U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

US Sustainable Aviation Fuels Taking Off

Jim Spaeth
Bioenergy Technologies Office (BETO)
Program Manager
Systems Development & Optimization
Sustainable Aviation & International Engagement

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Biden Administration and DOE Targets

Building on Past U.S. Leadership, including Efforts by States, Cities, Tribes, and Territories, the New Target Aims at 50-52 Percent Reduction in U.S. Greenhouse Gas Pollution from 2005 Levels in 2030

Accelerate and innovate RDD&D to transition America to a 100% clean energy economy no later than 2050 - ensure the benefits to all Americans.

DOE Program Priorities

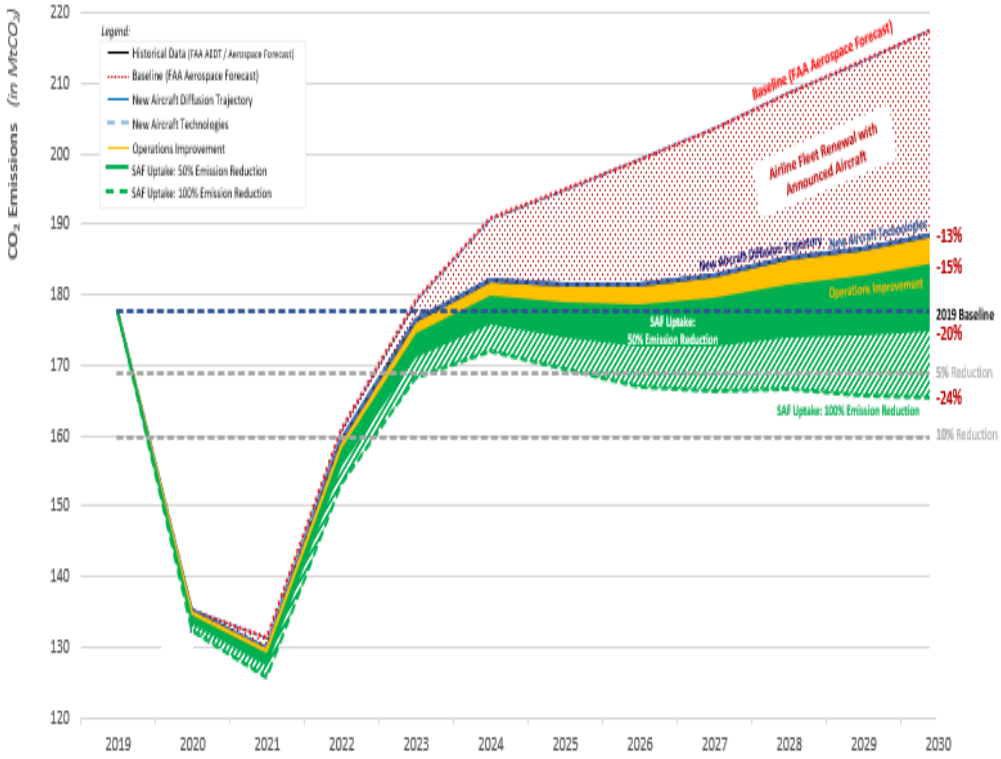
- 100% Decarbonized electricity by 2035
- Decarbonize:
  - Transportation across all modes
  - Energy intensive and high GHG industries
  - Buildings industry
  - To enable a net-zero agricultural sector

Prioritize DEPLOYMENT for greatest impact

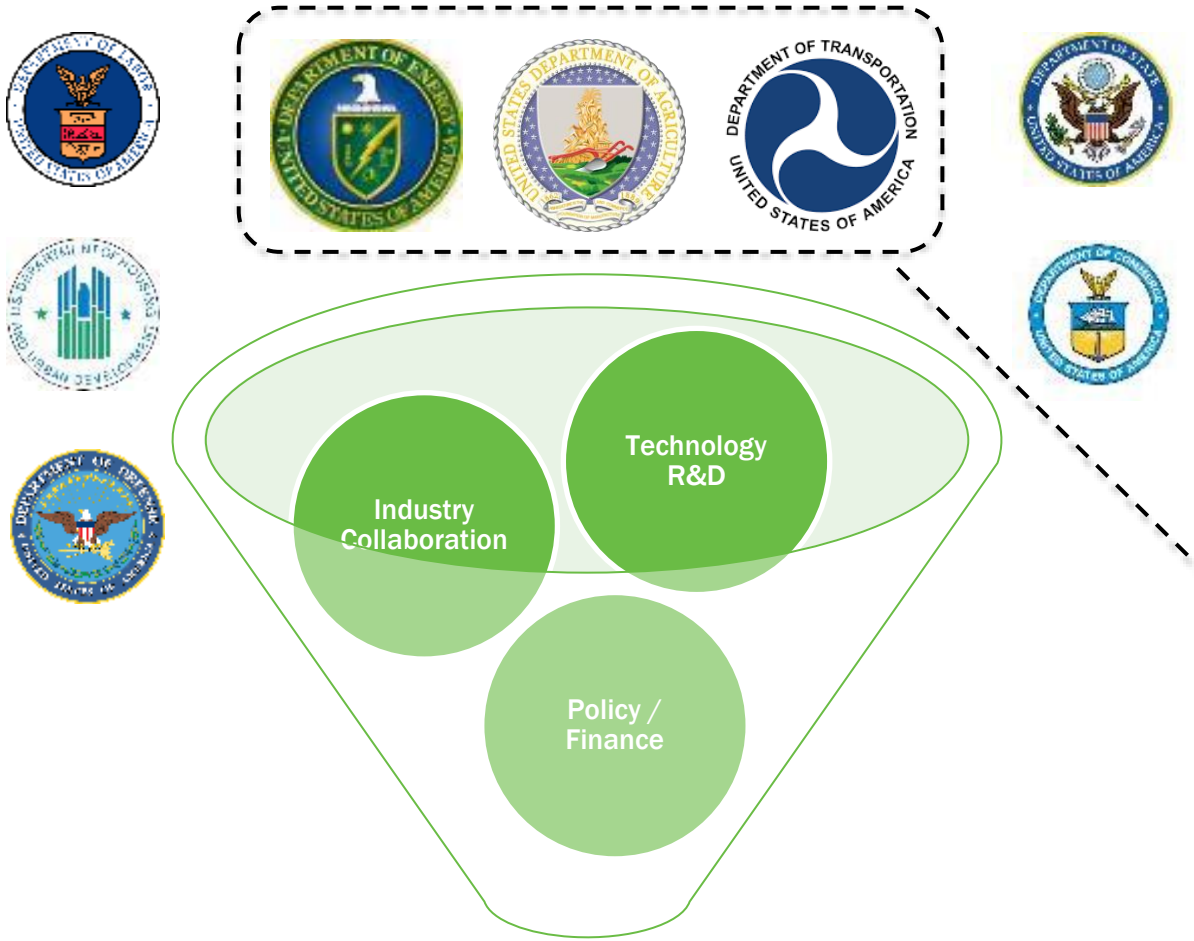
US Net Zero Aviation Sector Decarbonization Strategy

