MIT LABORATORY FOR
AVIATION AND
THE ENVIRONMENT

CAAFI BGM | Washington, DC | December 5, 2018

Long-term CO_2 emissions reduction potential of aviation biofuels in the US

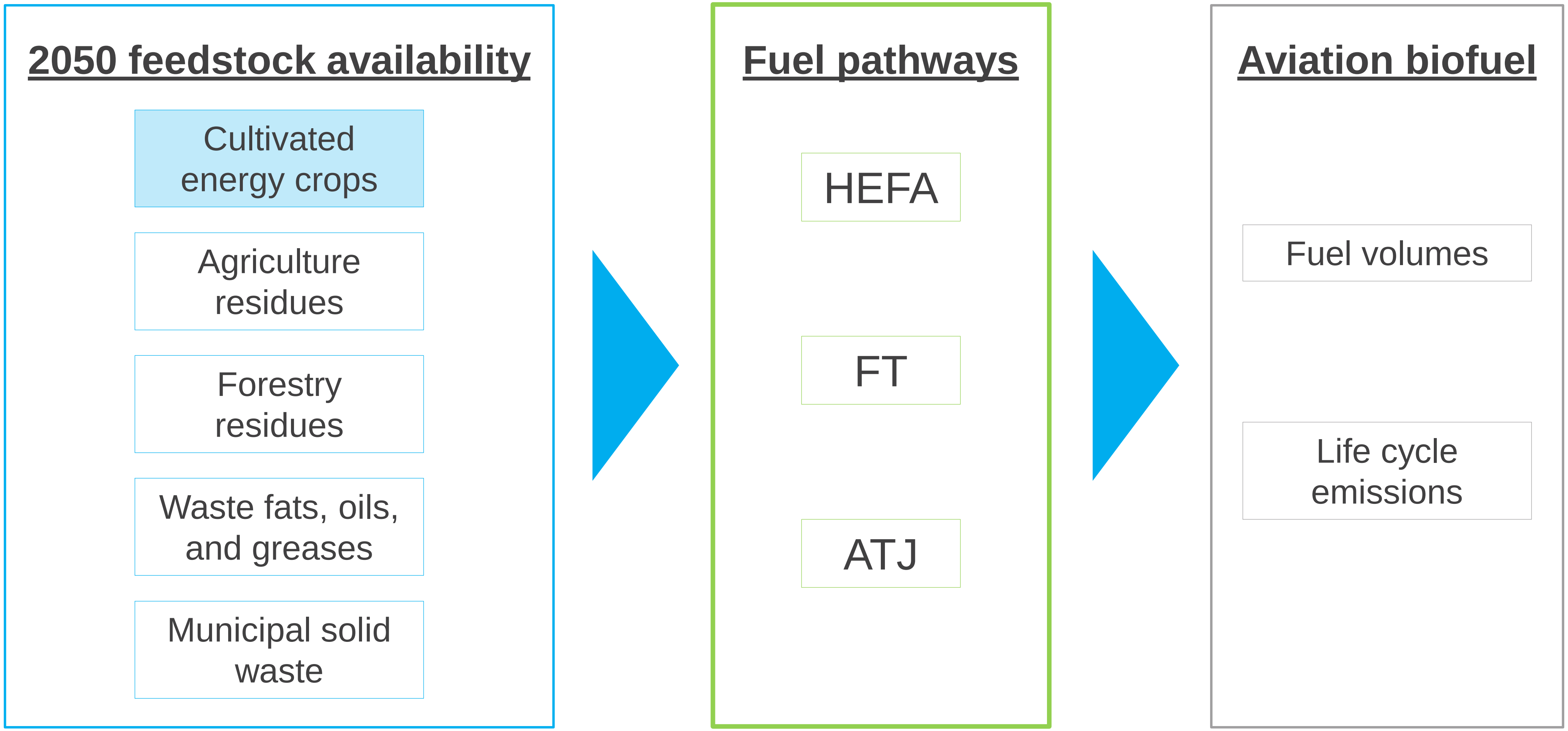
Dr. Mark Staples, MIT

Study objectives

Long-term CO_2 emissions reduction potential of aviation biofuels in the US

1. Quantify the physical limits to availability of aviation biofuels in the US by 2050
2. Evaluate GHG emissions impacts of using AJF to offset petroleum-derived jet fuel demand
3. Understand the potential for AJF to contribute to mitigating US aviation's climate impact, to better inform and policy-making

Methodology



2050 feedstock availability

- Cultivated energy crops
- Agriculture residues
- Forestry residues
- Waste fats, oils, and greases
- Municipal solid waste

Fuel pathways

- HEFA
- FT
- ATJ

Aviation biofuel

- Fuel volumes
- Life cycle emissions

Cultivated energy crops

Projected US land use patterns

Projected crop yields

Lands excluded *a priori* if:

a) unavailable for feedstock growth
- e.g. protected forest, cropland

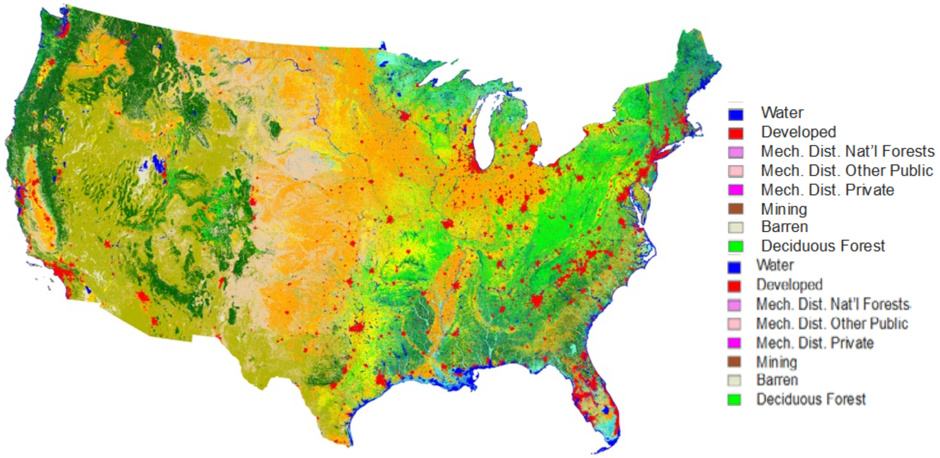
b) unsuitable for crop growth
- water, ice/snow, developed, mining

c) have conservation status
- e.g. natural state/limited extractive uses

d) agro-climatically unsuitable
- e.g. soil fertility, local climate, precip.

USGS 2050 land use projections

[Sohl et al. 2014]



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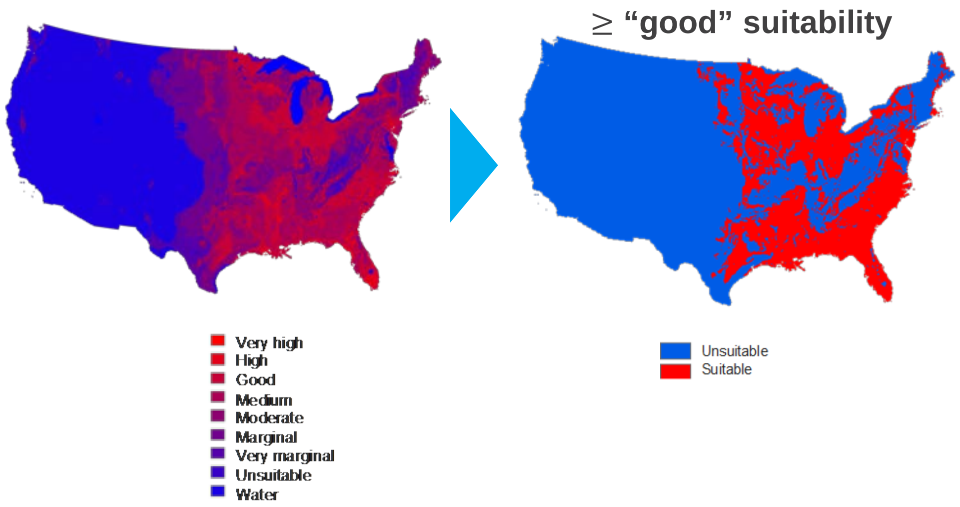
GAEZ agro-climatic suitability for corn cultivation

[Fischer et al. 2002]



Cultivated energy crops

Projected US land use patterns

Projected crop yields

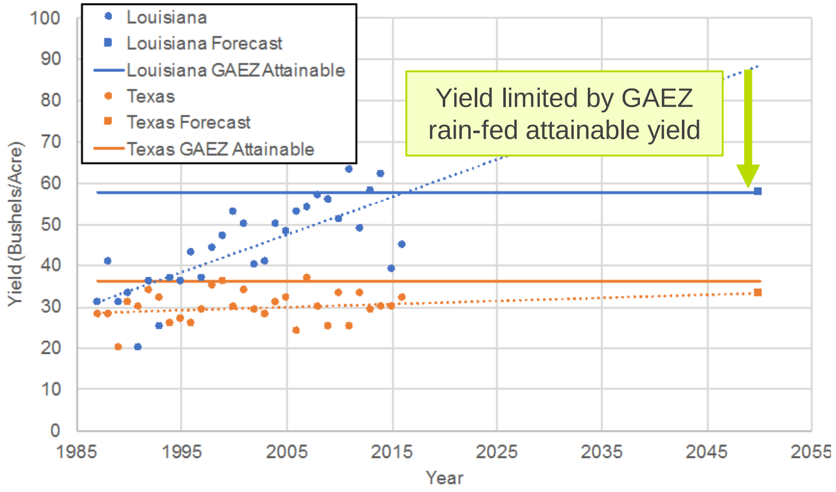
USDA NASS historical crop yields for:
- canola
- corn
- rapeseed
- soybeans
- sugarbeet
- wheat

Yield growth extrapolated linearly to 2050

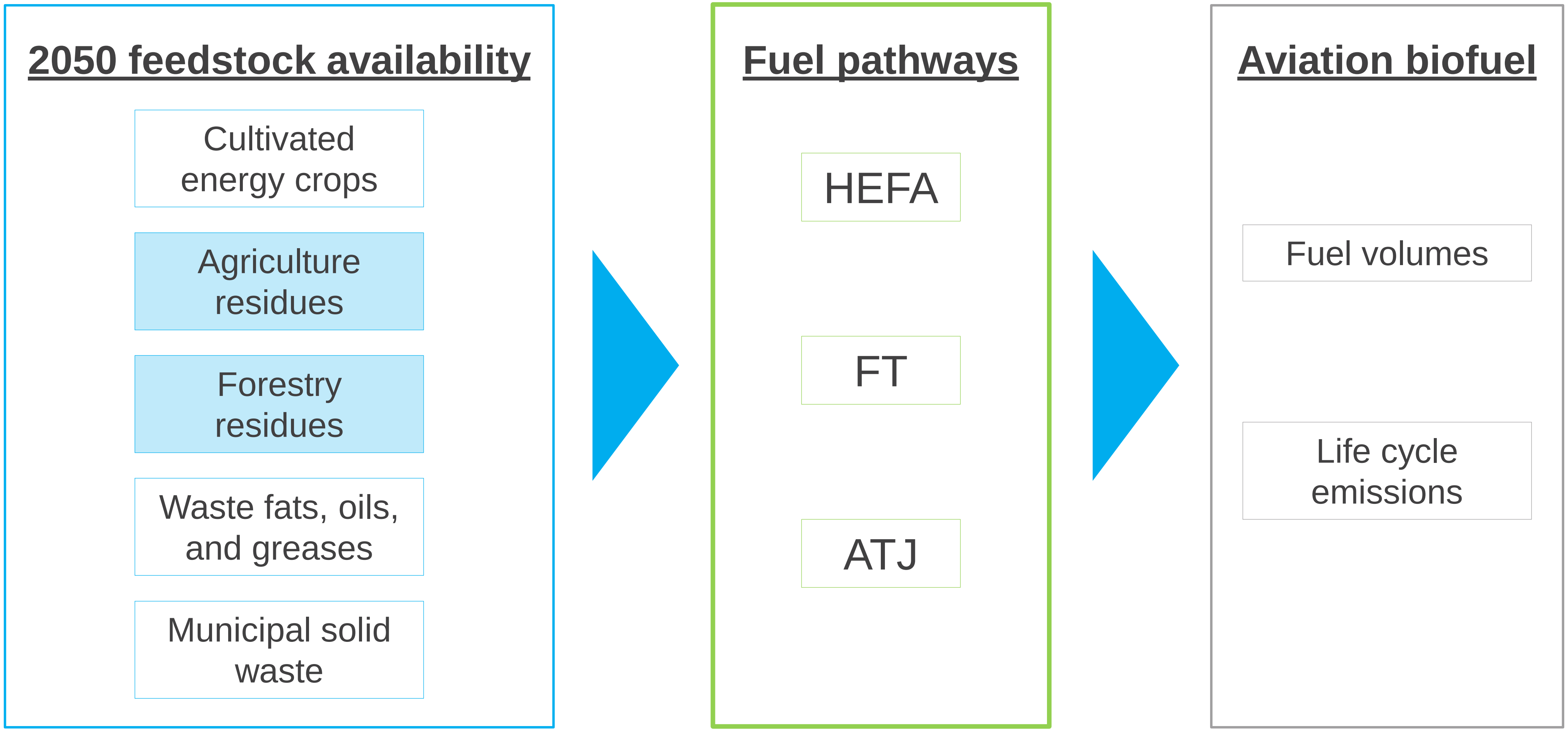
Growth limited by agro-climatically attainable yield

