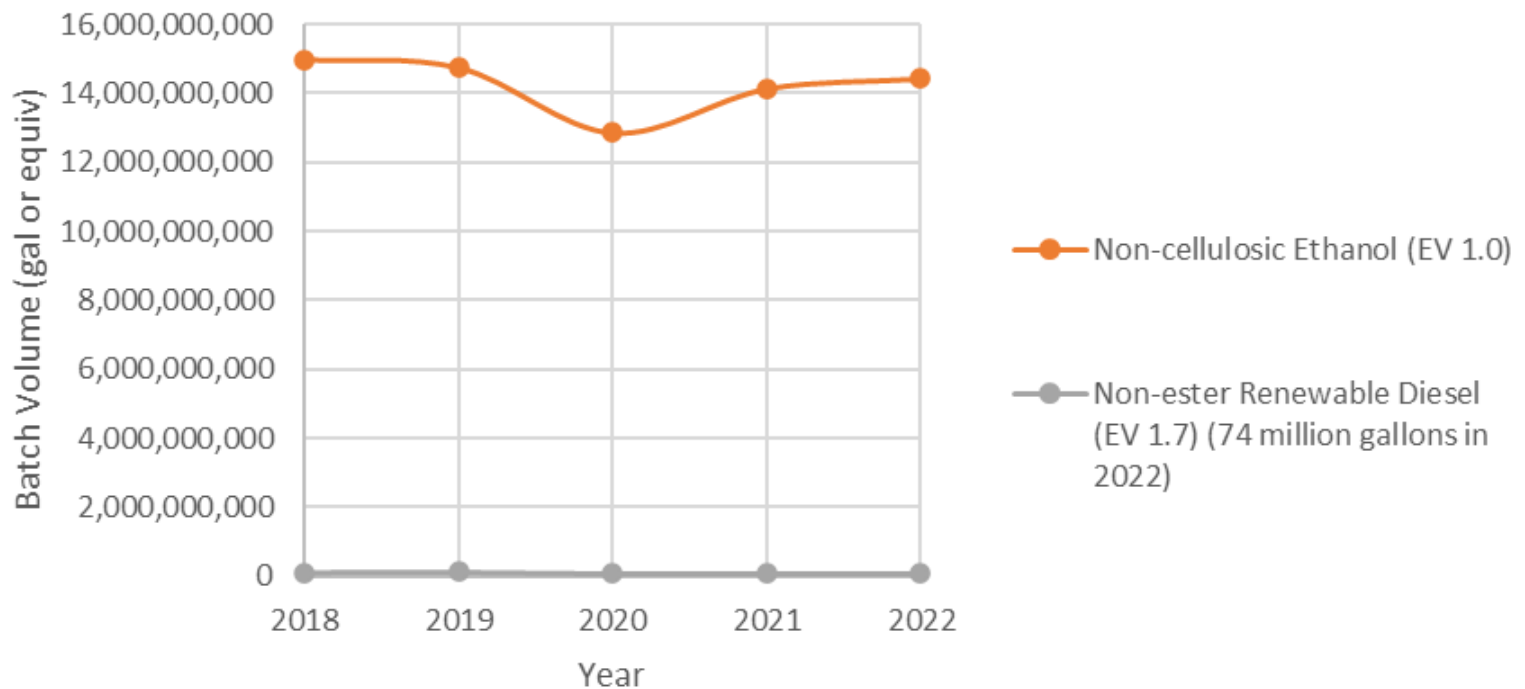
Biofuels Production tallied by RIN Generation



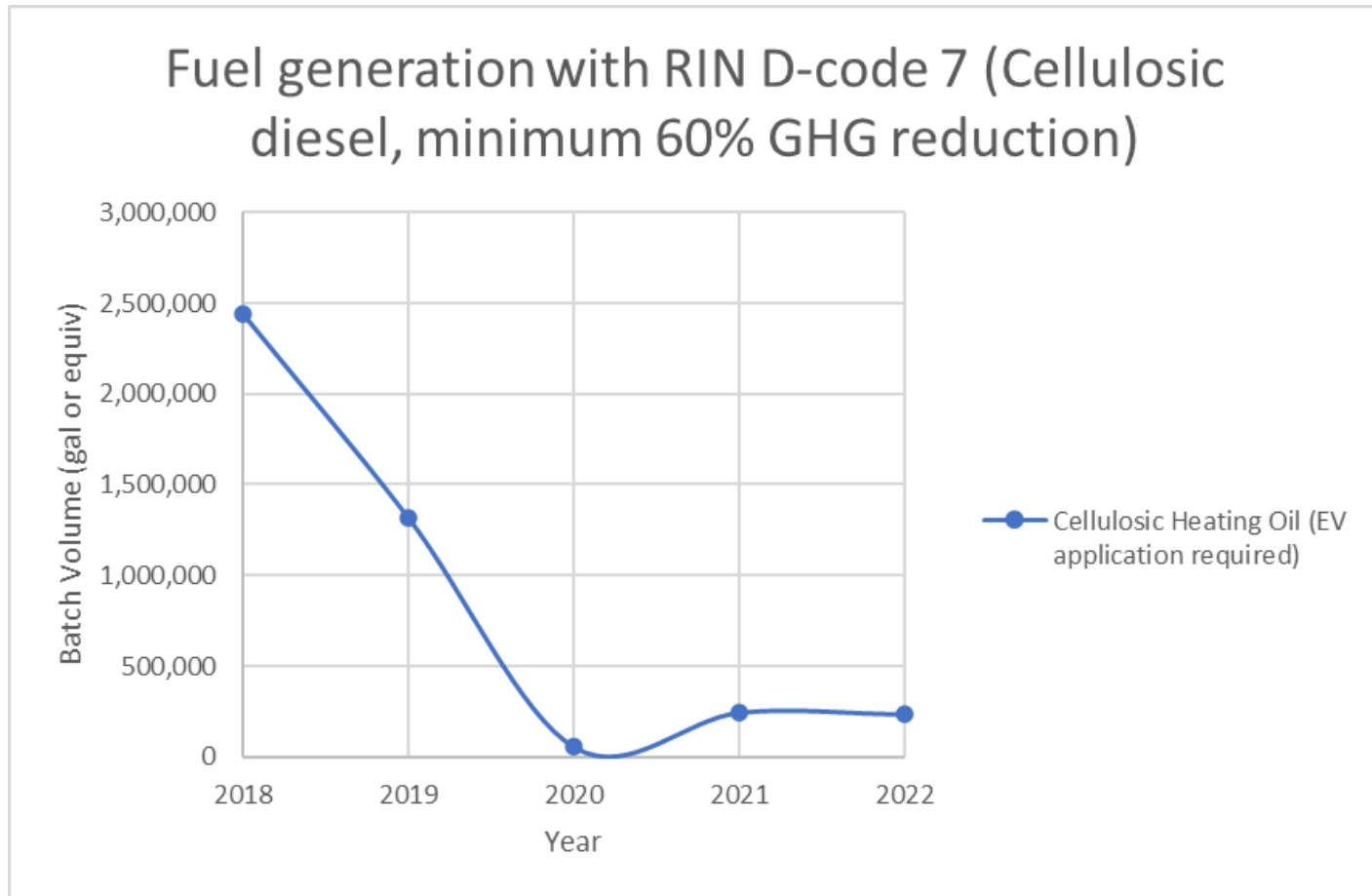
Note: RIN generation can be nested (e.g., ethanol with 50% GHG production can generate both D-code 5 and D-code 6 RIN)