Sustainable Aviation Fuel Grand Challenge:

- Minimum of a 50% reduction in lifecycle greenhouse gas (GHG) (>70% average)
- 2030 Goal – 3B gallons of SAF
  - Minimum 20% CO2 reduction
- 2050 - 35B gallons of SAF
  - Enough for all US aviation fuel needs
- Require doubling of domestic capacity yearly



Multi-Agency Collaboration



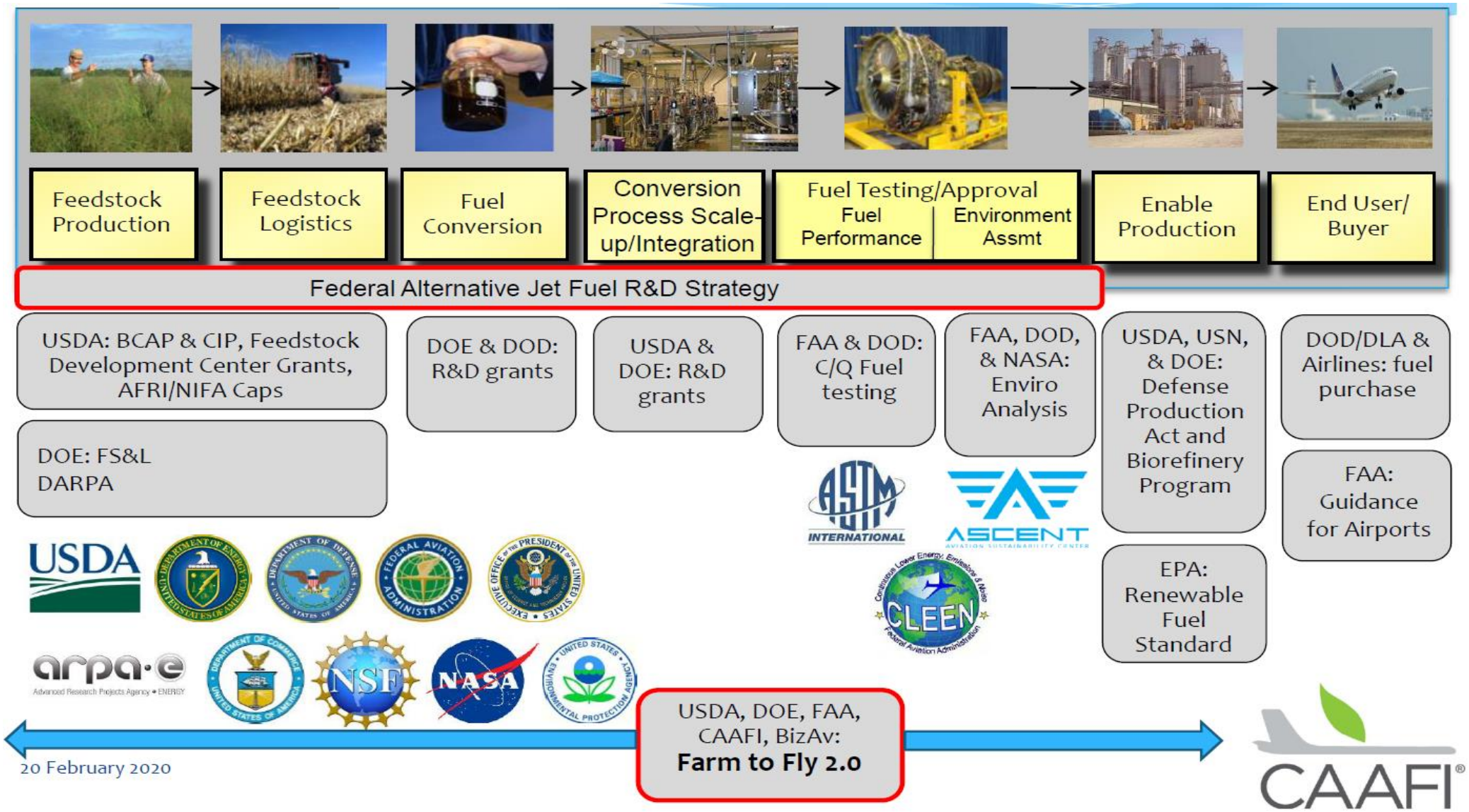
Aviation Sector Solutions

Collaboration between federal agencies will accelerate:

- Decarbonization and action

U.S. Department of Energy (DOE)	U.S. Department of Agriculture (USDA)	U.S. Department of Transportation (DOT)
DOE Technical, analytical capabilities for sustainable solutions	USDA Feedstock development and production and Climate-Smart Agriculture	DOT Regulatory, policy, and infrastructure planning and deployment