Projected wheat yields by capped by GAEZ

[Fischer et al. 2002]


Yield limited by GAEZ rain-fed attainable yield

Agriculture & forestry residues



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Agricultural residues

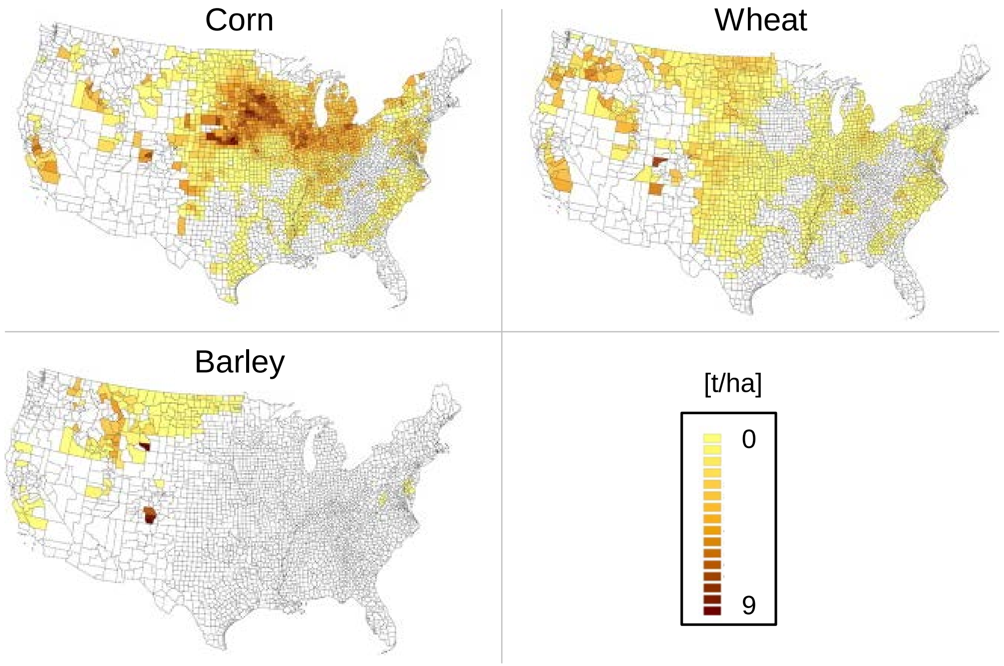
Residue availability based on:

a) Energy crop growth & projected food crop growth *[USDA 2017b]*

b) Food crop mix *[USDA 2017c]*

c) Location and crop-specific sustainable residue removal rates *[Muth et al. 2013]*

Sustainable residue removal rate
[Muth et al. 2013]



Forestry residues

Forestry production
[Howard 2016]

Harvested residue fraction (slash piles) = 0.52
[Seale & Malins 2015, Smeets & Faaij 2007]

Recoverable fraction = 0.375
[Smeets & Faaij 2007]

Total woody biomass residue

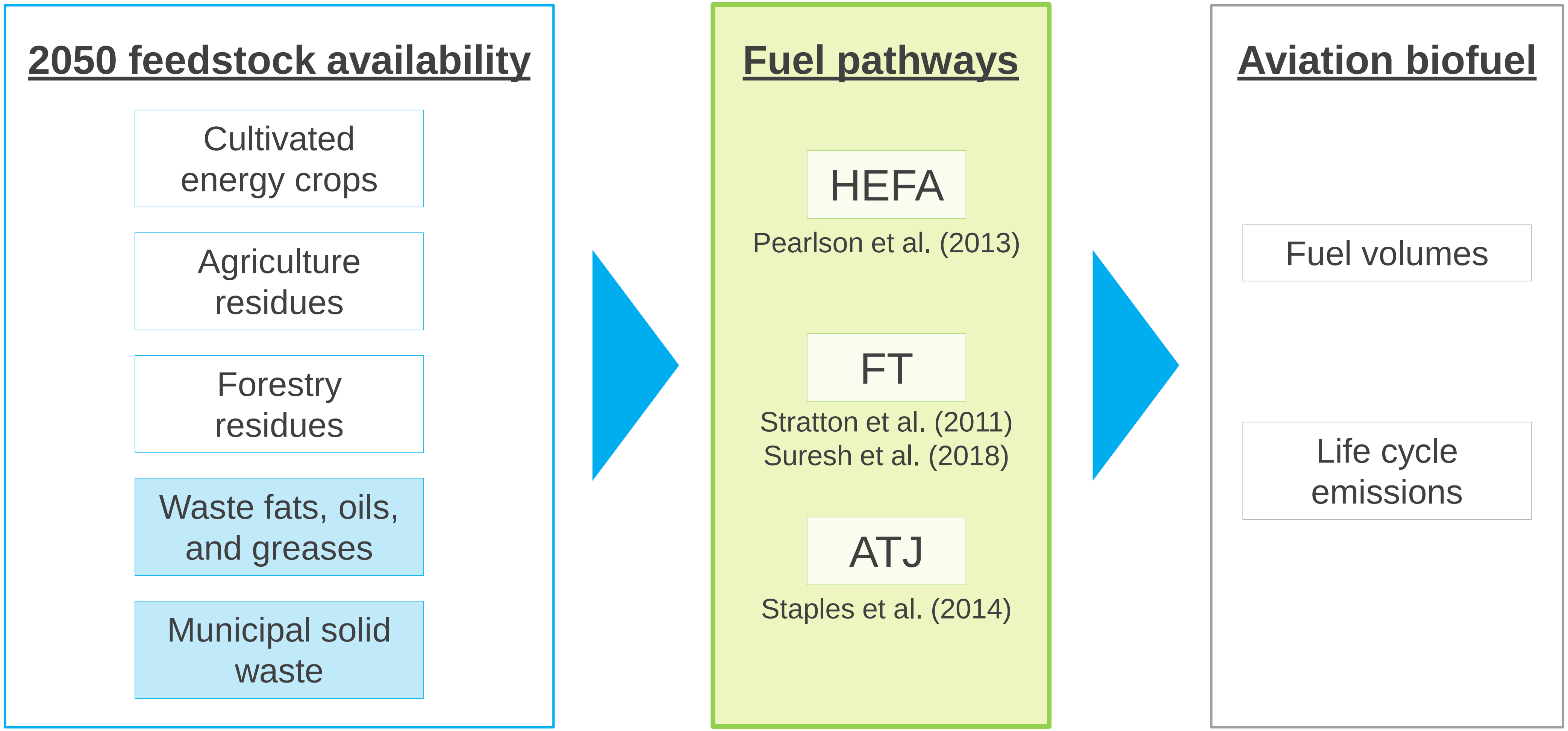
Processed wood products
[Howard 2016]

Processing residue fraction (sawdust, chips) = 0.5
[Seale & Malins 2015, Smeets & Faaij 2007]

Recoverable fraction = 0.75
[Smeets & Faaij 2007]

Residues used for char, pellets, on-site energy = 0.7
[McKeever 2004]

Waste feedstocks and fuel pathways



2050 feedstock availability

- Cultivated energy crops
- Agriculture residues
- Forestry residues
- Waste fats, oils, and greases
- Municipal solid waste

Fuel pathways

HEFA
Pearlson et al. (2013)

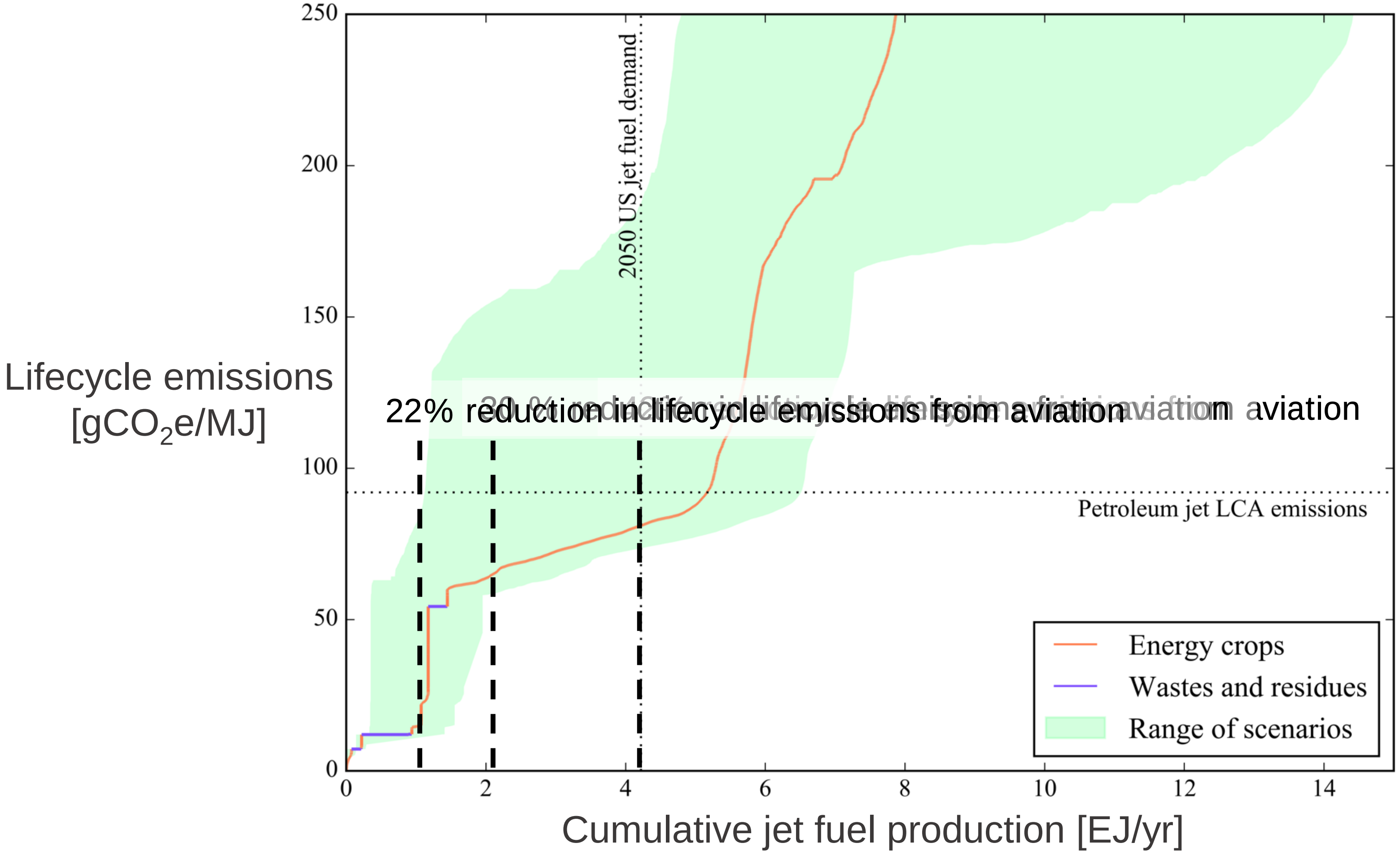
FT
Stratton et al. (2011)
Suresh et al. (2018)