Biofuels Production tallied by RIN Generation

Fuel generation with RIN D-code 6
(Renewable biofuel, minimum 20% GHG
reduction)



Biofuels production tallied by RIN Generation



US 2030 Outlook (operating, planned, pending)

Refinery	Estimated Diesel nameplate capacity (MGY)	Estimated SAF nameplate capacity (MGY)	Estimated Naphtha nameplate capacity (MGY)
Hydroprocessing of esters and fatty acids	5,768	1,852	549
Alcohol-to-jet	13	702	67
Gas-to-liquids	39	514	16
Power-to-liquids	0	169	0
ALL	5,820	3,237	632

US HEFA Operating in 2023

Refinery	Estimated Diesel nameplate capacity (MGY)	Estimated SAF nameplate capacity (MGY)	Estimated Naphtha nameplate capacity (MGY)	Notes
Diamond Green Diesel (Norco, Louisiana)	690	0	30	Operations started in 2013 with capacity 290 MGY diesel, then expanded in 2021. Feedstocks include animal fats, used cooking oil, and distillers corn oil. Estimated investment \$1.1 billion.
Chevron (Geismar, Louisiana)	81	0	7	Operations started in 2010. Feedstocks include tallow, soybean oil, corn oil, used cooking oil. Estimated investment \$950 million.
World Energy (Paramount, California)	13	23	9	Operations started in 2015. Feedstocks include tallow and other animal fats.
East-Kansas Agri-Energy (Garnett, Kansas)	5	0	0	Operations started in 2017. Feedstocks include distillers corn oil.
HF Sinclair (Sinclair, Wyoming)	138	0	12	Operations started in 2018. Feedstocks include soybean oil.
Marathon Petroleum (Dickinson, North Dakota)	169	0	14	Operations started in 2020. Feedstocks include soybean oil and others; feedstocks are pretreated at Marathon facilities in Beatrice, Nebraska and Cincinnati, Ohio.
Phillips 66 (Rodeo, California)	138	0	0	Operations started in 2021. Feedstocks include soybean oil. Estimated investment \$350 million.
Diamond Green Diesel (Port Arthur, Texas)	450	0	20	Operations started in 2022. Feedstocks include animal fats, used cooking oil and distillers corn oil. Estimated investment \$1.88 billion.
Chevron (El Segundo, California)	23	2	0	Operations started in 2021. Feedstocks include vegetable oils. Estimated investment \$365 million.
HF Sinclair (Cheyenne, Wyoming)	90	0	0	Operations started in 2021. Feedstocks include soybean oil. Estimated investment \$150 million.
Marathon Petroleum (Martinez, California)	250	0	10	Operations started in 2023. Feedstocks include animal fat, soybean oil, and corn oil. Estimated investment \$1.2 billion.
Calumet (Great Falls, Montana)	125	46	10	Operations started in 2023. Feedstocks include vegetable oils, distillers corn oil, used cooking oil, tallow. Estimated investment \$415 million.
BP (Cherry Point, Washington)	109	0	0	Operations started in 2018, then expanded in 2022. Feedstocks include animal fat, waste fats/oils/greases.
Seaboard Energy (Hugoton, Kansas)	85	0	4	Operations started in 2022. Feedstocks include tallow, soybean oil. Estimated investment \$300 million.
Kern Oil (Bakersfield, California)	4	0	0	Operations started in 2009. Feedstocks include tallow.
HF Sinclair (Artesia, New Mexico)	110	0	0	Operations started in 2022. Feedstocks include distillers corn oil.
CVR Energy (Wynnewood, Oklahoma)	94	0	6	Operations started in 2022. Feedstocks include soybean oil and corn oil.
Vertex Energy (Mobile, Alabama)	115	0	12	Operations started in 2023. Feedstocks include soybean oil, distillers corn oil, tallow, yellow wax, grease, and used cooking oil. Estimated investment \$200 million.
TOTAL	2,689	71	134	

HEFA Announced for 2030

Refinery	Estimated Diesel nameplate capacity (MGY)	Estimated SAF nameplate capacity (MGY)	Estimated Naphtha nameplate capacity (MGY)	Notes	Planned Feedstocks
World Energy (Paramount, California)	88	148	59	Expansion of existing facility that started operating in 2015. Project is under construction, plan to start operations in 2025. Will use green hydrogen.	Tallow, used cooking oil, yellow grease, distillers corn oil
ReadiFuels (Hull, Iowa)	27	5	2		Used cooking oil, distillers corn oil, yellow grease, brown grease, animal fats
NEXT Renewable Fuels (Port Westward, Oregon)	613	115	38	Renewable propane will be recycled into refinery. Project under Planning, expected operational date 2025, originally planned to be operational in 2021.	Used cooking oil, animal fats, vegetable oils, waste grease
Global Clean Energy (Bakersfield, California)	173	0	18	Offtake agreement with Exxon who will invest \$125 million with option to acquire up to 25% equity stake, but also Exxon said if the facility is not operational by July 2023 they would terminate the offtake agreement	Camelina oil, used cooking oil, soybean oil, distillers corn oil
Phillips 66 (Rodeo, California)	520	120	0	Expansion of existing facility that started operating in 2021. Project is in FID stage with plans to operate in 2024.	Used cooking oil, animal fats, greases and soybean oil
Chevron (Geismar, Louisiana)	225	0	20	Expansion of existing facility that started operating in 2010.	Tallow, soybean oil, distillers corn oil, used cooking oil
CVR Energy (Coffeyville, Kansas)	112	25	9	Design completed, waiting on FID to commit to construction.	Soybean oil initially then distillers corn oil, used cooking oil and animal fats one pretreatment unit is added
Gron Fuels (Port Charles, Louisiana)	405	405	186	Will use green hydrogen and CCS.	Distillers corn oil, tallow, camelina oil, carinata oil
Emerald Biofuels (Port Arthur, Texas)	90	0	10		
Chevron (El Segundo, California)	123	0	0	Converting petroleum diesel hydrotreater to 100% HEFA capability.	Vegetable oils
Heartwell Renewables (Hastings, Nebraska)	80	0	0	Under construction, plan to be operational in 2024	Tallow from Cargill, corn oil, soybean oil
UrbanX (Bakersfield, California)	58	0	20		Used cooking oil, animal fats
PBF Energy (Chalmette, Louisiana)	307	0	0	Conversion of an idle hydrocracking unit within the petroleum refinery. Plans to be operational in 2023.	Soybean oil, corn oil, used cooking oil, tallow
Vertex Energy (Mobile, Alabama)	46	0	4	Under repair due to failure in feed pumping system. Plans to be operational in 2024.	Soybean oil, distillers corn oil, tallow, yellow wax, grease, used cooking oil
HOBO	120	0	0	Planned for 2025	
Indaba (Imperial County, California)	30	50	0	Planned for 2024	
Indaba (Missouri)	30	50	0		
Calumet (Great Falls Montana)	-105	230	23	Planning to modify HEFA facilities to maximize SAF production; operations expected in 2025	
Marathon Petroleum (Martinez, California)	450	0	20	Expansion of existing HEFA facility; operations starting in 2023	Animal fat, soybean oil, corn oil
World Energy (Houston, Texas)	0	250	0	Under construction, planned for operations in 2025	
Shell (New Orleans, Louisiana)	?	?	?		
Diamond Green Diesel (Port Arthur, Texas)	-235	235	0	Modification of existing HEFA facility to have 50% SAF yield. Final investment decision made, planned for operations in 2025.	
Marathon Petroleum (Martinez, California)	-116	110	6	Modification of existing HEFA facility for SAF production. In planning stage.	
Aemetis (Riverbank, California)	25	25	0	Will use green hydrogen. In planning stage, to be operational in 2025.	
Aemetis (Riverbank, California)	13	13	0	Planned expansion of HEFA facility under planning, to be operational in 2026.	
TOTAL	3,079	1,781	415		