SAF: Coordinated Federal agency efforts across the Supply Chain

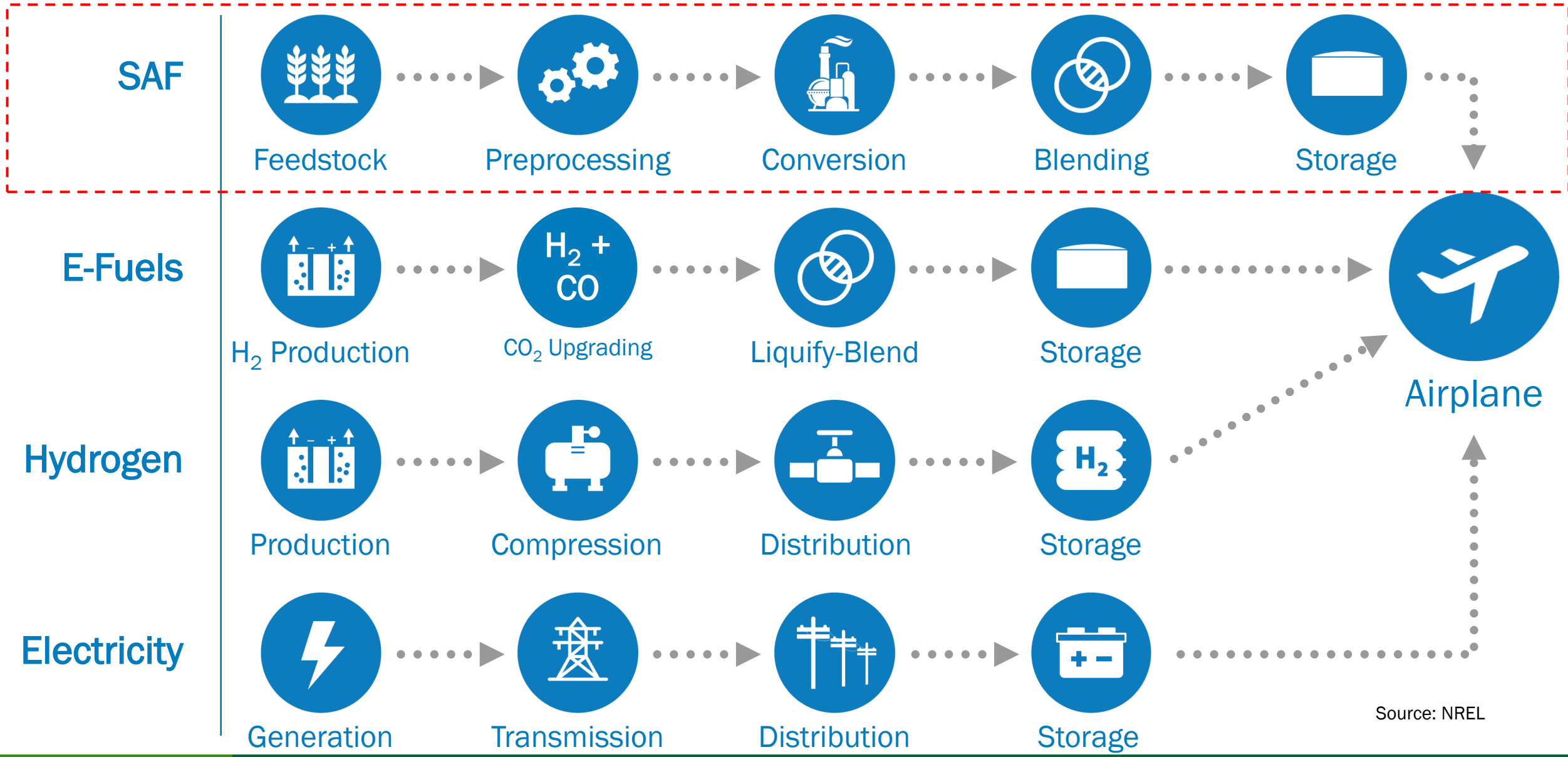


SAF Grand Challenge Roadmap

A multi-agency federal action plan

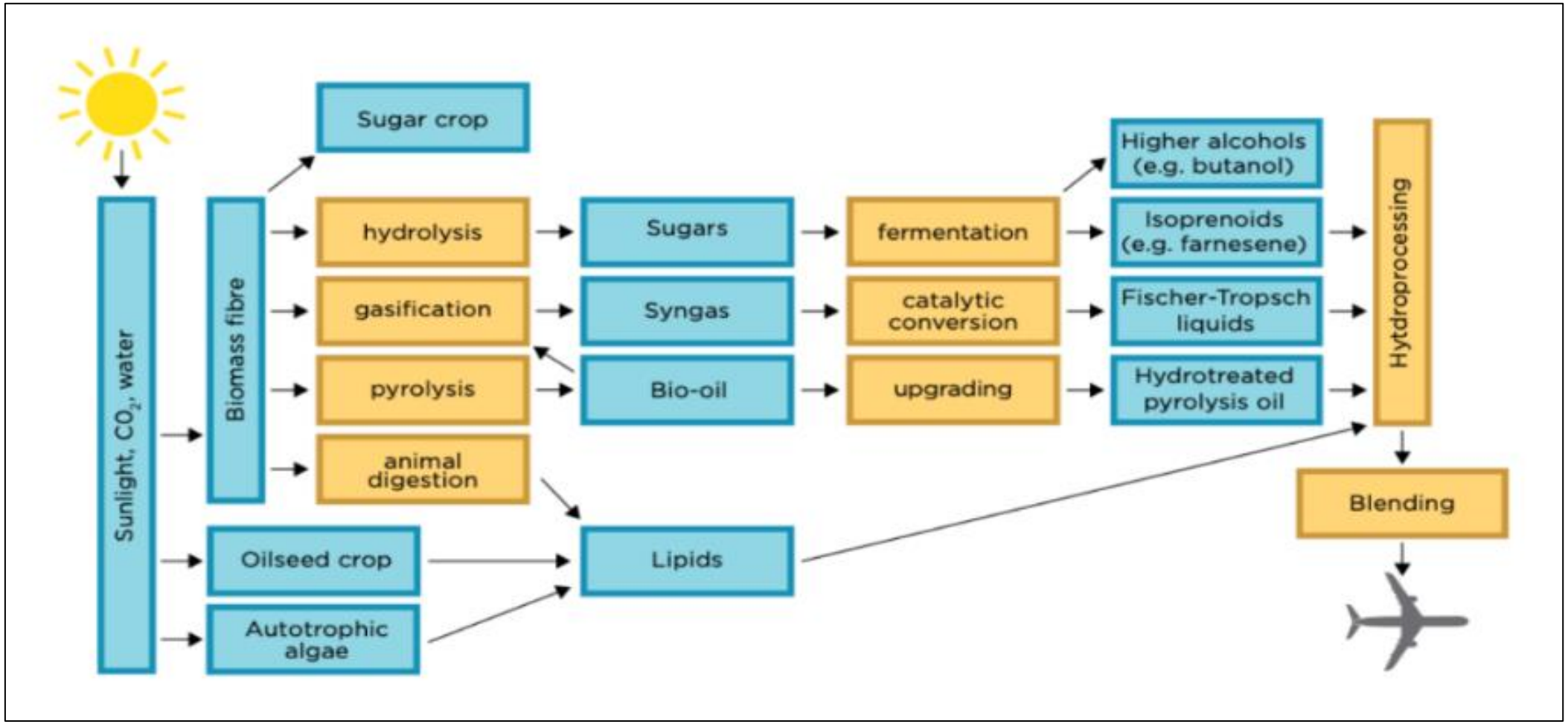
- De-risk and accelerate public/private R&D through commercialization
- Implement a supporting policy framework
- Enable motivated investors
- Catalyze development <u>across the supply SAF supply chain</u>

Next-Gen Aviation Energy Supply Chain



Source: NREL

DOE is developing Multiple SAF Pathways



Wide Diversity of Feedstocks Required

- U.S. - 1 billion tons of sustainable biomass annually
- About 645 million tons needed to make 35 billion gallons

FATS OILS GREASES

CORN ETHANOL

Urban Waste : Plastics

ENERGY CROPS : Switchgrass

FOREST WASTE : Harvest Debris

AG WASTE : Corn Stover

Algae

Commercial Today

Needed to Meet Goals

Additional feedstocks needed with new SAF conversion routes

Lignocellulosic Biomass (23 BGPY jet potential)

- Agricultural residues*	9.0 BGPY jet
- Forestry trimmings and residues*	7.1 BGPY jet
- Bioenergy crops by 2030*	7.4 BGPY jet

Assumes 34 gal of SAF range hydrocarbons per dry tonne of biomass, excluding other fuel cuts

Other Waste C Sources (10 BGPY jet potential)

- Inedible animal fats**	1.8 BGPY jet
- Animal manure**	4.7 BGPY jet
- Wastewater sludge**	2.0 BGPY jet
- Food waste**	2.7 BGPY jet
- MSW (paper, wood, yard)***	0.9 BGPY jet
- Industrial waste gas***	1.3 BGPY jet

BGPY = billion gallons per year; estimates of jet potential will vary based on conversion technology and feedstock composition

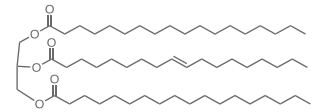
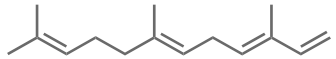