ATJ
Staples et al. (2014)

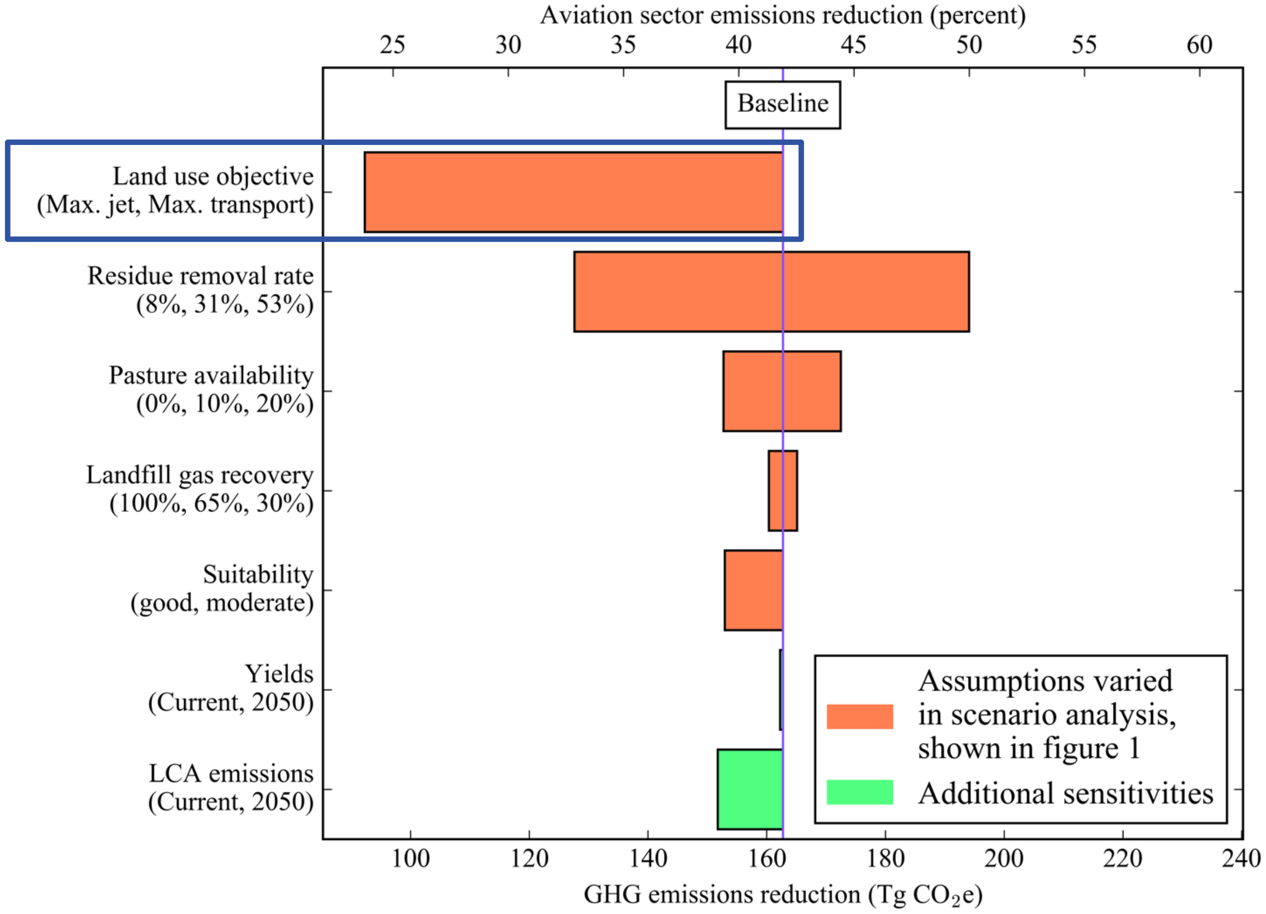
Aviation biofuel

- Fuel volumes
- Life cycle emissions

Scenario results

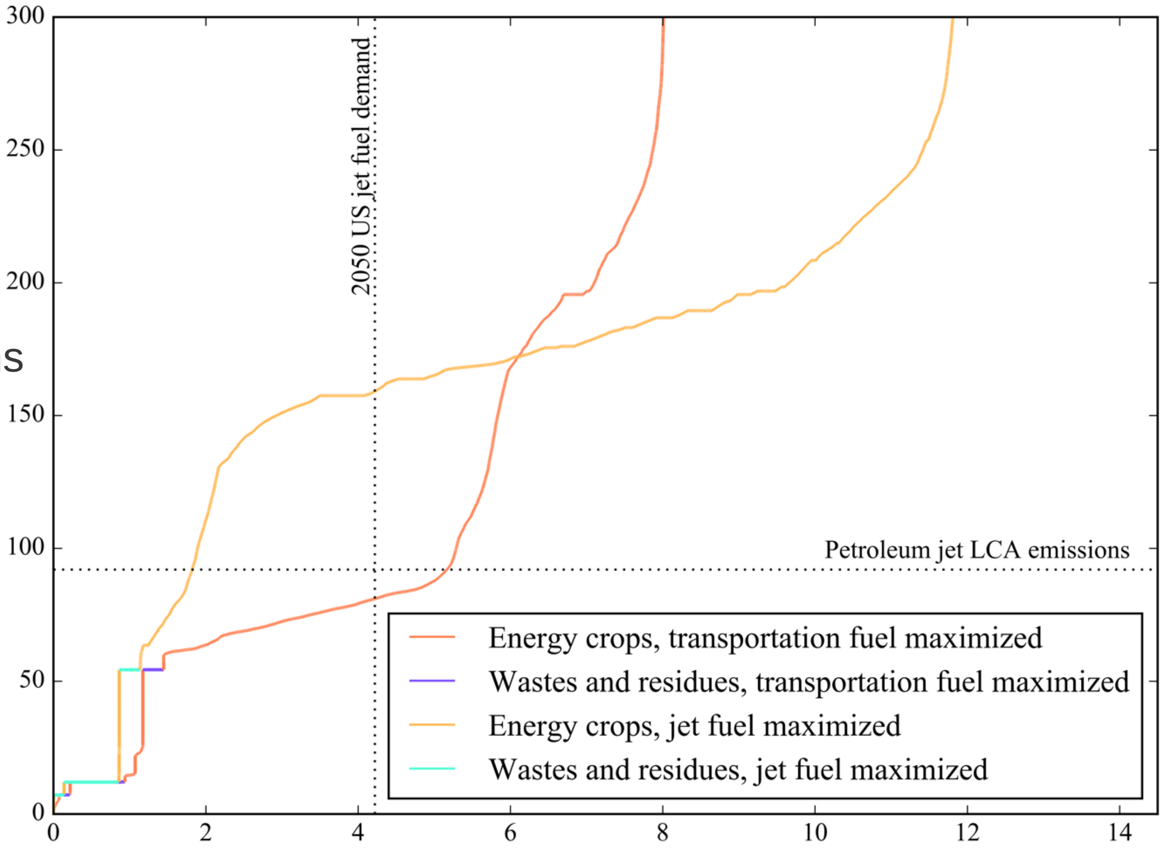


Scenarios & sensitivities



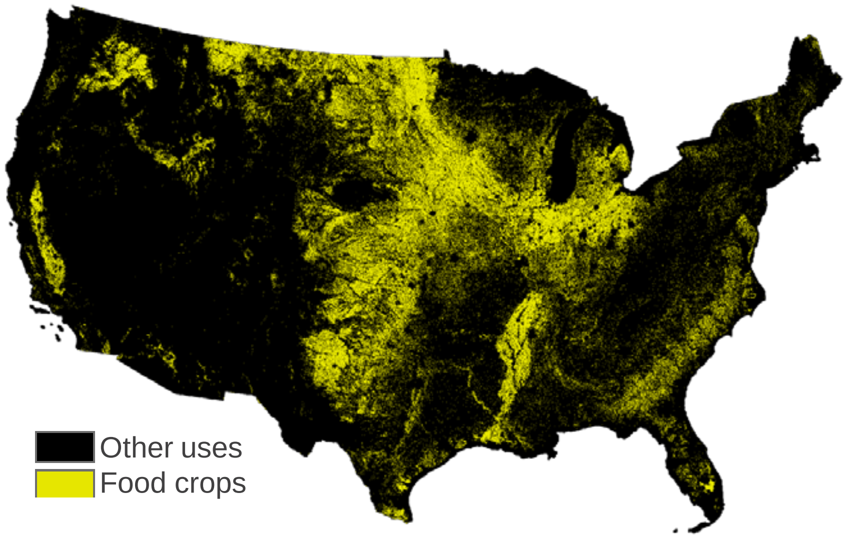
Sensitivity to land use objective

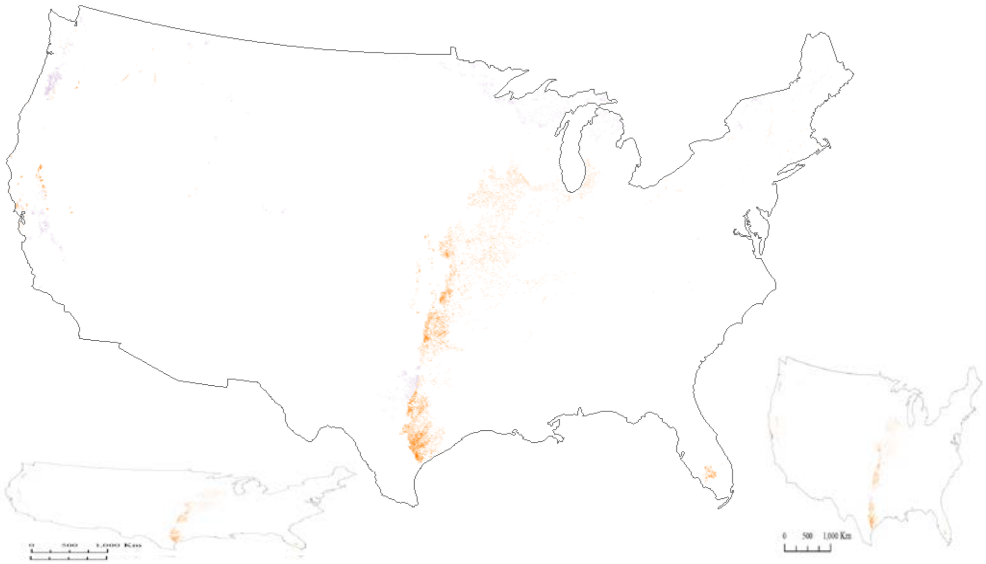
Lifecycle emissions [gCO_2e/MJ]



Cumulative jet fuel production [EJ/yr]

Required land areas


2050 food crop area
[Sohl et al. 2014]


Energy crop area
100% replacement of jet demand

Satisfying 100% of US jet fuel demand requires a 45% expansion in cultivated crop area

14-38% of US jet fuel demand could be satisfied by wastes & residues, and a 9-30% reduction in lifecycle GHG emissions from aviation

Summary

Key findings

100% of 2050 jet fuel demand could be satisfied by domestically produced aviation biofuels. But there may be decreasing marginal climate benefits of large fuel volumes.