ATJ for 2030

Refinery	Estimated Diesel nameplate capacity (MGY)	Estimated SAF nameplate capacity (MGY)	Estimated Naphtha nameplate capacity (MGY)	Notes
Gevo (Lake Preston, South Dakota)	0	55	7	Will use green hydrogen. Project under construction, to be operational in 2026. Using Axens alcohol-to-jet technology.
Gevo (Silsbee, Texas)	0	0	0	~0.1 MGY Demonstration-scale facility that has operated since 2011 and sold commercial volumes starting in 2016. 50% of isobutanol converted to SAF and 50% converted to iso-octane.
LanzaJet (Soperton, Georgia)	1	9	0	Operational around 2024
Summit Agriculture Group	0	250	0	To be operational 2025. Project under planning, will use corn-based ethanol imported from Summit's plant in Brazil, along with corn from U.S. from ethanol refineries using the Summit CO2 pipeline. Using Honeywell UOP ethanol-to-jet technology.
Marquis SAF (Hennepin, Illinois)	12	108	0	
Blue Blade Energy (Midwest)	0	135	0	Low-carbon-intensity ethanol from Green Plains. Project under planning, to be operational in 2028.
Nacero (Permian Basin, Texas)	0	145	60	Project is using Renewable Natural Gas as feedstock, then converting to methanol, then methanol-to-SAF.
TOTAL	13	702	67	

Gas to Liquids by 2030

Refinery	Estimated Diesel nameplate capacity (MGY)	Estimated SAF nameplate capacity (MGY)	Estimated Naphtha nameplate capacity (MGY)	Notes
Northwest Advanced Biofuels (Pacific Northwest Columbia River Corridor, Washington)	0	60	0	Feedstock to be wood waste and forest residue. Project in planning, operational date 2024.
Velocys (Natchez, Mississippi)	0	25	11	Feedstock to be wood waste and forest residue. Project in planning, operational date 2026.
Fulcrum Bioenergy (Gary, Indiana)	0	31	0	Feedstock to be municipal solid waste. Project in planning, operational date 2026.
Fulcrum Bioenergy (Reno, Nevada)		11		Product is syncrude that is shipped and upgraded to SAF, diesel, and gasoline. Feedstock is municipal solid waste. Operations started in 2022.
Fulcrum Bioenergy (Texas)	0	31	0	Feedstock to be municipal solid waste. Project in planning, operational date 2025.
DG Fuels (St. James Parish, Louisiana)	0	120	0	Project in planning stage, operational date 2026. Feedstocks to be cellulosic waste. Will use green hydrogen.
DG Fuels (Aroostock County, Maine)	0	175	0	Project in planning stage, operation date 2027. Feedstocks to be timber and agricultural waste. Power to be supplied by hydroelectricity. Will use green hydrogen.
CastleRock Green Energy (Shelton, Washington)	0	0	0	Feedstock to be cellulosic residue from industrial timber. This is possibly a heating oil project using Ensyn technology and belongs in a pyrolysis category not GTL.
Agra Energy (New Franken, Wisconsin)	1	0	0	Feedstock is biogas from dairy manure. Project under construction.
Raven SR (California)	0	18	0	Project in planning phase for operations by 2025.
Raven SR (California)	0	54	0	
Strategic Biofuels (Caldwell Parish, Louisiana)	27	0	5	Feedstock to be wood waste. Project in planning, operational date 2025.
TOTAL	39	514	16	

Power to Liquids by 2030

Refinery	Estimated Diesel (MGY)	Estimated SAF (MGY)	Estimated Naphtha (MGY)	Notes
Dimensional Energy (western New York)	0	1	0	Project in planning stage for operations by 2026.
HIF Global (Matagorda, Texas)	0	0	0	Project in planning stage for operations by 2027. Project will produce LPG and 900m kg/yr green hydrogen, capture 6 million tonnes/yr CO2. Will use UOP eFinishing technology. Will use wind electricity.
Orsted (Gulf Coast)	0	0	0	Project in planning stage for operations by 2025. Will produce 300,000 tonnes/yr methanol for sustainable marine fuel for Moller-Maersk.
HIF Global (Matagorda, Texas)	0	168	0	Project in planning stage for operations by 2030. Will be expansion of first facility under planning.
TOTAL	0	169	0	

U.S. Biorefining Status: Hydroprocessing of Esters and Fatty Acids

Lead

Partners / Vendors / End Users

Status



October 2021: Diamond Green Diesel completed expansion of Norco, Louisiana biorefinery to 690 MGY renewable diesel
January 2023: Completed construction of 470 MGY renewable diesel refinery in Port Arthur, TX. Diamond Green Diesel Port Arthur plant is now undergoing upgrades to be completed in 2025 and will have capability to produce 235 MGY SAF from the renewable diesel cut.
 Diamond Green Diesel uses the Honeywell UOP Ecofining HEFA technology.