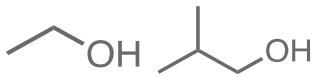
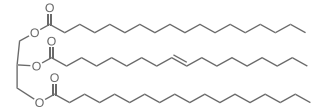
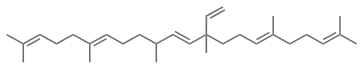
- U.S. has the potential capacity to produce a billion tons of biomass which can be converted to ~ 60 BGPY of biofuels
- SAF provides links to agriculture, food security, and waste management with opportunities for cross-sector benefits at the intersection of energy and environment

Sources: *2030 estimate from DOE 2016 Billion-Ton Report; **Bhatt et al. (2020) iScience, 23, 101221; ***CAAFI U.S. Jet Fuel production potential from wastes

Source: NREL

Currently seven ASTM annexes approved to produce SAF

- Currently 7 ASTM approved SAF routes with intermediates that include lipids, alcohols, syngas, and biobased hydrocarbons (D7566)
- Several new SAF routes currently in ASTM evaluation process that include aqueous phase sugars to SAK (Virent), catalytic pyrolysis oil to SAF (Shell IH2), Alcohol to jet with aromatics (several)

	Starting Feedstock for SAF Route	
A1: FT-SPK 50% blend Fischer Tropsch Synthesized Paraffinic Kerosene	Syngas	CO + H2
A2: HEFA-SPK 50% blend Hydroprocessed Esters & Fatty Acids Synthesized Paraffinic Kerosene	Triglycerides & Fatty Acids	
A3: HFS-SIP 10% blend Hydroprocessed Fermented Sugars Synthesized Isoparaffins	Farnesene	
A4: FT-SKA 50% blend Fischer Tropsch Synthesized Kerosene with Aromatics	Syngas	CO + H2
A5: ATJ-SPK 50% blend Alcohol-to-Jet Synthesized Paraffinic Kerosene	Ethanol & Isobutanol	
A6: CHJ 50% blend Catalytic Hydrothermolysis Jet Synthesized Kerosene Esters and Fatty Acids	Triglycerides & Fatty Acids	
A7: HC-HEFA SPK 10% blend Hydroprocessed Hydrocarbons & HEFA Synthesized Kerosene	Algal Botryococcene	