Greatest climate benefit comes from waste & residue pathways, and lignocellulosic pathways that maximize total fuel yield (not jet fuel yield).

Publications

MIT master's thesis submitted in February 2018. Associated paper currently under revision for publication *[Galligan et al. (under review)].*

Global assessment published this year in *Energy Policy* *[Staples et al. (2018)].*

Next steps

A follow-on study could account for non-emissions climate impacts of large-scale LUC (e.g. albedo and evapotranspiration) *[Caiazzo et al. 2014].*

Acknowledgements

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MIT contributors

Timothy Galligan, Mark Staples, Raymond Speth, Steven Barrett

MIT LABORATORY FOR AVIATION AND THE ENVIRONMENT

Mark Staples
mstaples@mit.edu

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NREL
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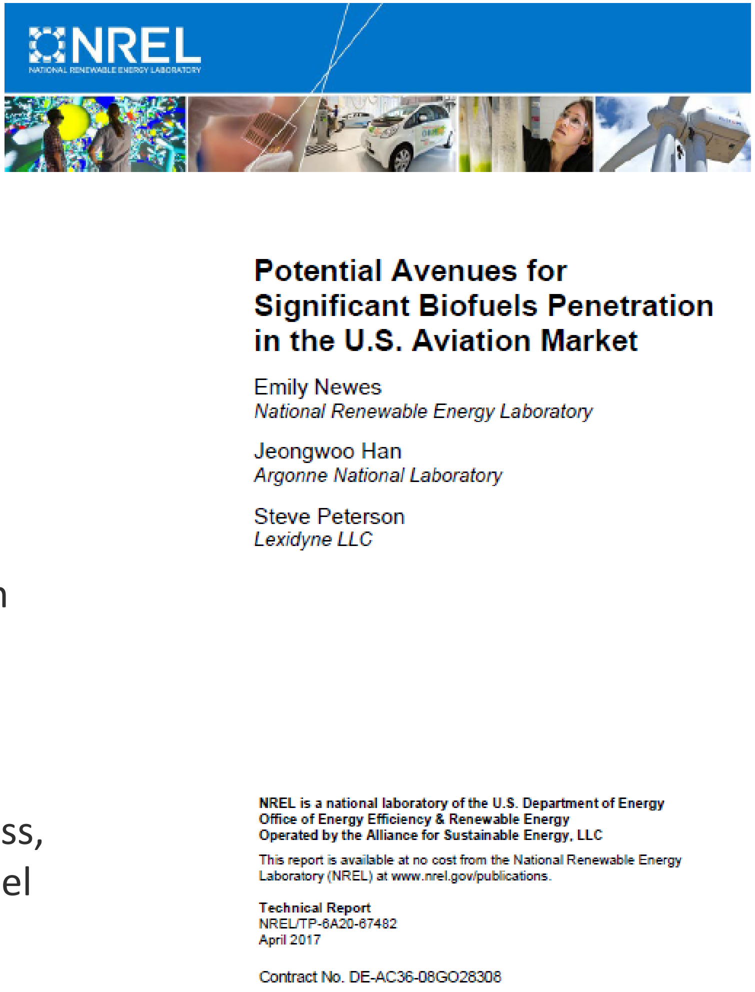
Future Aviation Biofuel Analysis Using The Biomass Scenario Model

Emily Newes
National Renewable Energy Laboratory
CAAFI Biennial General Meeting
December 5, 2018

Overview

Today's talk will:

- Provide a brief overview of the Biomass Scenario Model (BSM)
- Summarize findings from two articles that use the BSM to explore potential future aviation biofuels scenarios.
  - Newes, E., J. Han, and S. Peterson. "Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market." Golden, CO: National Renewable Energy Laboratory, 2017. http://www.nrel.gov/docs/fy17osti/67482.pdf.
  - Lewis, K., E. Newes, S. Peterson, M. Pearlson, E. Lawless, K. Brandt, D. Camenzind, et al. "U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons." *Biofuels, Bioproducts and Biorefining*, Accepted 2018. https://doi.org/10.1002/bbb.1951.



Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market

Emily Newes
National Renewable Energy Laboratory

Jeongwoo Han
Argonne National Laboratory

Steve Peterson
Lexidyne LLC

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Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

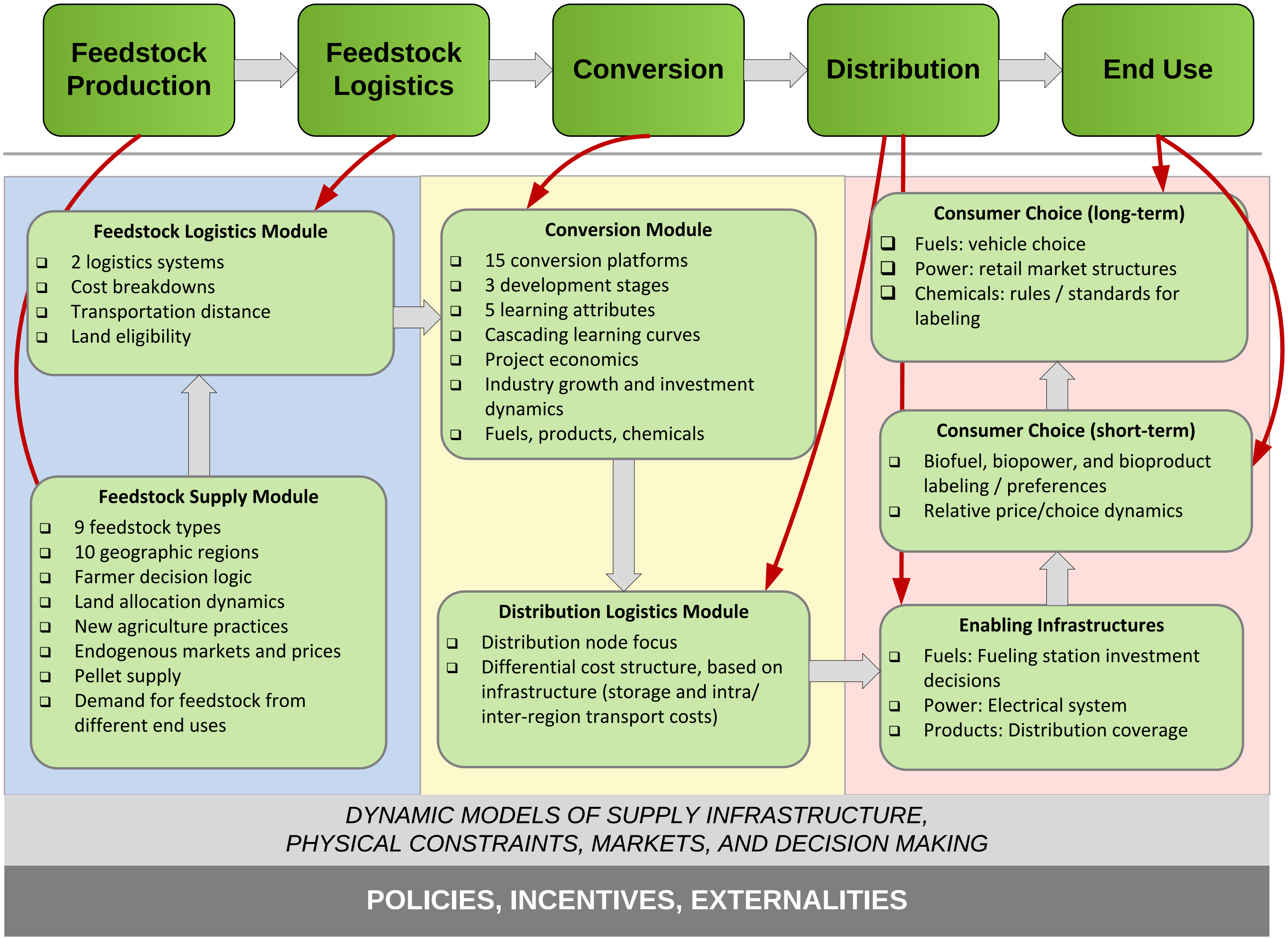
This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-6A20-67482
April 2017

Contract No. DE-AC36-08GO28308

Overview of the BSM

The BSM models the bioeconomy



SUPPLY CHAIN

Feedstock Production → **Feedstock Logistics** → **Conversion** → **Distribution** → **End Use**

Feedstock Logistics Module
- 2 logistics systems
- Cost breakdowns
- Transportation distance
- Land eligibility

Feedstock Supply Module
- 9 feedstock types
- 10 geographic regions
- Farmer decision logic
- Land allocation dynamics
- New agriculture practices
- Endogenous markets and prices
- Pellet supply
- Demand for feedstock from different end uses

Conversion Module
- 15 conversion platforms
- 3 development stages
- 5 learning attributes
- Cascading learning curves
- Project economics
- Industry growth and investment dynamics
- Fuels, products, chemicals

Distribution Logistics Module
- Distribution node focus
- Differential cost structure, based on infrastructure (storage and intra/ inter-region transport costs)

Consumer Choice (long-term)
- Fuels: vehicle choice
- Power: retail market structures
- Chemicals: rules / standards for labeling

Consumer Choice (short-term)
- Biofuel, biopower, and bioproduct labeling / preferences
- Relative price/choice dynamics

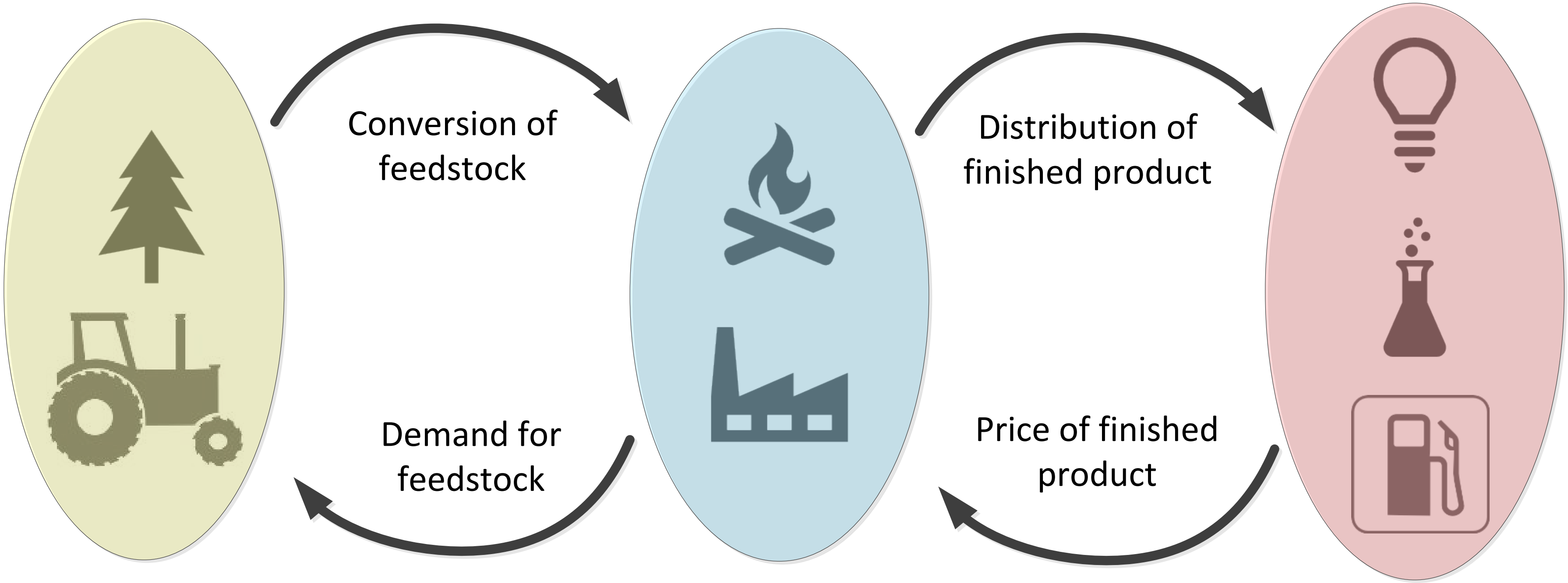
Enabling Infrastructures
- Fuels: Fueling station investment decisions
- Power: Electrical system
- Products: Distribution coverage

DYNAMIC MODELS OF SUPPLY INFRASTRUCTURE, PHYSICAL CONSTRAINTS, MARKETS, AND DECISION MAKING

POLICIES, INCENTIVES, EXTERNALITIES

System relationships drive progress across the bioeconomy

The BSM allows scenario exploration to support decision making highlighting **interactions across systems**, with nonlinearity, constant change, historical dependence, and evolving markets.