~50 MGY Paramount, California refinery, repurposed from a former Paramount petroleum refinery and using Honeywell UOP Ecofining HEFA technology
2019: United Airlines renews contract for up to 10 MGY SAF over next 2 years from World Energy
July 2020: Amazon Air agreed to 6 MG SAF with World Energy and Shell
April 2022: announced expansion plans to 340 MGY (including 250 MGY SAF) at the 50 MGY Paramount refinery
August 2022: announced plans to build a 250 MGY SAF plant in Houston, TX for completion by 2025



2022: Cheyenne, Wyoming renewable diesel refinery completed and operational; Artesia, New Mexico renewable diesel refinery's pretreatment unit operational. Total output of both WY and NM is 200 MGY renewable diesel

U.S. Biorefining Status: Hydroprocessing of Esters and Fatty Acids (continued)

Lead

Partners / Vendors / End Users

Status



May 2022: Alaska Airlines signs agreement for 13 million gallons jet fuel (40% SAF blend) over 7 years with Aemetis from its planned HEFA refinery in Riverbank, California



Kern Energy co-processes up to 5% renewable diesel in 420,000 gallons per day CARB ULSD (~7 MGY renewable diesel)



Montana Renewables is modifying existing assets including existing hydrocracker at its Great Falls, Montana facility to process up to 15,000 barrels per stream day of HEFA feedstocks (230 MGY)



January 2022: Managing construction delays on Louisiana 82 MGY refinery supported from 2014 DPA Title III












New Rise Renewables opens 44 MGY renewable diesel refinery in Reno, Nevada after Ryze Renewables' construction effort Fuels are being sold to Phillips 66 for the California market



May 2021: Seaboard Energy announced plans to build an 85 MGY renewable diesel refinery in Hugoton, Kansas at the site of the Abengoa cellulosic ethanol plant site it purchased

U.S. Biorefining Status: Hydroprocessing of Esters and Fatty Acids (continued)


Lead	Partners / Vendors / End Users	Status
		<p><u>Marathon</u> is repurposing its idled <u>Martinez</u>, California refinery into a renewable diesel refinery in a JV with Neste, for 260 MGY initial capacity and future expansion to <u>730 MGY</u></p> <p><u>2021</u>: Marathon's 184 MGY renewable diesel and naphtha refinery in Dickinson, North Dakota is fully operational</p>
		<p><u>Phillips 66</u> converted the diesel hydrotreater of their Rodeo, California refinery into a renewable diesel hydrotreater at 120 MGY capacity</p> <p><u>April 2021</u>: Phillips 66 invests in Shell Rock Soy Processing in Iowa for soybean feedstock</p>
	 	<p><u>September 2022</u>: EPA approves D-code 6 RIN eligibility for Chevron El Segundo Soy FCC Pathway. Assessment was 52% GHG reduction for renewable gasoline, 52% GHG reduction for renewable jet fuel, and 45% GHG reduction for renewable diesel</p> <p><u>June 2022</u>: Chevron acquires biodiesel and renewable diesel producer REG</p> <p><u>2021</u>: Chevron invests in Bunge for soybean crushing capability</p> <p><u>October 2020</u>: REG announces plans to expand its 90 MGY Geismar, Louisiana renewable diesel refinery (formerly Syntroleum/Tyson Foods) to 340 MGY</p>
		<p><u>Neste</u> is shipping their hydrotreated FOG renewable diesel from Finland to <u>Texmark Chemicals</u> in Texas who fractionate a SAF cut</p>

U.S. Biorefining Status: Alcohol-to-Jet

Lead

Partners / Vendors / End Users


Status



2022: Completion plans of 10 MGY SAF and renewable diesel Freedom Pines Fuels biorefinery in Soperton, Georgia

June 2020: LanzaJet was formed as a spin-off from LanzaTech. LanzaJet is commercializing the alcohol-to-jet catalyst technology developed at Pacific Northwest National Laboratory in 2010. The technology was scaled up by LanzaTech. The SAF was approved in Annex A5 of ASTM D7566 in 2018 and demonstrated in subsequent passenger flights.

January 2023: EPA approves D-code 4 RINs for sugarcane ATJ LanzaJet Soperton. Assessment was 54-66% GHG reduction for renewable jet and diesel fuels



February 2022: Marquis and LanzaJet enter into MOU to construct 120 MGY SAF/renewable diesel refinery in Hennepin, Illinois



0.1 MGY SAF and renewable gasoline in Silsbee, TX

July 2022: Gevo purchases land for planned 60 MGY SAF/gasoline refinery called Net-Zero 1 in Lake Preston, South Dakota

August 2022: Alaska Airlines signs for 37 MGY SAF for 5 years

July 2022: American Airlines signs for 100 MGY SAF for 5 years

July 2022: Aer Lingus signs for 6 MGY SAF for 5 years

June 2022: Finnair signs for 7 MGY SAF for 5 years

March 2022: Delta signs for 75 MGY SAF for 7 years

October 2021: Gevo enters agreement with Axens for ATJ technology

October 2021: Gevo and ADM sign a MOU to support production of up to 500 MGY SAF using ADM's dry mills in Nebraska, Iowa, and Illinois and Gevo's isobutanol technology

November 2021: Gevo signs MOU with Sweetwater Energy for producing cellulosic biofuels

U.S. Biorefining Status: Alcohol-to-Jet (continued)

Lead

Partners / Vendors / End Users

Status



June 2022: NREL's Deacetylation and Mechanical Refining (DMR) biomass pretreatment technology, which was developed as an alkaline alternative to the acidic pretreatment method and operates under milder conditions and enables cleaner lignin byproduct, is being scaled up by D3Max LLC in a pilot project called SAFFiRE in Nevada, Iowa that would produce cellulosic alcohol-to-jet fuel. The DMR technology was developed at NREL through BETO support over last ~decade. Enzymatic hydrolysis step supplied from Novozymes. Initial funding for this came pilot project came from a FY21 BETO FOA award. The technology is estimated to have 84% reduction in carbon intensity compared to conventional jet fuel. D3Max estimates the technology could produce up to 7.5 BGY SAF by 2040.



February 2022: Vertimass enters MOU with World Energy to develop ATJ SAF integrated with HEFA. The Vertimass technology was developed at Oak Ridge National Laboratory.