Source: ASTM D7566-20; Wang et al. (2016) NREL TP-5100-66291; Holladay et al. (2020) DOE/EE-2041 8292

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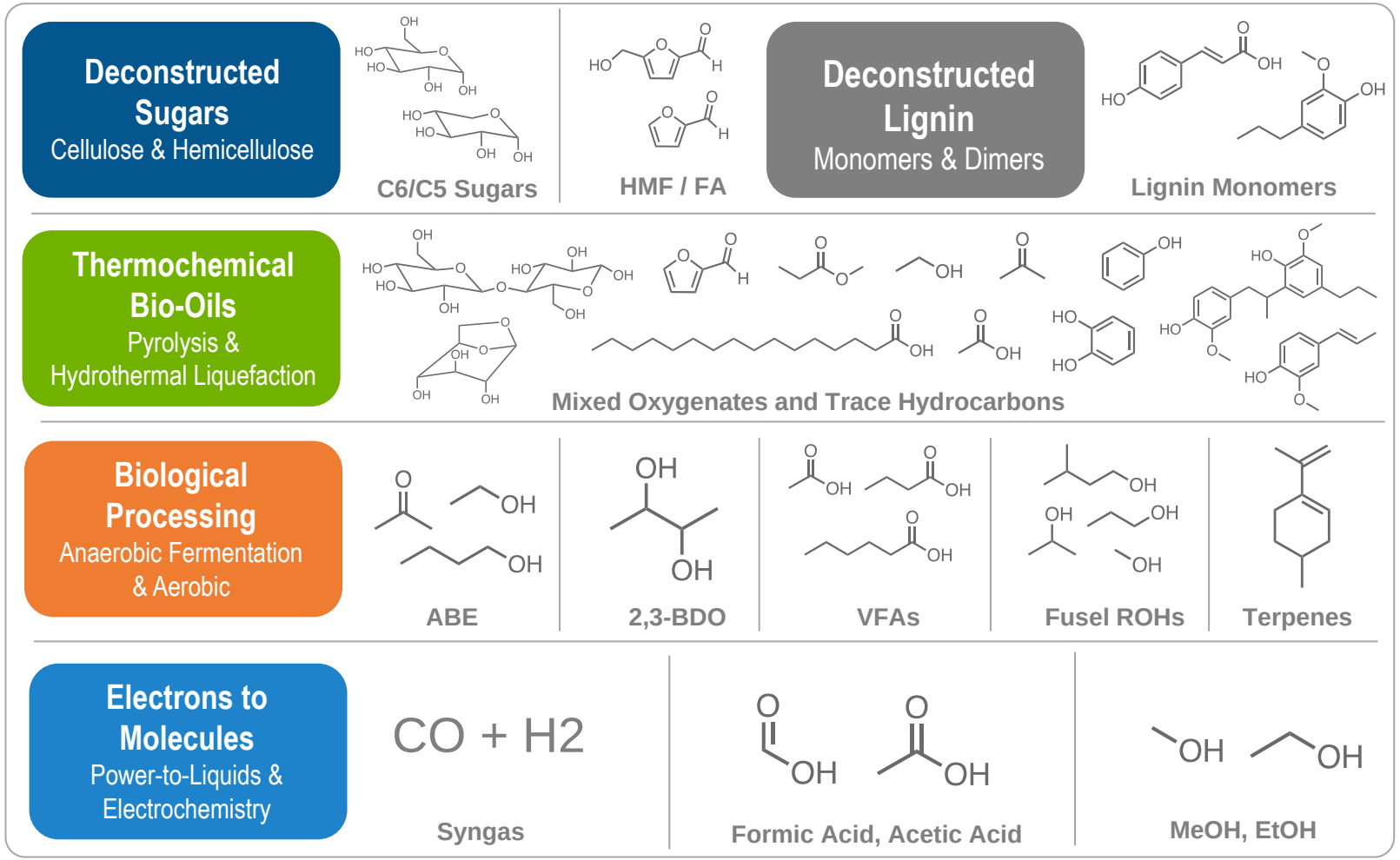
Emerging Routes to Produce SAF From Biomass and Waste Stream