Conversion of feedstock

Distribution of finished product

Demand for feedstock

Price of finished product

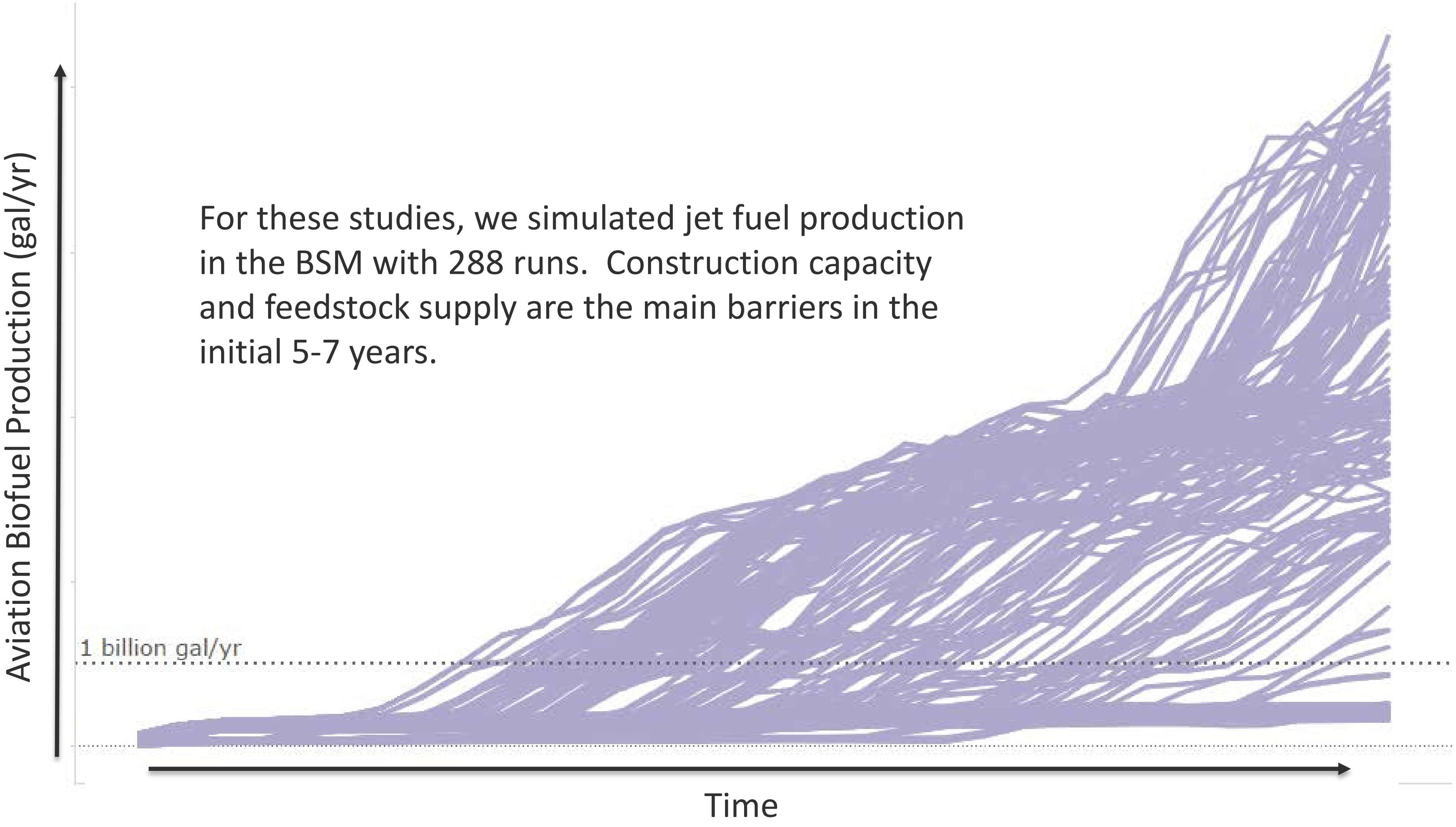
Simplistic representation of basic feedback between supply chain sectors

Potential Future Scenarios for Aviation Biofuel

Analysis Questions

- Is it possible to displace 30% of the jet fuel market (6 billion gallons) with biofuels by 2030? 2040?
- What are the characteristics of scenarios in which the aviation biofuel system, as modeled with current policy and prices, reaches 1 billion annual gallons of production in the near term?
- What would you have to assume to reach 1 billion annual gallons of aviation biofuel at an earlier date?

Wide Range of Jet Fuel Production Trajectories



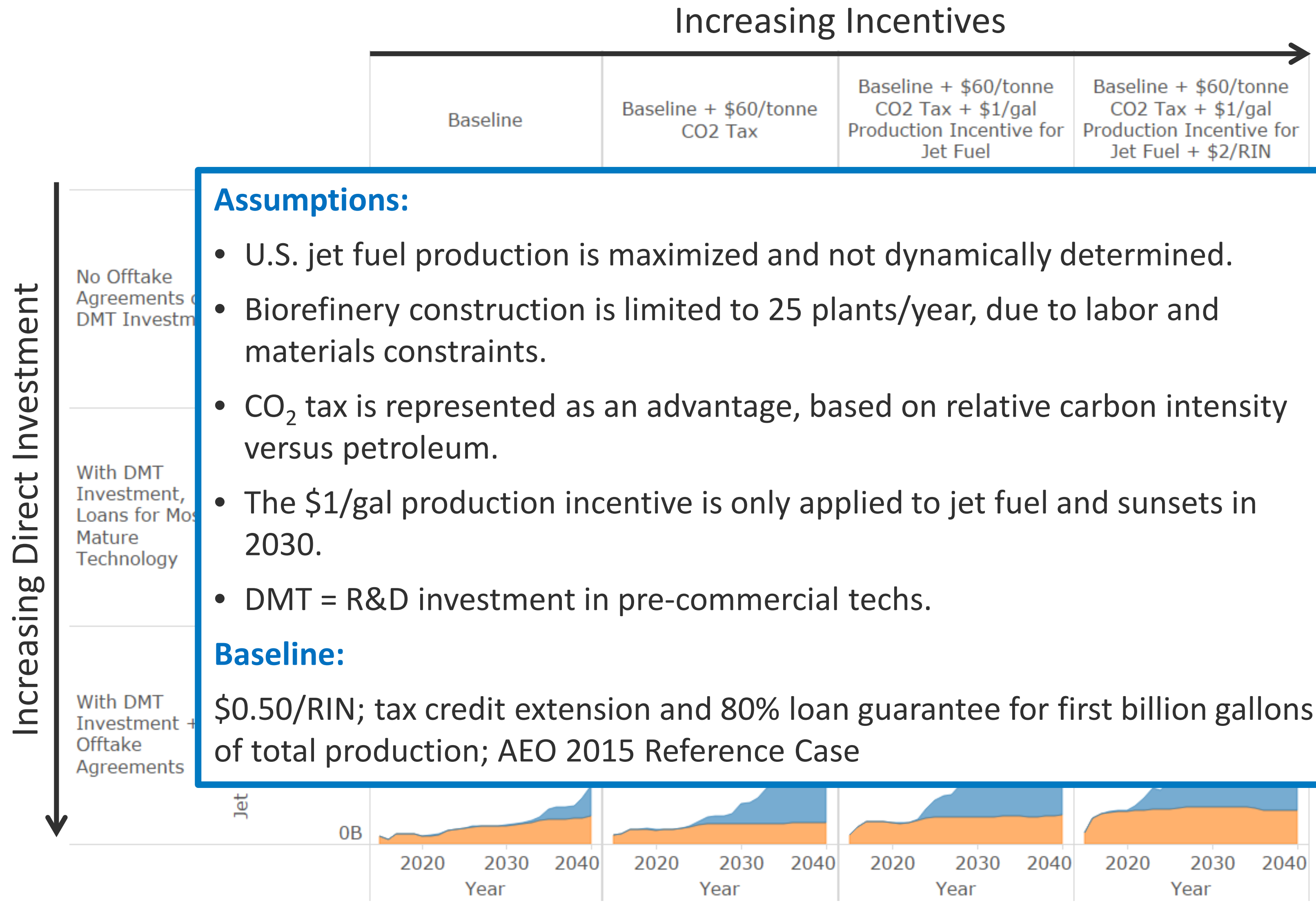
For these studies, we simulated jet fuel production in the BSM with 288 runs. Construction capacity and feedstock supply are the main barriers in the initial 5-7 years.

Source = Lewis et al. (Accepted 2018)

Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market

Newes, E., Jeongwoo H., and S. Peterson. "Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market." Golden, CO: National Renewable Energy Laboratory, 2017.

Analysis suggests 6 billion gallons of aviation biofuel by 2030 is possible with aggressive assumptions



Assumptions:

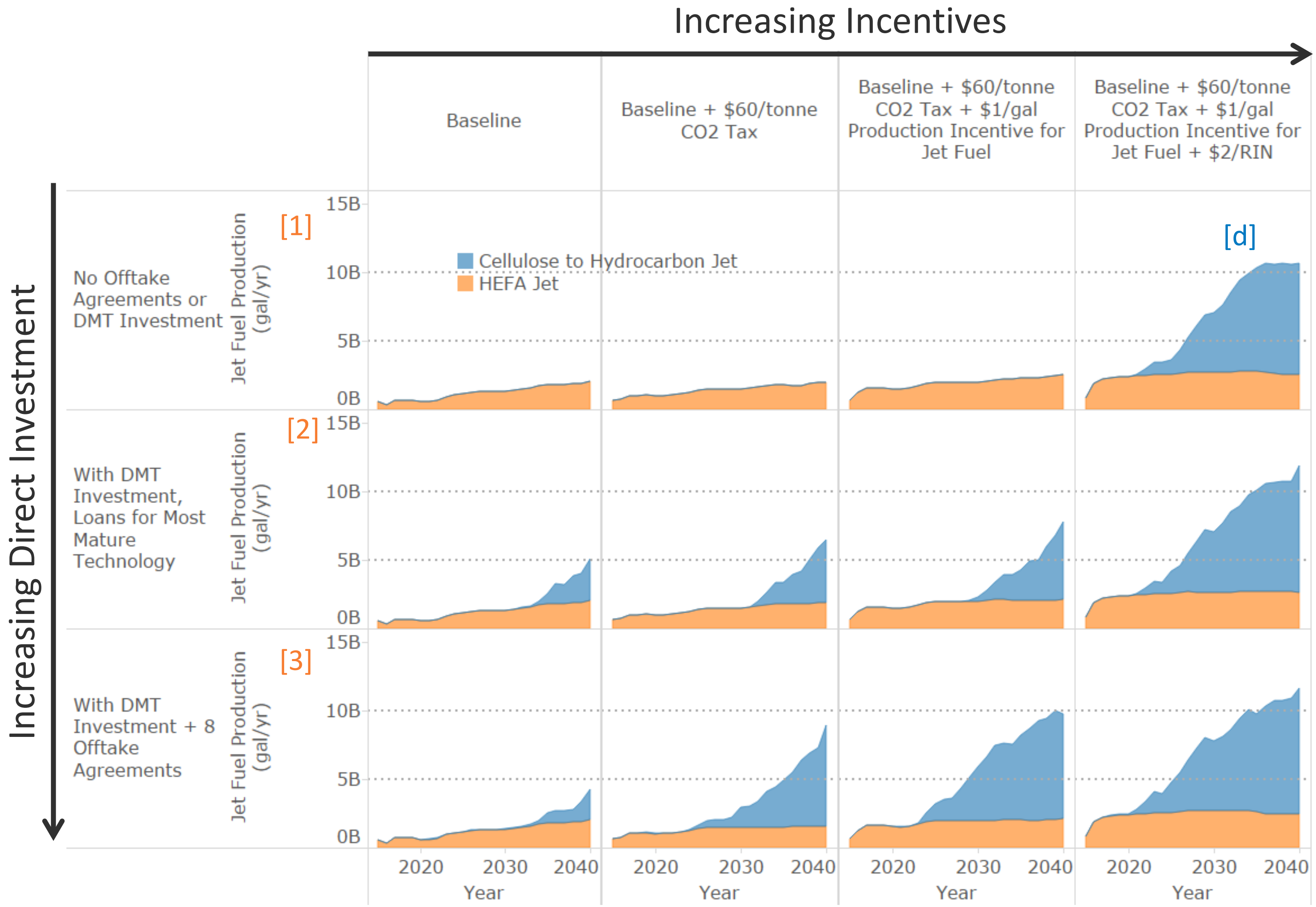
- U.S. jet fuel production is maximized and not dynamically determined.
- Biorefinery construction is limited to 25 plants/year, due to labor and materials constraints.
- CO_2 tax is represented as an advantage, based on relative carbon intensity versus petroleum.
- The $1/gal production incentive is only applied to jet fuel and sunsets in 2030.
- DMT = R&D investment in pre-commercial techs.