January 2023: United Airlines, Tallgrass, and Green Plains inc announce JV called Blue Blade Energy to commercialize new ATJ SAF tech developed at Pacific Northwest National Laboratory. Construction of pilot to proceed in 2024 with full-scale operations by 2028 at up to 135 MGY SAF

U.S. Biorefining Status: Gasification and Fischer-Tropsch

Lead

Partners / Vendors / End Users

Status



May 2022: 12 MGY constructed and undergoing commissioning at [Sierra BioFuels](#) near Reno, Nevada, a 2014 DPA Title III project. MSW gasification operating, now focusing on Fischer-Tropsch. The Fischer-Tropsch catalyst is planned to be a [Johnson Matthey / BP](#) system.
February 2023: Fulcrum shipped syncrude from Sierra BioFuels to Marathon refinery for upgrading



25 MGY SAF and 10 MGY naphtha facility using woody biomass from nearby pine, completed Pre-FEED and permitting, at [Bayou Fuels](#) in Mississippi. The project will also include carbon capture and storage led by Oxy Low Carbon Ventures to [enable](#) negative carbon emissions up to -144 gCO₂/MJ
November 2021: Southwest Airlines agrees to 219 MG SAF over 15 years
November 2021: British Airways agrees to 73 MG over 10 years



February 2022: Developing new partnerships and advisors in support of constructing Oregon 12 MGY biorefinery supported by 2014 DPA Title III. The gasification system is [planned](#) to be a Frontline BioEnergy system. The Fischer-Tropsch catalyst is [planned](#) to be an Emerging Fuels Technology system
August 2022: Red Rock and Frontline announce successful testing of gasification system



February 2022: Announces plans for 34 MGY woody biomass to SAF/renewable diesel in Texas

U.S. Biorefining Status: Gasification and Fischer-Tropsch (continued)

Lead

Partners / Vendors / End Users

Status



TOPSOE



November 2021: Arbor Renewable Gas announces site in Beaumont, TX for woody biomass to gasoline



September 2022: DG Fuels announces agreement for 55 MGY SAF for seven years starting by 2028 with Delta

U.S. Biorefining Status: Catalytic Upgrading of Sugars

Lead

Partners / Vendors / End Users

Status



December 2021: United Airlines flies a passenger aircraft using 100% SAF (Marathon's Virent's synthesized aromatic kerosene blended with World Energy SAF) in one engine and petroleum jet fuel in the other engine.

Virent's BioForming technology takes conventional sugars or cellulosic sugars and catalytically converts them to hydrocarbons

U.S. Biorefining Status: Renewable Natural Gas / Landfill Gas to Liquids

Lead

Status



Goal is 30 MGY SAF in the Pacific Northwest by 2027 from feedstocks such as RNG and green H₂. Initial funding to verify the technology and design a demonstration-scale facility is being supported by BETO.



January 2020: T2C partnering with Citrus County Landfill
July 2022: The U.S. Department of Energy's BETO announces validation of pilot-scale production of T2C's renewable diesel at modeled cost of \$2.91/GGE and GHG emissions reduction of 130% compared to petroleum diesel.
Initial funding to verify the technology and design a demonstration-scale facility is being supported by BETO



June 2021: Agra Energy places order with Primoris Design & Construction for gas-to-liquids facility processing waste methane from 6,000 cows



TOPSOE

April 2021: Nacero selects Topsoe TIGAS for upgrading on planned facility to use natural gas and bio-methane as feedstocks

U.S. Biorefining Status: Pyrolysis

Lead

Partners / Vendors / End Users

Status

ALDERFUELS

Honeywell



July 2022: Alder Fuels announces partnership to test its fuels with Boeing

June 2022: Business aviation fuel supplier Avfuel signs agreement for 1 billion gallons SAF over a 20-year period with Alder Fuels

September 2021: United and Honeywell invest in Alder Fuels and United agrees to 1.5 BG SAF over 20 years



2020: Frontline building pyrolysis plant in Redfield, Iowa for bio-oil production

ENSYN

Honeywell

Ensyn is developing a 20 MGY biocrude refinery in Dooley County, Georgia, using Envergent RTP technology co-developed with Honeywell UOP. The feedstock is expected to be mill residues, forest residues, and thinnings. The biocrude will be directed to refinery co-processing and/or for a heating oil.

Anellotech



Anellotech is demonstrating its Bio-Tcat process to convert woody biomass to hydrocarbons at a pilot plant in Silsbee, Texas.

August 2022: Anellotech announces successful processing trial in its 0.5 ton/day TCat site that converted, via catalytic fast pyrolysis, post-consumer plastic waste into light olefins and aromatics

U.S. Biorefining Status: Algae

Lead

Partners / Vendors / End Users

Status

Genifuel

AECOM

March 2022: Genifuel announces partnership with AECOM for developing SAF production technology by applying AECOM's algae harvesting technology with Genifuel's algae and wastewater biosolids conversion technology.

Genifuel's hydrothermal processing technology was developed at Pacific Northwest National Laboratory.

U.S. Biorefining Status: CO₂ to Liquids

Lead

Partners / Vendors / End Users

Status

—twelve

LanzaTech

Alaska
AIRLINES

EMERGING FUELS
TECHNOLOGY

July 2022: Twelve partners with Alaska Airlines and Microsoft on e-SAF from recaptured CO₂ and renewable energy, including plans for future demo flight
2021: US Air Force tests Twelve's e-SAF
Twelve is partnering with LanzaTech on CO₂-to-ethanol and partnering with Emerging Fuels Technology to produce SAF samples.

Dimensional
Energy

Heliogen

UNITED

July 2022: Dimensional Energy announces partnership to use Dimensional's high-temperature CO₂ methanation technology with Heliogen's concentrated solar thermal technology in Lancaster, California
June 2022: United Airlines agrees to 300 MG SAF from Dimensional over 20 years



American Airlines

July 2021: American Airlines agrees with Prometheus Fuels to 10 MG SAF
The Prometheus Fuels technology was developed at Oak Ridge National Laboratory and includes direct air capture, electrolysis, and membrane fuel extraction.

AIR COMPANY

nel BOOM

September 2022: Air Company entered into agreement with Boom Supersonic for up to 5 MGY SAF

HIF
Highly Innovative Fuels

TOPSOE

September 2022: HIF partners with Topsoe for methanol synthesis and TIGAS upgrading at HIF's planned Texas facility

U.S. Biorefining Status: Oilseed Cover Crops for HEFA

Lead

Partners

Feedstock

Status



Camelina oil

March 2022: Global Clean Energy announced \$145M financing completion from ExxonMobil



Carinata oil

February 2022: Nuseed enters 10-year strategic partnership with BP for purchasing carinata oil for biofuels
Nuseed estimates that planting its carinata as cover crop on 1.5% of all existing farmland in the Americas and Europe (~6.3 million acres) would be sufficient feedstock for 1 BGY SAF by 2030

June 2022: EPA approves carinata pathway for jet fuel, LPG, naphtha, and renewable diesel RINs



Pennycress oil

August 2022: Bayer AG acquires 65% controlling interest in CoverCress, with remaining interest held by Chevron and Bunge

CoverCress says the 2030 target is 3 million acres



Camelina oil

March 2022: Yield10 Bioscience announces its CRISPER-designed Camelina line E3092, designed for renewable diesel, demonstrated 5% increase in oil content. USDA said the line does not meet the definition of a regulated article

Canola oil

March 2022: Yield10 Bioscience announces its C3020 line demonstrated 9% increase in oil content and its C3007 canola line demonstrated 5% increase in oil content

U.S. Biorefining Status: Cellulosic Crops

Lead

Feedstock

Status



Sugarcane

January 2021: California Ethanol + Power announces engagement with Imperial Valley, California farmers to grow 20,000 acres sugarcane for Sugar Valley Energy, the company's planned 68 MGY sugarcane ethanol and 49 MW biomass power generation facility. Eventually 48,000 acres are planned.