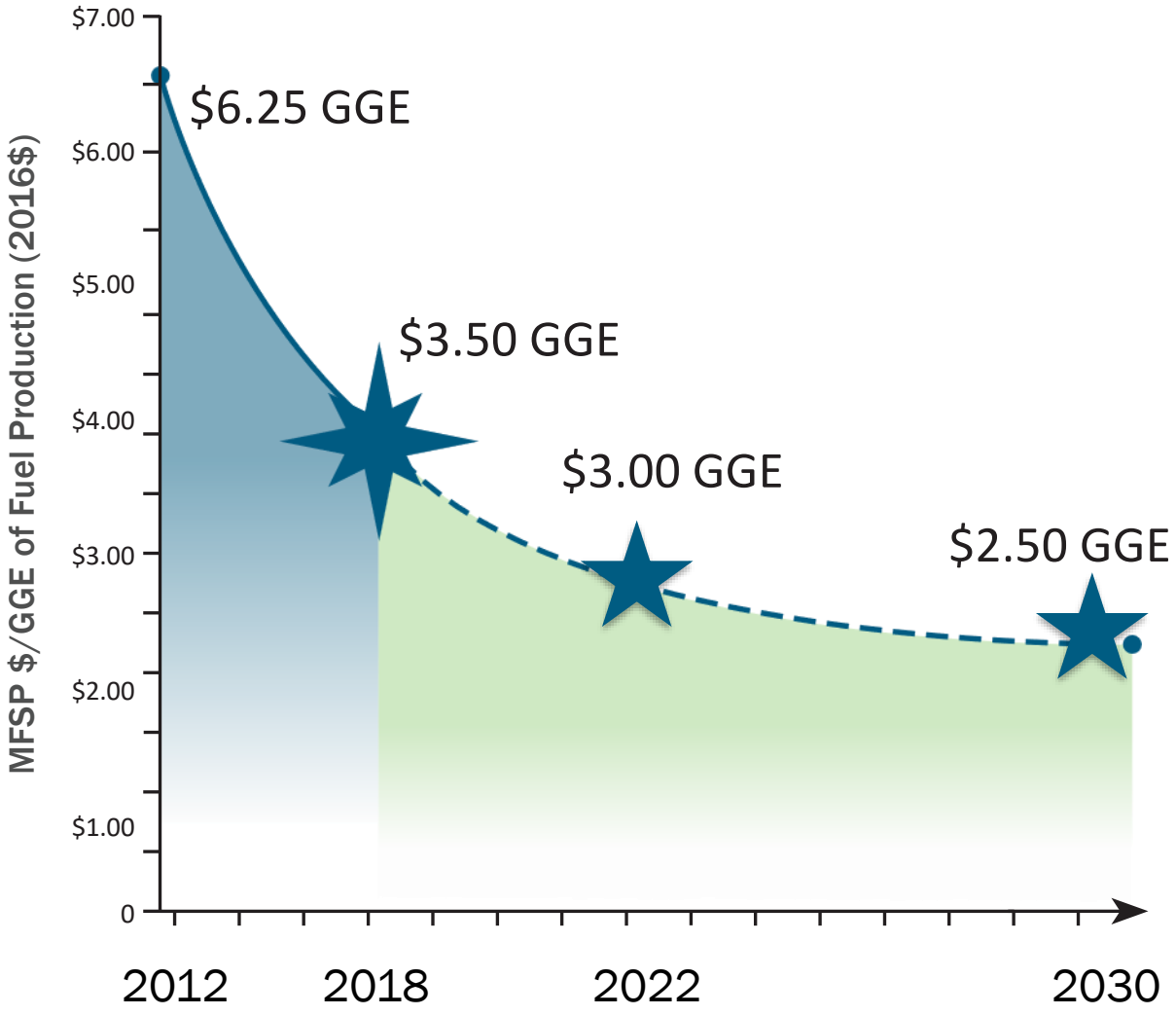


- Multiple biofuel technologies can produce SAF-range fuels from biomass and waste C
- Processes range from thermochemical, biological, hybrid, and electrochemical for biomass, waste, and CO2 feedstocks

Sources: Wang et al. (2016) NREL TP-5100-66291; Holladay et al. (2020) DOE/EE-2041 8292; Zhang et al. (2020) Recent Treads, Opportunities and Challenges of Sustainable Aviation Fuel; DOE (2021) BETO Project Peer Review

Source: NREL

DOE SAF Goals and Impacts



MFSP = minimum fuel selling price | GGE = gallon gas equivalent

GOALS

Cost Reduction with Maximum CO_2 Reduction

2022	• $3.00/GGE, 60% GHG reduction
2030	• $2.50/GGE, 70% GHG reduction

Increase Commercial Supply of SAF

2030	• Demonstrate minimum of 4 - 5 technology pathways at engineering scale • Equip traditional biofuel industry to transition to SAF with GHG reductions of >70% • Enable 3B gallons by 2030
2050	• Aggressive industrial build-out to deliver 35B gal SAF to the market

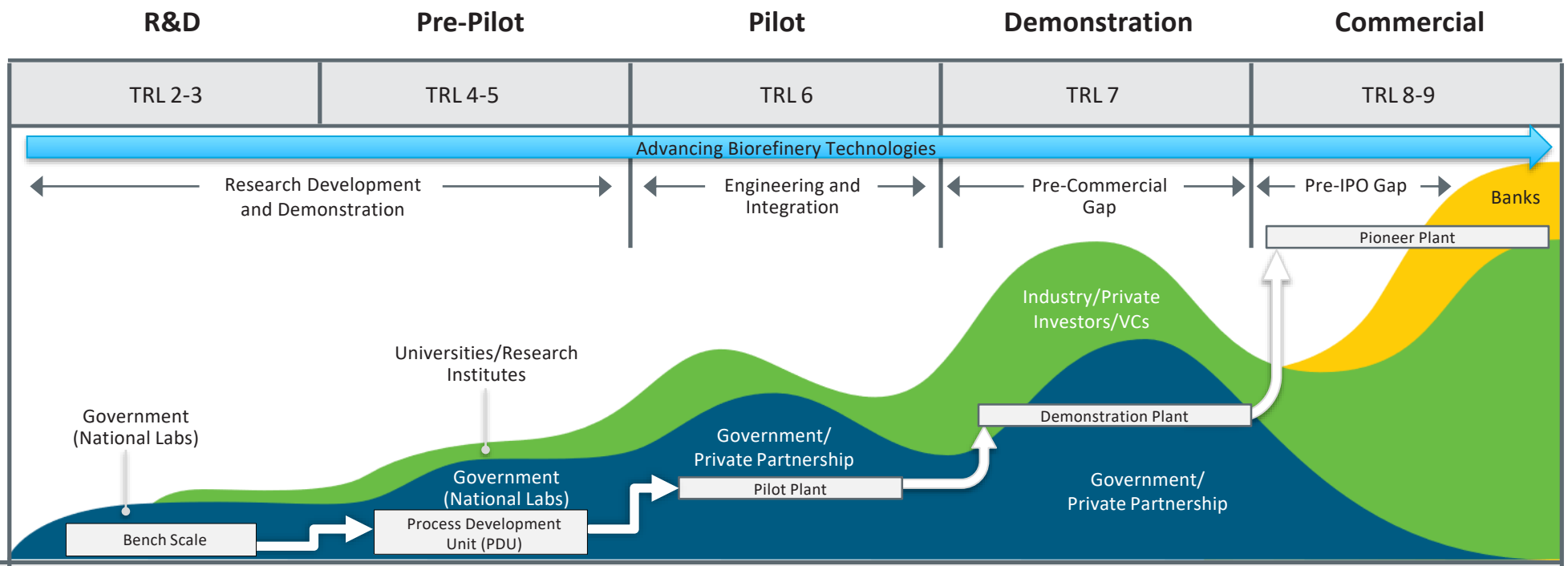
Long-Term Impacts

2050	• 60B gal renewable hydrocarbon fuels • 40B pounds of renewable chemicals • >450 million tons CO_2 reduced annually • 1 million direct jobs