Baseline:

$0.50/RIN; tax credit extension and 80% loan guarantee for first billion gallons of total production; AEO 2015 Reference Case

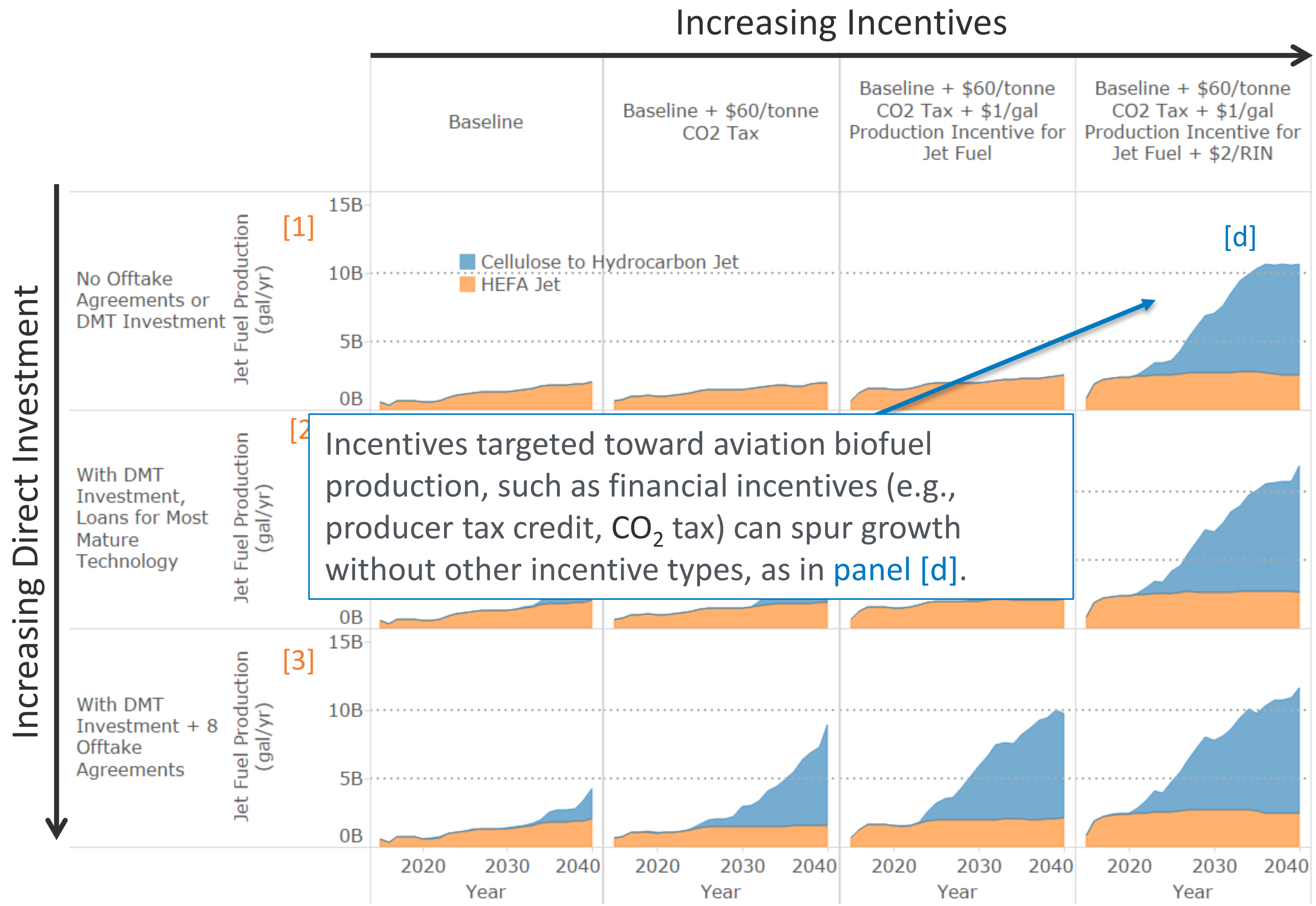
Source = Newes et al. (2017)

Analysis suggests 6 billion gallons of aviation biofuel by 2030 is possible with aggressive assumptions



Source = Newes et al. (2017)

Analysis suggests 6 billion gallons of aviation biofuel by 2030 is possible with aggressive assumptions

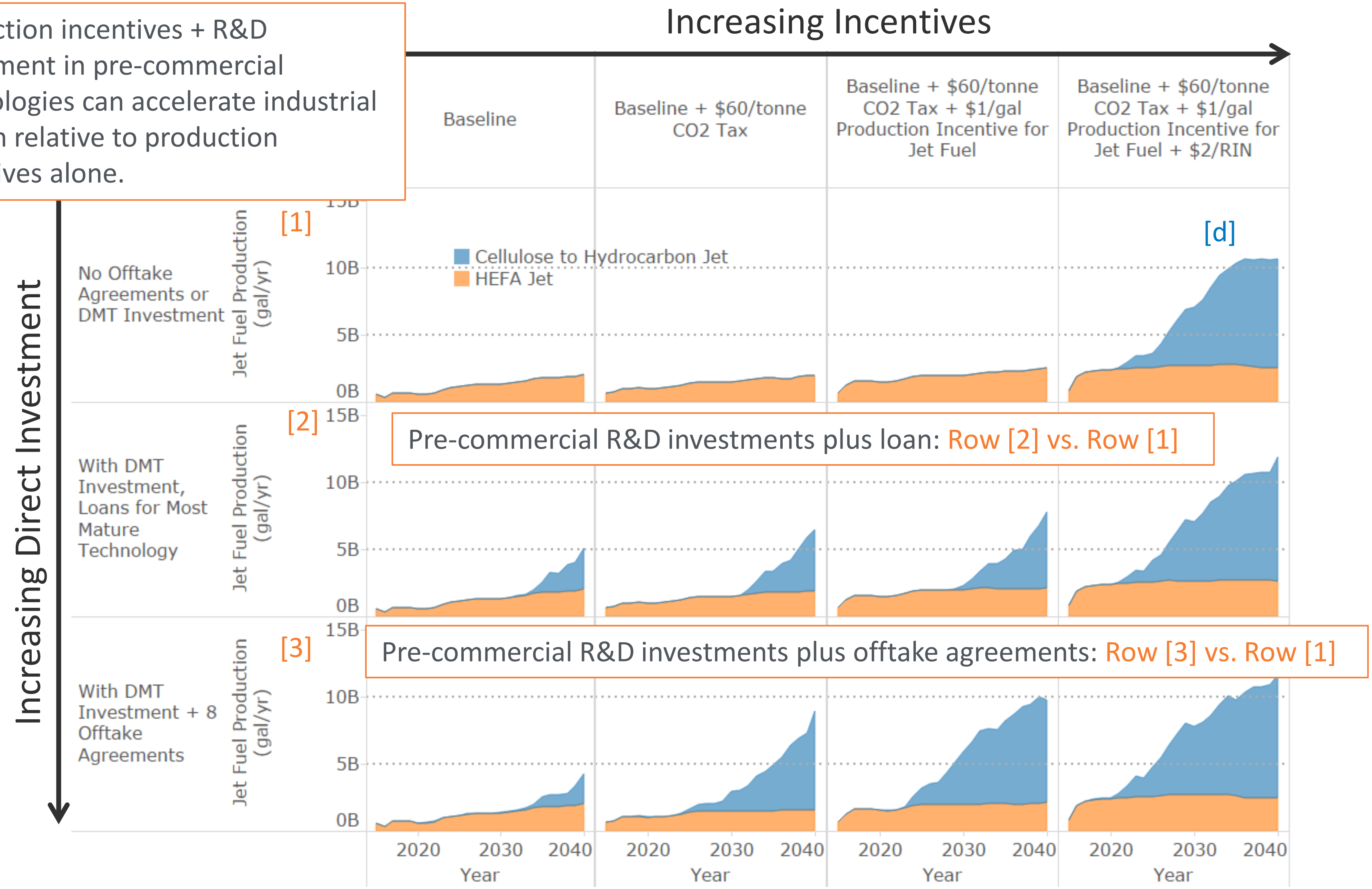


Incentives targeted toward aviation biofuel production, such as financial incentives (e.g., producer tax credit, CO_2 tax) can spur growth without other incentive types, as in panel [d].

Source = Newes et al. (2017)

Analysis suggests 6 billion gallons of aviation biofuel by 2030 is possible with aggressive assumptions

Production incentives + R&D investment in pre-commercial technologies can accelerate industrial growth relative to production incentives alone.



Pre-commercial R&D investments plus loan: Row [2] vs. Row [1]

Pre-commercial R&D investments plus offtake agreements: Row [3] vs. Row [1]

Source = Newes et al. (2017)

U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons

Lewis, K., E. Newes, S. Peterson, M. Pearlson, E. Lawless, K. Brandt, D. Camenzind, et al. “U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons.” *Biofuels, Bioproducts and Biorefining*, Accepted 2018.