Switchgrass

2021: Tennessee-based Genera offers a Switchgrass Establishment Assistance program offering up to \$200/acre for growers committing to 5 years of production from at least 15 acres



Woody biomass

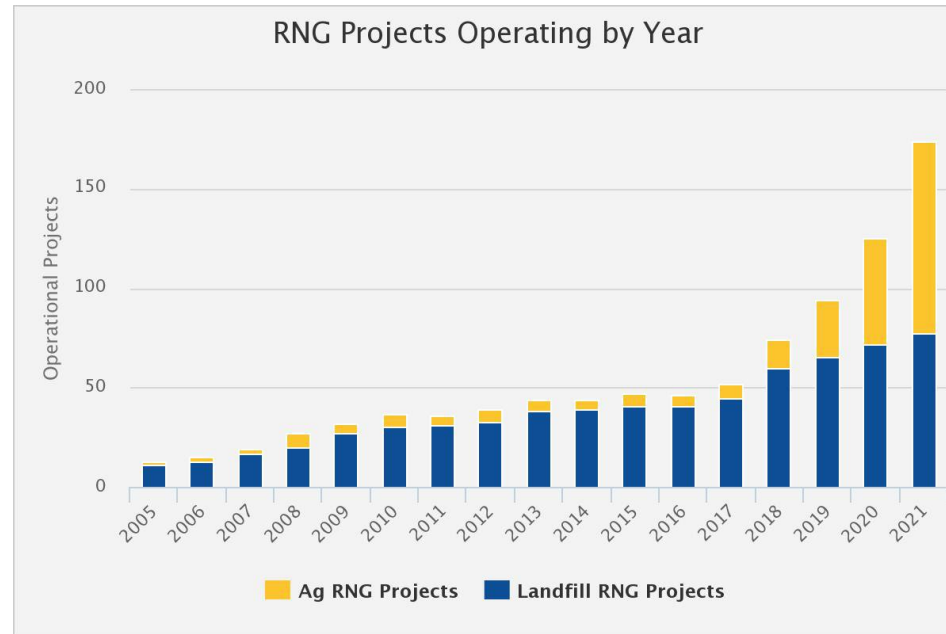
2021: Forest Concepts installs its M24M modular Crumbler system for biomass size reduction at the Biomass Feedstocks National User Facility at Idaho National Laboratory



Woody biomass

September 2022: Enviva and Alder Fuels sign contract for up to 750,000 metric tons per year of sustainably sourced woody biomass for Alder in the southeastern U.S.

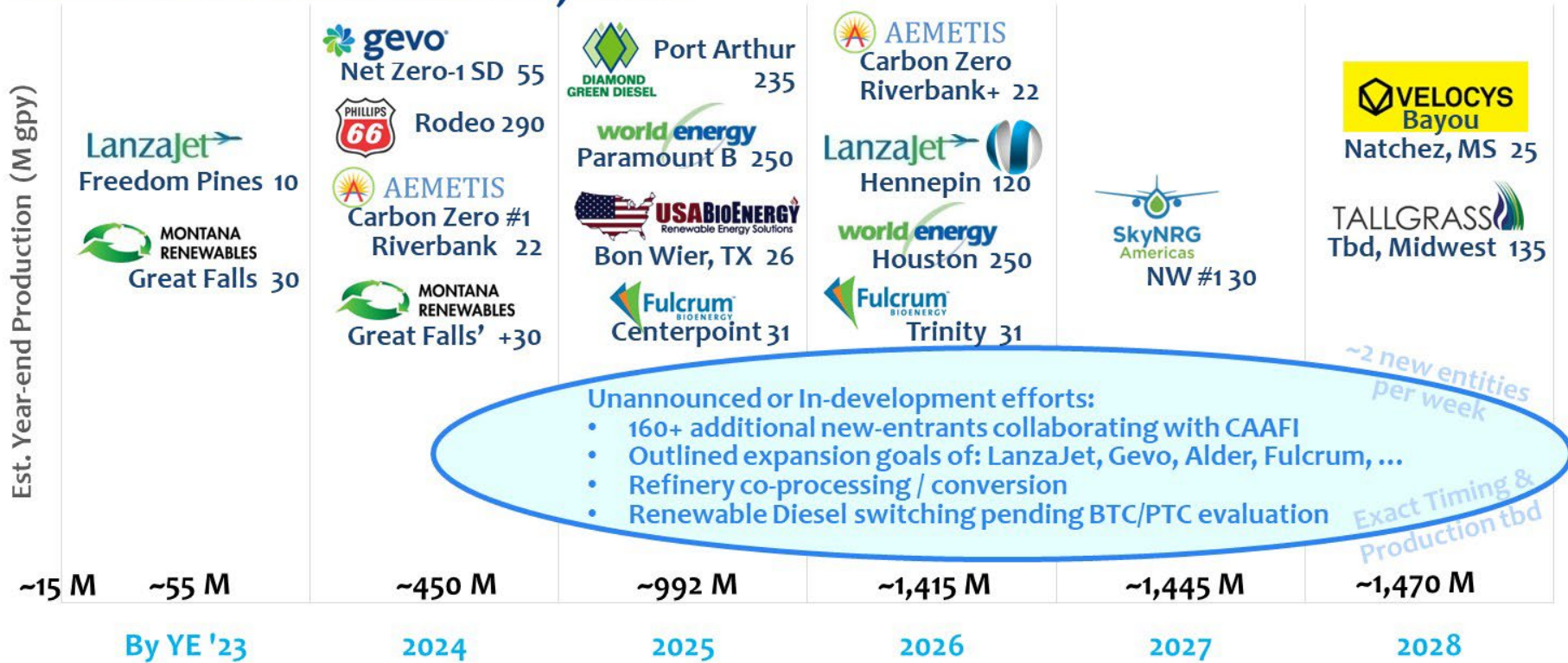
U.S. Biorefining Status: Expanded production of RNG and LNG



- The number of Ag RNG and Landfill RNG operational projects has increased from about 10 in 2005 to about 175 in 2021
- VERBIO North America bought DuPont's cellulosic ethanol refinery site in Necedah, Iowa in 2018, converted it to a stillage RNG and corn ethanol facility, started production in 2021, and plans to reach full scale by 2023 producing 19 million ethanol gallons equivalent of RNG and 60 MGY corn ethanol
- PacificAg is developing SunnysideRNG, an 800K MMBtu RNG facility in Washington state that will use agricultural residues

Current Estimate of Global SAF Production

Announced intentions, neat*



- Not comprehensive; CAAFI estimates (based on technology used & public reports) where production slates are not specified. Does not include various small batches produced for testing technology and markets.
- Does not include fractions of substantial Renewable Diesel capacity (existing and in-development) that can be shunted to SAF based on policy support