DOE Technology SAF Scale-up Strategy

- **Annual Opportunities for pre-pilot, pilot, and demonstration scale projects**
- **Wide variety of feedstocks**
  - Traditional cellulosic feedstocks
  - MSW, CO_2, CO, flue gas, and biogas
  - Corn starch and oilseeds
- **Allow bioproduct opportunities**
- **Leveraging existing industrial infrastructure supply chains**
  - 1st Generation ethanol, pulp and paper, petroleum refineries
- **Predictive models and high-performance computing**

R&D, Pilot, Demonstration, Pioneer Refinery to Commercialization



	R&D	Pre-Pilot	Pilot	Demonstration	Commercial
Average Total Project Cost	$1–$5 Million	$5–$10 Million	$25–$50 Million	$100–$500 Million	$250–$500 Million
Average Biomass Throughput	Grams/Day	Kilograms/Day	<50 Tonnes/Day	50–250 Tonnes/Day	+250 Tonnes/Day
Production Volumes	mL/L (batch)	Liters/Gallons (batch)	0.1–1 M GPY (campaign)	1–10 M GPY (extended campaign continuous)	50 M GPY (continuous)

Government Project Recipients and Partners Banks/Bonds/Institutional Investors

2021 Scale-up Project Selections

	Selectee	Feedstock(s)	Basics	Product	Fuel Opportunity Size (billion gal/year)
Pre-pilot	MicroBio Engineering Inc.	WWT Sludge	HTL	- SAF - Fertilizer (Focus)	8.3
	Alder Energy	Miscanthus	Advanced pyrolysis oil fractionization Test flight at end of project	- SAF	8.8
	Gas Technology Institute #1	AD Biogas & Waste CO2	Electric Reformer & Gasification	- SAF - Diesel	2.6 to 12.6
	Gas Technology Institute #2	MSW & 3 cellulosic feeds	Feed system & Gasification	- SAF	3.3 to 8.8
	Texas A&M AgriLife Research	Corn Stover	Fermentation	- PHA (Focus) - SAF	7.2
	University of Maryland: College Park	WWT Sludge	HTL (with supercritical CO2)	- SAF - Diesel	8.3
	LanzaTech, Inc.	Waste CO2	Gas Fermentation	- SAF - Diesel	4.6
	Global Algae Innovations	CO2 (direct air capture)	Algae	- SAF	5.6
Pilot	D3MAX, LLC	Corn Stover	Fermentation	- SAF	7.2
Demo	T2C-Energy	Landfill Gas	Gas to Liquids	- Diesel	6.4
	SkyNRG Americas, Inc	Landfill Gas	Gas to Liquids	- SAF	1.6

LanzaTech Sustainable Aviation Fuel and Diesel History

2010-2012: Initial Research and Proof of Concept
- 2010: PNNL
- 2011: DARPA
- 2011: FAA
- 2012: DOE

2011+: Collaboration with Industry Leaders
- Virgin Atlantic
- HSBC
- Boeing
- RSB

2014-2017: Scale up and Fuel Production
- Freedom Pines pilot facility
- 4,000 gallons of jet produced
- 600 gallon of diesel produced
- DOE demo funding

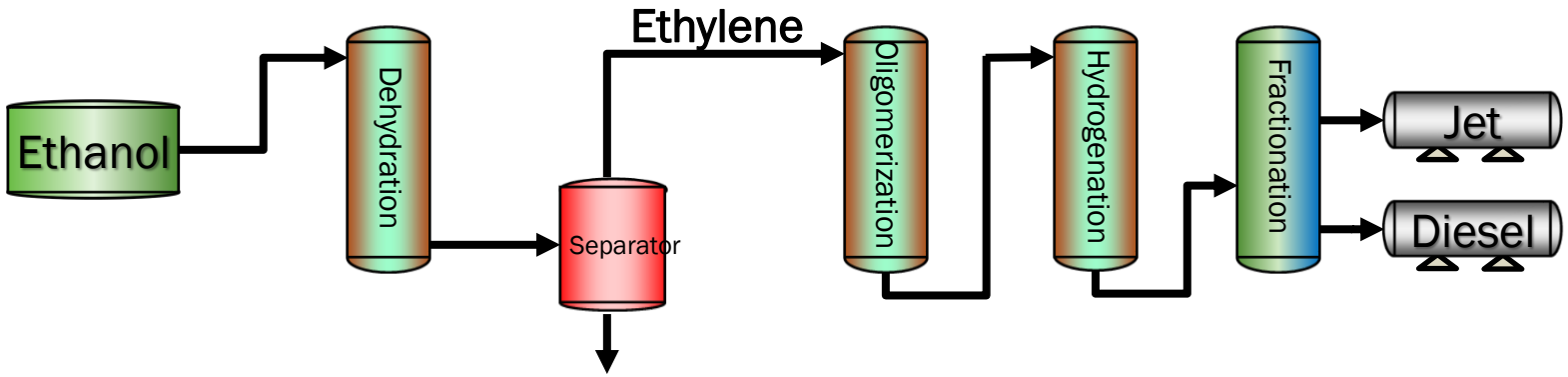
2016-2018: ASTM
- LanzaTech Research Report on Ethanol Based ATJ-SPK Submitted September 2016
- ASTM SAF Standard including Ethanol as Feedstock for Jet Published April 2018
- Based on LanzaTech data