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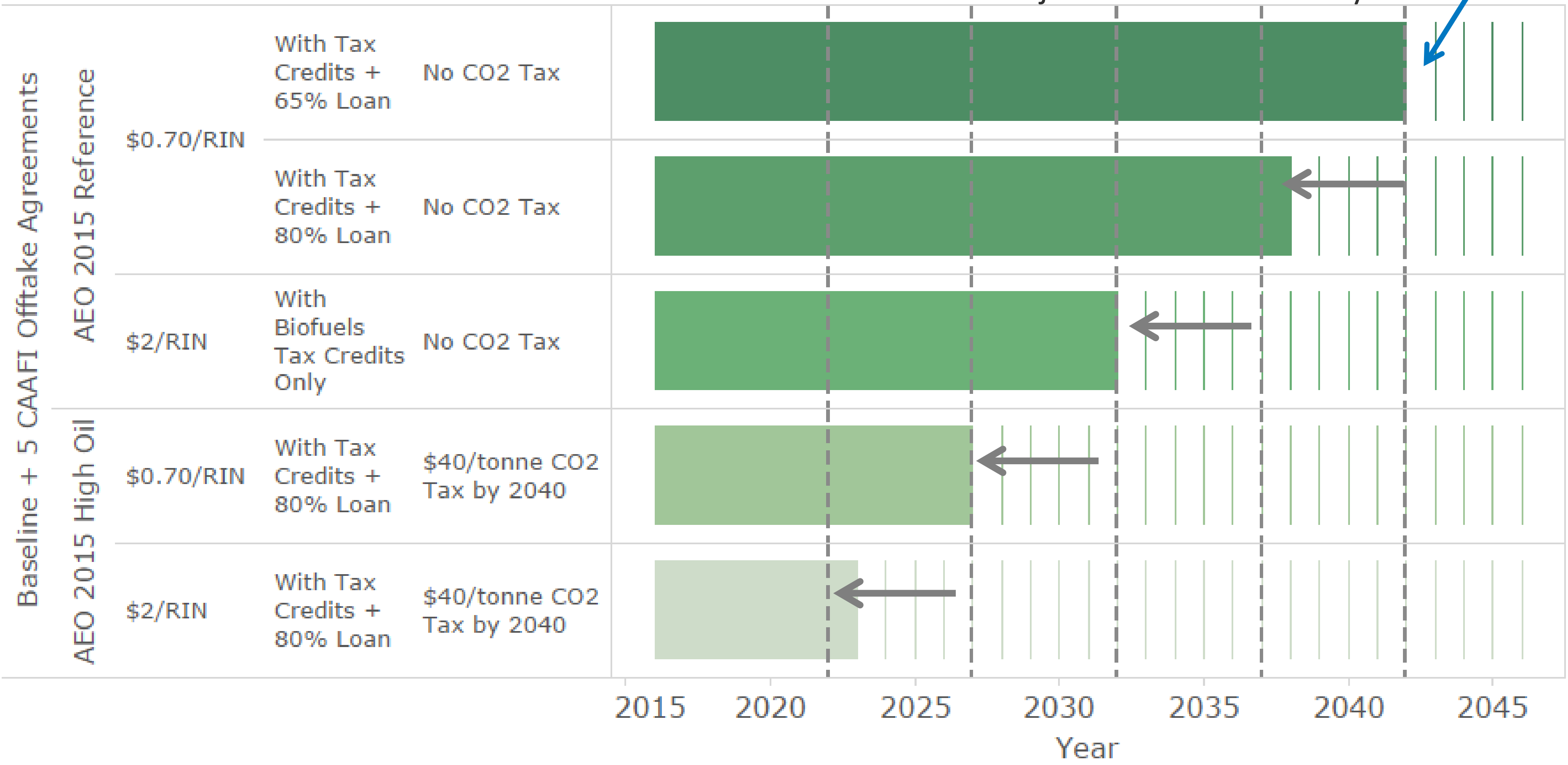
Necessary Assumptions for One Billion Gallons by _____ Year



With 2016 conditions continuing, 1 billion gallons of renewable jet fuel are reached by 2042

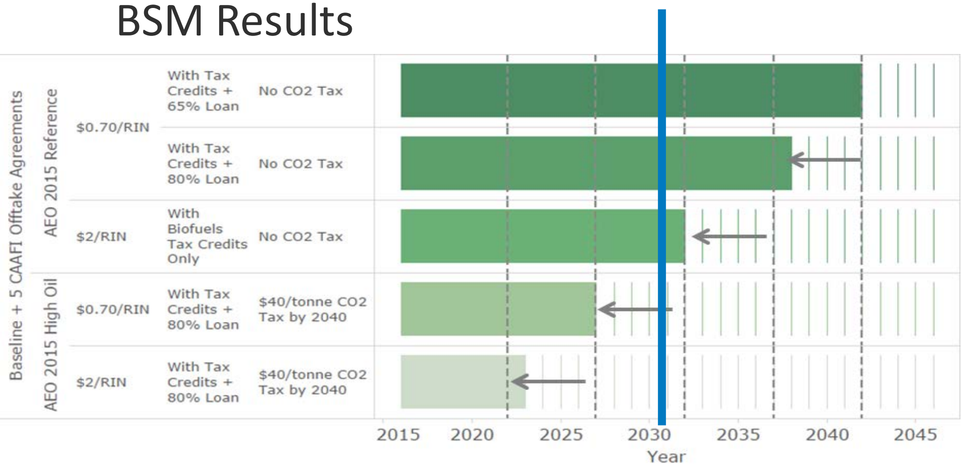
This figure shows possible scenarios that would accelerate reaching 1 billion gallons of renewable jet fuel production by 5, 10, 15, or 20 years.

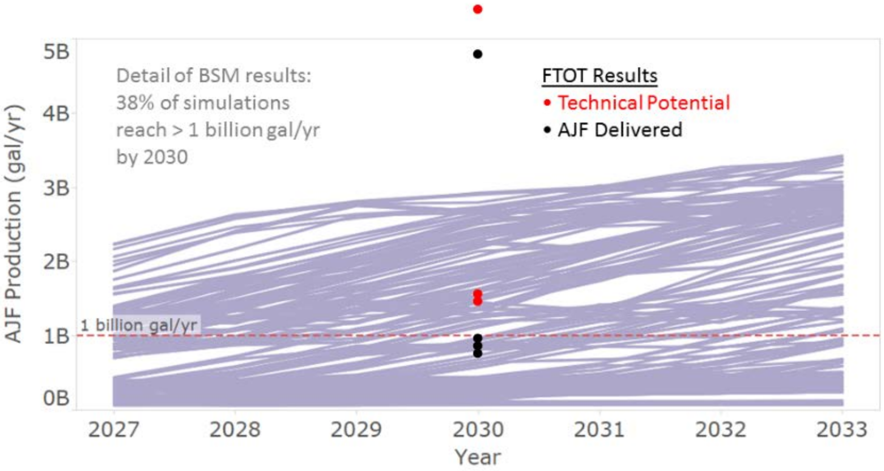
Source = Lewis et al. (Accepted 2018)

Future Alternative Jet Fuel Deployment

BSM Results

FTOT Scenario Year





- Analysis focused on two questions:
    1) How much alternative jet fuel (AJF) can be produced and how soon?
    2) What is the likely geospatial distribution of feedstock and fuel production and AJF delivery?
- Freight and Fuel Transportation Optimization Tool (FTOT) results for certain scenarios are well within BSM results.

Key Takeaways

Newes et al. (2017)

- Construction/build out capabilities and development of the feedstock market are key bottlenecks in the initial years.
- Displacement of jet fuel by 30% with biofuels by 2030 is possible, but several factors related to policy design—in the absence of high oil prices or policy uncertainty—contribute to the timing and magnitude of aviation biofuels production:
  - Incentives targeted toward jet fuel production, such as financial incentives (e.g., a producer tax credit or a CO_2 tax) could be sufficient to reach six billion gallons.
  - R&D investment in pre-commercial technologies is needed to reduce the cost of production through learning-by-doing.
  - Reduction of investment risk through loan guarantees and offtake agreements may allow production to ramp up more quickly through accelerating industry learning.

Lewis et al. (Accepted 2018)

- Both BSM and FTOT suggest that
  - 200 million to 1 billion gallons per year of alternative jet fuel production are possible by 2030 given multiple incentives and a favorable investment climate.
  - However, different capital costs and technology maturation rates in the two models will affect deployment of different fuel production technologies and therefore the feedstocks needed.
  - Further collaboration on these modeling approaches would reduce methodological blind spots while providing insights into future industry trajectories.

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Co-authors:

“Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market”

- Jeongwoo Han (formerly Argonne National Laboratory)
- Steve Peterson (Lexidyne LLC and Dartmouth College)

“U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons”

- Kristin Lewis, Steve Peterson Matthew Pearlson, Emily Lawless, and Andrew Malwitz (Volpe)
- Kristin Brandt, Dane Camenzind, Michael Wolcott (Washington State University)
- James Hileman, Nathan Brown (U.S. Federal Aviation Administration)
- Zia Haq (Bioenergy Technologies Office)

BSM Team:

Brian Bush, Daniel Inman, Amy Schwab, Dana Stright, Steve Peterson, Laura Vimmerstedt

Thank you!

Emily.Newes@nrel.gov

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A Snapshot in Time - Optimal Scenario Flow Analyses with the Freight and Fuel Transportation Optimization Tool (FTOT)

Kristin C. Lewis, Ph.D.

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The National Transportation Systems Center

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What is the Freight / Fuel Transportation Optimization Tool?

- ❑ Flexible scenario-testing tool designed to analyze future freight and fuel scenarios for various commodities, datasets, and assumptions
- ❑ Optimizes routing and flows at scenario level using a Geographic Information System (GIS) module and an optimization module
- ❑ Multimodal network: road, rail, waterway, pipeline, intermodal facilities
- ❑ Outputs of optimized scenarios:
  - **material/commodity flows**
  - **costs**
  - **CO_2 emissions**
  - **fuel burn**
  - **number of vehicle trips**
  - **distance, vehicle miles traveled**

Supply Chain Oriented Use Cases

Case 1

Origin a,b,c

▼

Destination x, y, z

Case 2

Raw material origin a, b, c

▼

Processor facility p, q, r

▼

Destination x, y, z

Case 3

Raw material origin a, b, c

▼

Processor p,q,r (FTOT-generated candidates)

▼

Destination facility x, y, z

Case 4

R. m. origin a, b, c

Commodity a, b, c

Time a, b, c

▼

Variable intermediate supply chain steps

▼

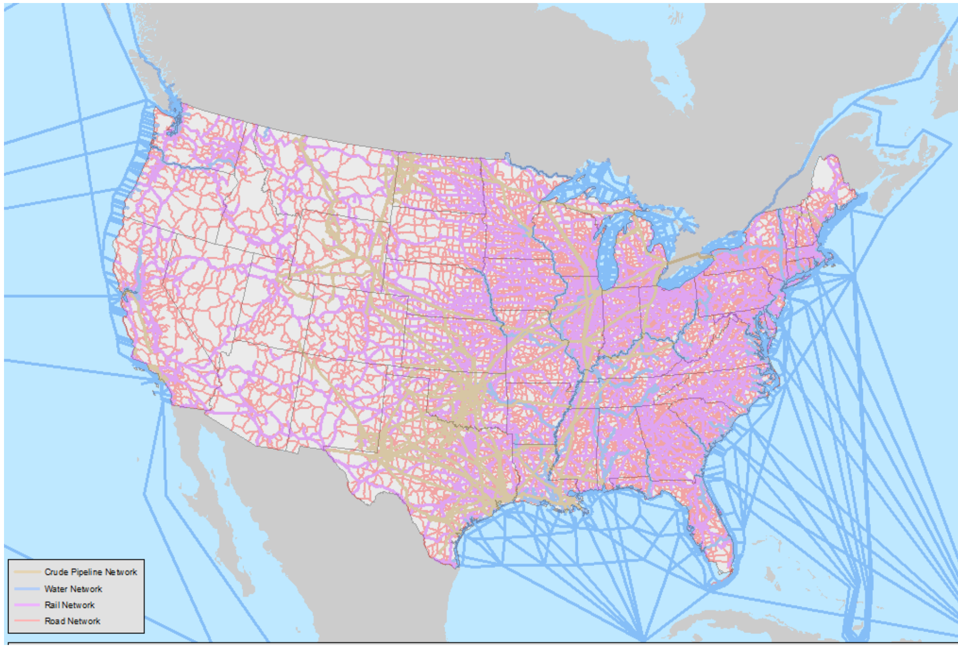
Destination a, b, c

Commodity a, b, c

Time a, b, c

Optimized flows over multimodal network

- Optimized for cost based on:
  - Per ton mile or tariff cost
  - Transloading cost
  - Impedances/weightings
  - Facility characteristics (size, conversion factors, capex)
  - Demand at destinations
  - Modal flow capacity