1 March 2023

Source: CAAFI <https://caafi.org/>

US Policy Outlook

New Laws to Revolutionize U.S. Energy Sector

1. Bipartisan Infrastructure Law (BIL) (Nov 2021)

- Largest long-term investment in our nation's infrastructure in nearly a century
- \$63B for energy and climate

2. CHIPS and Science Act (July 2022) \$280B

- Cutting-edge science and innovation to boost American competitiveness, including for semiconductors

3. Inflation Reduction Act (IRA) (August 2022)

- Incentivizes deployment of clean technologies and lowering energy costs for American families
- \$391B for clean energy



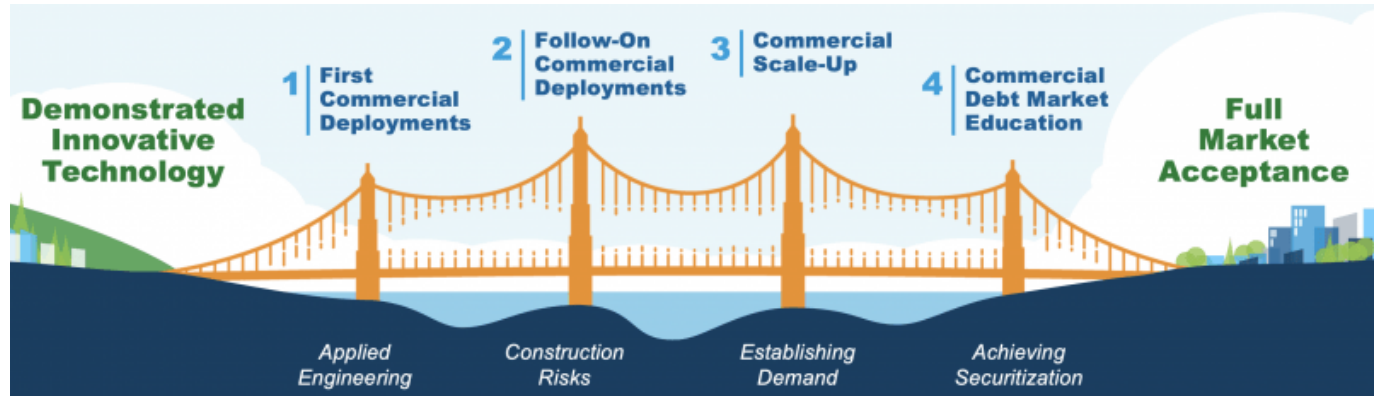
BIL + IRA invests more than \$450 billion in US Energy System

Clean Fuel Tax Credits

- **Extension of tax credits through 2024**
 - Biodiesel, renewable diesel, and alternative fuels
 - Second generation biofuels
- **Sustainable Aviation Fuel Tax Credit through 2025**
 - Emissions-based credit, starting with 50% GHG reduction
- **Clean Fuels Production Tax Credit through 2025/2027**
 - Technology neutral incentive based on well-to-wheel lifecycle GHG emissions
- **Clean Hydrogen Production Tax Credit**
 - Emissions-based credit for facilities constructed before 2033
 - Option for investment tax credit



DOE Loan Programs Office Expansion



- **New \$250 billion loan authority for Energy Infrastructure Reinvestment program**
 - For projects that **retool, repower, repurpose, or replace** energy infrastructure that has already retired
 - And for operating energy infrastructure to **avoid, reduce, sequester, or use air pollution or GHG emissions**
- **Expansion of LPO's existing loan programs:**
 - **Triples** loan authority for innovative energy technologies (\$40 billion)
- **Appropriates a total of \$11.7 billion to LPO** to support issuing new loans

BETO Activities

BETO Activities: Recent BETO IBR Workshops

- Predictive Models and High Performance Computing as Tools to Accelerate the Scaling-Up of New Bio-Based Fuels
 - New ways to accelerate scale-up, reduce uncertainty, and optimize operations
 - Understand if effective utilization of mathematical models and AI/ML in conjunction with highly instrumented bench-, pilot-, and demonstration-scaled facilities can be used to validate and improve system and subsystem models

BETO Activities: Recent BETO IBR Workshops

- Gen-1 Ethanol Opportunities: Improving Life Cycle GHG Benefits of Existing Biofuel Production
 - The U.S. has over 200 fuel ethanol plants, supporting about 70,000 jobs
 - Existing technologies have the potential to reduce the lifecycle GHG emissions of Gen-1 ethanol from about 40% today to over 70% compared to the petroleum baseline
 - Strategies discussed:
 - Fuel switching to renewable process heat and power
 - New productivity or conversion efficiency measures
 - Carbon capture technology
 - Process technology for higher value co-products or conversion of ethanol to SAF

BETO Activities: Energy Justice

- **December 2020**: DOE opens call for small business proposals on **Cultivating a More Competitive Bioeconomy Through Strengthening Small Business Workforces**. Specific areas of interest include:
 - Development of software for workforce development that address barriers associated with urban and rural areas as well as engaging people with underrepresented backgrounds within bioenergy R&D and deployment
- **2022**: DOE-BETO opens a funding opportunity with the **MSI STEM Research & Development Consortium**

BETO Activities: Recent BETO IBRs

- **FY17 Integrated Biorefinery Optimization FOA topics:**
 - Robust, continuous handling of solid materials and feeding systems to reactors under various operating conditions
 - High value products from waste streams in an integrated biorefinery
 - Industrial separations within an integrated biorefinery
 - Analytical modeling of solid materials and reactor feeding systems
- **Awards around \$1-2M Federal share each**

Recipient	Technology
Thermochemical Recovery International	Improved feed systems for MSW thermochemical conversion
Texas A&M Agrilife Research	Lignin products
White Dog Labs	Fermentation of ethanol refinery residue stillage syrup to animal feed protein
South Dakota School of Mines and Technology	Carbon products from lignin and biorefinery aqueous waste streams
National Renewable Energy Laboratory	Modeling of biomass feeding system
Forest Concepts	Modeling of biomass feeding system
University of Arkansas	Modeling of biomass feeding system
Purdue University	Modeling of biomass feeding system

BETO Activities: Recent BETO IBRs

- **FY18 Process Development for Advanced Biofuels and Biopower FOA topics:**
 - Test unit operations for producing drop-in renewable SAF and diesel
 - Convert wet wastes such as MSW and biosolids into biopower
- **Awards around \$1-2M Federal share each**