2018+: Flight Demos and Demonstration Scale Fuel Production
- First Commercial flight on October 2, 2018
- DOE Demonstration Plant

World First Transatlantic Flight
October 3, 2018

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
BIOENERGY TECHNOLOGIES OFFICE

LanzaJet Takes Off!
June 2, 2020



Commercialization of Alcohol-to-Jet (ATJ) catalyzed by a partnership between LanzaTech and PNNL

Jim Spaeth

Bioenergy Technologies Office

Program Manager

Systems Development & Optimization

Sustainable Aviation

International Engagement

Jim.Spaeth@ee.doe.gov

Learn more about BETO: energy.gov/bioenergy

Photo courtesy of iStock

Global Clean Energy Action Forum

Clean Energy Ministerial 13 / Mission Innovation 7

Pittsburgh - 21 – 23 September

U.S. DEPARTMENT OF ENERGY

CEM13/MI•7 USA 2022

*"The joint CEM/MI ministerial meetings represent an opportunity to lock in climate commitments through **big bets on innovation** that **empower an energy transition** by 2050—averting the worst effects of climate change and supercharging economic opportunities for the global workforce."*

- Secretary of Energy Jennifer M. Granholm

Register at gceaf.org.

Streamline Innovation To Deployment Pipeline & Accelerate Global Action In Pittsburgh

INNOVATION

MISSION INNOVATION
accelerating the clean energy revolution

MI serves as: an innovation accelerator and a catalyst for global action by fostering results-drive collaboration among various international partners and public-private Missions.

CLEAN ENERGY MINISTERIAL

The CEM serves as: an implementation platform to drive clean energy technology deployment and solution with a bottom-up, government led community building on networks and partnerships across clean energy globally

DEPLOYMENT

GLOBAL CLEAN ENERGY ACTION FORUM
CEM13/MI•7 USA 2022

DOE's Vision is to transform the annual CEM/MI ministerial into **the** clean energy technology event of the year for government ministers, private sector leaders, NGOs, labor, and the public. It will be a new center of gravity, attracting a constellation of energy sector representatives and gatherings.

CEM13 IN PITTSBURGH 21 – 23 SEPTEMBER

- Preparations are in full swing
- Jointly planned by the DOE, the CEM Secretariat, and CEM member countries

PITTSBURGH

12:00	19	20	21	22	23
	United Nations General Assembly	**NYC Climate Week** **Biofuture Evening Event**	Opening Ceremony Reception	CEO – Minister Roundtables Side Events Plenary	Side Events

GCEAF Agenda

Wednesday 21 September	Thursday 22 September	Friday 23 September
Minister, VIP and Invited Guests Only AM/PM: Off-Site Visits to Pittsburgh Clean Energy landmarks Evening: • Registration open for Ministers and VIPs • Opening Ceremony • Private Minister and VIP Dinner	AM (community-wide): Off-site visits to Pittsburgh Clean Energy landmarks AM (ministers and invited guests) • State of Transition Report Launch • CEO-Minister Roundtables • Business Forum Opening Plenary PM (community-wide) • General Registration • Side Events • Clean Energy Technology Showcase • Youth Forum • Joint CEM/MI Private Plenary (focused on institutional business) • Joint CEM/MI Public Plenary (announcements and awards) • Business Forum	Community-wide dialogues, partner events, side events, business forum • Mainstage Events with Ministers, Philanthropies, CEOs and other VIPs • Closing Ceremony • Press Conference

Building on Glasgow at Pittsburgh:

Action-oriented & Sectoral-approach

Bringing clean energy actors together based on overall climate goals:

- Leveraging CEM Workstreams and MI Missions in a **sectoral approach** to convene stakeholders by finding mutual equities, measured progress, and opportunities to innovate, and by facilitating commercialization

THEME:
RAPID INNOVATION AND DEPLOYMENT

SUBTHEMES:
1. JOBS AND COMMUNITY
2. TECHNOLOGY TRANSFORMATION
3. UNPRECEDENTED DEPLOYMENT

The Biofuture Platform

A government-led, multi-stakeholder initiative aimed to promote international coordination on the sustainable low-carbon bioeconomy.

2016 - Established – led by Brazil
2019 – IEA assumes Secretariat role
2020 – Adopted as a CEM Initiative
2021 – US assumes Chair role
2021 – Campaign established

MEMBER COUNTRIES

Argentina • Brazil • Canada • China • Denmark • Egypt • Finland • France • Hungary India • Indonesia • Italy • Morocco • Mozambique • Netherlands • Paraguay • Philippines • Portugal • South Africa • United Kingdom • United States • Uruguay

COLLABORATING ORGANIZATIONS

IEA Bioenergy
Technology Collaboration Programme

Food and Agriculture Organization of the United Nations

IEA

IRENA
International Renewable Energy Agency

SUSTAINABLE ENERGY FOR ALL

UNITED NATIONS UNCTAD

UNIDO UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

EXPECTED CEM13 BIOFUTURE EVENTS

CEM13/MI-7
USA 2022

1) Private CEO – Minister Roundtable

2) Public High-level SAF Panel with CEOs, Ministers, Secretaries

3) Public Bioenergy Business Forum

4) Public Side Event Discussing CI-based Policy For Transport And Chemicals

5) Private Meeting Of The Biofuture Platform

6) Private Meeting Of The Biofuture Campaign

Join us in Pittsburgh, PA, USA for DOE's Global Clean Energy Action Forum (CEM13/MI-7 Ministerials). Sept 21-23, 2022. Register at gceaf.org.

GLOBAL ENGAGEMENT BEYOND CEM13|MI7