Recipient	Technology
Technology Holding LLC	Cellulosic sugars fermentation to isoprene and catalytic conversion to cycloparaffinic SAF
Washington State University	Co-processing of cellulosic bio-oils with commercial HEFA
Applied Research Associates	Hydrothermal cleanup of brown grease and catalytic hydrothermolysis to SAF
Gas Technology Institute	Catalytic conversion of biogas to liquids
LanzaTech	Catalytic conversion of ethanol to renewable diesel
Research Triangle Institute	Catalytic fast pyrolysis and hydroprocessing
West Biofuels Development	Thermochemical conversion and co-processing
Mosaic Materials	MOF separations for biogas upgrading
University of Illinois at Urbana-Champaign	Anaerobic membrane bioreactor for wastewater biosolids conversion to methane
Worcester Polytechnic Institute	HTL of MSW and catalytic conversion of biocrude

BETO Activities: Recent BETO IBRs

- **FY19 FOA topics:**
 - Systems research of hydrocarbon biofuel technologies
 - Optimization of bio-derived jet fuel blends
- **Awards around \$1-2M Federal share each**

Recipient	Technology
OxEon Energy	Non-thermal plasma reforming of methane to syngas, solid oxide electrolysis of CO ₂ to syngas, and Fischer-Tropsch upgrading to liquids
Research Triangle Institute	In-situ catalytic fast pyrolysis
Gas Technology Institute	Biogas reforming to hydrogen and use of hydrogen for integrated hydrolysis and hydroconversion
Purdue University	Catalytic conversion of ethanol to cycloparaffinic SAF
University of Colorado Boulder	Deacetylation and mechanical refining of lignocellulose to sugars and Virent catalytic conversion to cycloparaffinic SAF
Vertimass	Catalytic conversion of ethanol to cycloparaffinic SAF
T2C Energy	Catalytic conversion of biogas to renewable diesel

BETO Activities: Recent BETO IBRs

- **FY20 FOA topics:**
 - Scale-up of bench applications to engineering scale with testing of 500 cumulative hours on stream with minimum 100 continuous hours
- **Awards around \$3-4M Federal share each**

Recipient	Technology
University of Alabama Tuscaloosa	Improvement of the Szego mill for deacetylation and mechanical refining for lignocellulose pretreatment
University of North Dakota Grand Forks	Deacetylation and mechanical refining of corn stover and lignin catalytic conversion to cycloparaffinic SAF
Alder Fuels	Arrested anaerobic digestion of wet waste to volatile fatty acids and catalytic conversion to SAF
Global Algae Innovations	Scale-up of algae drying and extraction processes
North Carolina State University	Delayed coking of fast pyrolysis bio-oil and conversion to battery anodes
Oregon State University	Microchannel reactor for catalytic conversion of ethanol to n-butene
Research Triangle Institute	Scale-up and integration of separation technologies with catalytic fast pyrolysis
Georgia Institute of Technology	Fermentation of sugars to 2,3-butanediol and catalytic conversion to SAF

BETO Activities: Recent BETO IBRs

- **FY21 FOA topics:**
- **Pre-Pilot testing 500 hours cumulative time on stream including 100 hours continuous, at 0.5 dry tons per day; \$3-4M each**
- **Pilot: Verification & Design Basis only; pending future appropriations, testing of 1,000 hours cumulative time on stream including 500 hours continuous, at 20,000 gallons biofuel per year scale**
- **Demonstration: Verification & Design Basis only; pending future appropriations, testing of 1,000 hours cumulative time on stream including 500 hours, at 1 MGY scale**

Recipient	Technology
MicroBio Engineering	Pre-Pilot: Hydrothermal liquefaction of sludge and algae, and conversion to SAF
Alder Fuels	Pre-Pilot: Pyrolysis of miscanthus and hydrotreating to SAF
Gas Technology Institute	Pre-Pilot: Reverse water gas shift conversion of CO ₂ to syngas and Fischer-Tropsch upgrading to liquids
Gas Technology Institute	Pre-Pilot: Entrained flow gasification of biomass or MSW to syngas and Fischer-Tropsch upgrading to liquids
Texas A&M	Pre-Pilot: Biological lignin conversion to polyhydroxyalkanoates, and hydrolysate to 2,3-butanediol to SAF
University of Maryland	Pre-Pilot: Supercritical CO ₂ and subcritical water liquefaction for biomass and waste processing to bio-oil
Global Algae Innovations	Pre-Pilot: Direct air capture algae cultivation and harvesting
LanzaTech	Pre-Pilot: SAF from CO ₂
D3Max	Pilot: Deacetylation and mechanical refining of corn stover, enzymatic hydrolysis to cellulosic sugars, fermentation to ethanol, and catalytic upgrading to SAF
T2C Energy	Demonstration: Biogas catalytic conversion to liquids
SkyNRG Americas	Demonstration: Landfill gas conversion to SAF

BETO Activities: Recent BETO IBRs

- FY22 FOA topics
 - Pre-Pilot
 - Pilot
 - Demonstration
- <https://www.energy.gov/eere/bioenergy/articles/us-department-energy-awards-118-million-accelerate-domestic-biofuel>

Recipient	Technology
Lanzatech	Pilot: Woody biomass gasification and gas phase fermentation to ethanol
MicroBio Engineering	Pilot: Hydrothermal Liquefaction of waste water treatment solids to biocrude
Alder Energy	Demonstration: Pyrolysis of woody biomass to biocrude
AVAPCO	Demonstration: Woody biomass to cellulosic ethanol to jet

Stakeholders

Major National Stakeholders and Partners in Biorefining: BETO consortia



<https://www.chemcatbio.org/>



<https://agilebiofoundry.org/>



<https://bioesep.org/>



<https://discovr.labworks.org/>



energy.gov/fcic



<https://www.bottle.org/>



energy.gov/ccpc

2023 BETO Peer Review

- The U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO) is hosting its 2023 Project Peer Review on April 3–7, 2023. Projects in BETO's research and development portfolio will be presented to the public and systematically reviewed by external subject-matter experts from industry, academia, and federal agencies. Simultaneous review sessions of projects across the BETO technology areas will occur.
- <https://www.energy.gov/eere/bioenergy/2023-project-peer-review>

Bioenergy Publications

- <https://www.energy.gov/eere/bioenergy/beto-publications>

Recent BETO Publication	Date of Publication
Co-Optima Findings and Impact Report	June 2022
Advancing Synergistic Waste Utilization as Biofuels Feedstocks: Preprocessing, Coproducts, and Sustainability: Workshop Summary Report	April 2021
Leveraging Existing Bioenergy Data: Workshop Summary Report	March 2021
Bioprocessing Separations Consortium Three-Year Overview	October 2020
Sustainable Aviation Fuel: Review of Technical Pathways Report	September 2020
Plastics for a Circular Economy Workshop: Summary Report	July 2020
Federal Activities Report on the Bioeconomy: Algae	July 2020
BETO R&D State of Technology	May 2020

Contact Information

- **United States contacts:**

Mark Shmorhun, Ph.D.

Mark.Shmorhun@ee.doe.gov

Robert Natelson

Robert.Natelson@ee.doe.gov

Jim Spaeth

Jim.Spaeth@ee.doe.gov