Future Alternative Jet Fuel Deployment

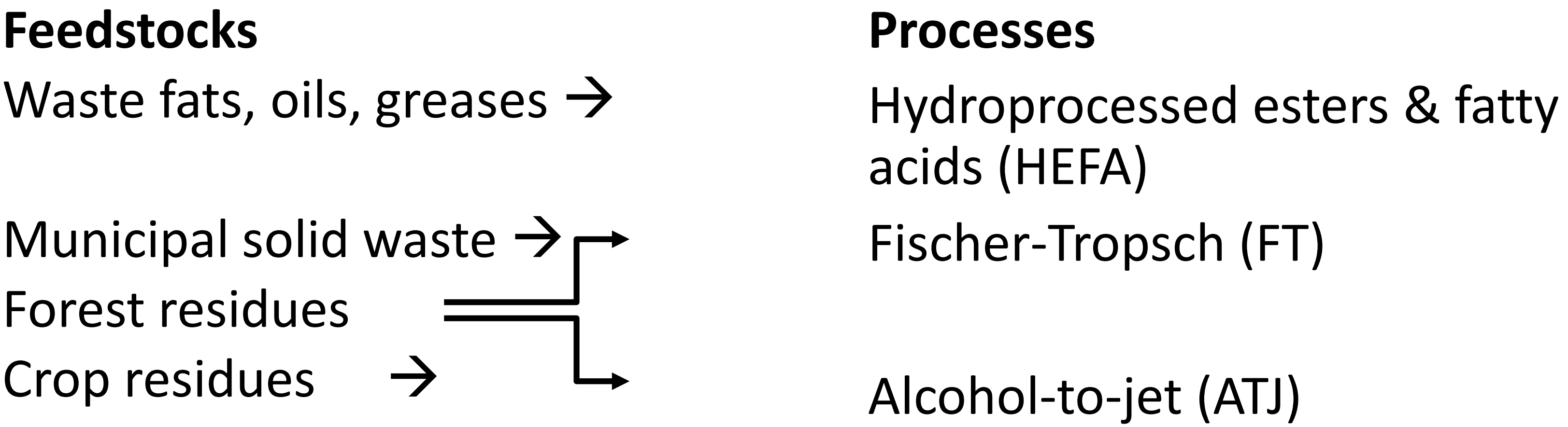
Goal: Understand potential near term deployment of AJF based on waste/residue feedstocks and ASTM-qualified processes.

1) How much AJF can be produced and how soon?
2) What is the likely geospatial distribution of feedstock and fuel production and AJF delivery?

Approach:

- ❑ Identify future "snapshot" of feedstock availability/ conversion tech with BSM scenarios and ASCENT feedstock projections.
- ❑ Explore flow optimization based on:
  - Range of feedstock availability.
  - Variation in incentives to drive transport.
- ❑ Provides screening-level estimate of cost-effective fuel transport patterns for particular time/conditions based on BSM modeling.

Scenario Elements



Feedstocks

Waste fats, oils, greases →

Municipal solid waste →

Forest residues

Crop residues →

Processes

Hydroprocessed esters & fatty acids (HEFA)

Fischer-Tropsch (FT)

Alcohol-to-jet (ATJ)

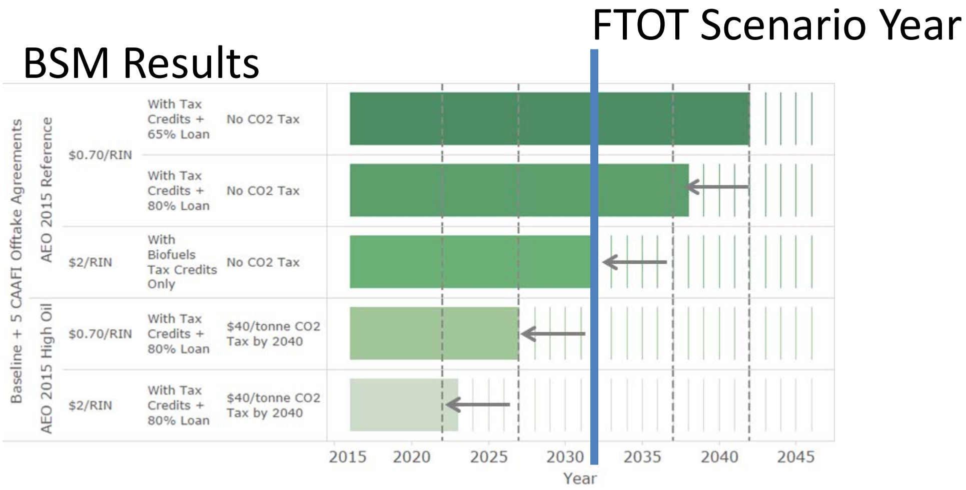
Production at county level provided via ASCENT collaboration

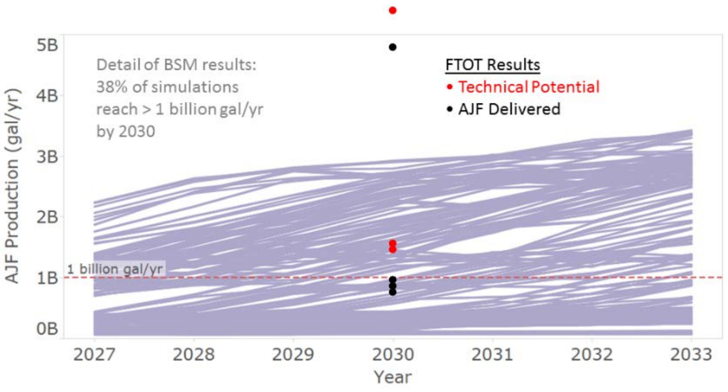
Conversion efficiency and product slate based on ASCENT collaboration

Destinations

- ❑ Small, medium, large hub airports

Future Alternative Jet Fuel Deployment

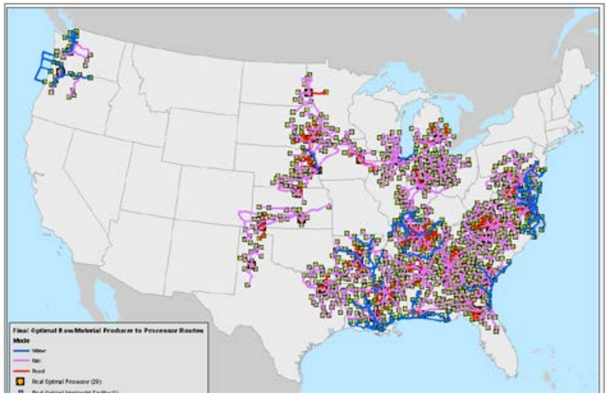




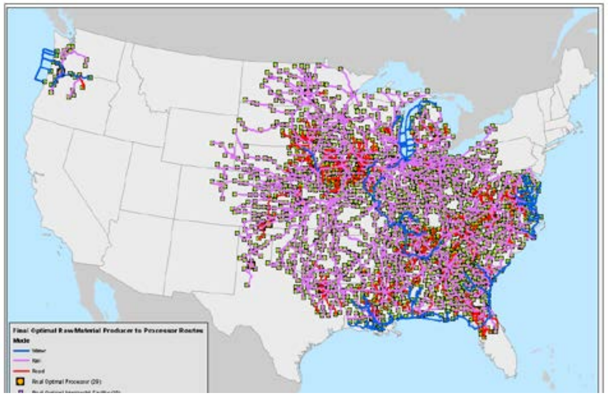
- FTOT results for Scenarios 1-3 fall within BSM scenario trajectories.
- FTOT showed more ATJ than in BSM results, driven by lower capex in FTOT due to the option to convert existing ethanol refineries at lower capex than greenfield facilities assumed in BSM.
- Based on FTOT analysis, cost effective to move close to a billion gallons of AJF given strong financial incentives.

Geographic patterns

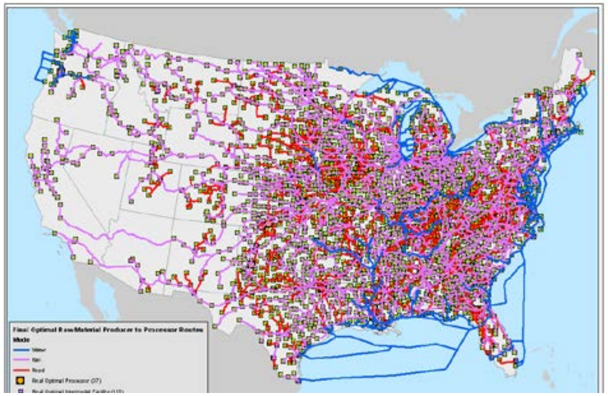
Feedstock to Conversion Facility



Low incentive

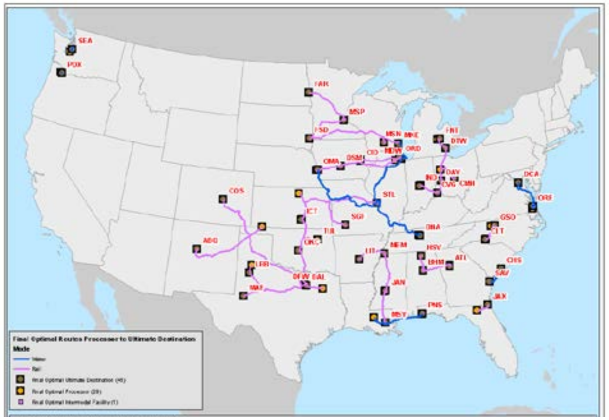


Medium incentive

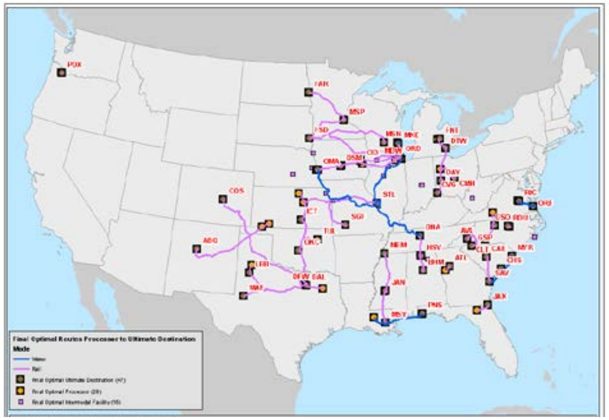


High incentive

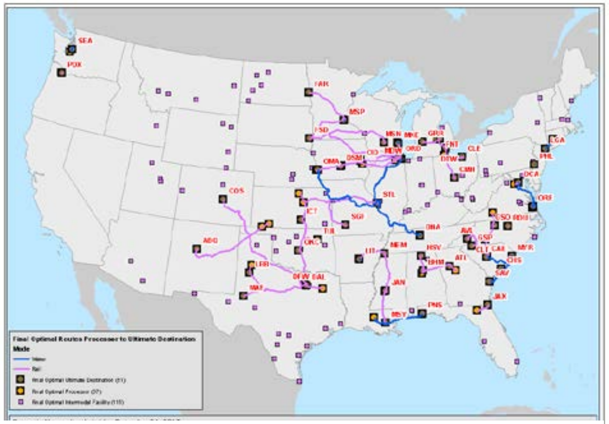
Conversion Facility to Airport



Low incentive



Medium incentive



High incentive

Future Alternative Jet Fuel Deployment

- Transport costs = $0.69-0.84/gallon of delivered AJF
- Capital costs (e.g., greyfield versus greenfield development) & technology maturation rates affect relative importance of conversion types.
- Geographic variation in incentives (e.g., LCFS) could strongly alter modeled flow patterns.
- FTOT “optimal” solution may underestimate actual costs and emissions.
- Reaching a billion gallons of AJF using only FT, HEFA, and ATJ by 2030 will require concerted policy support and incentives.
- Future work would focus on greater alignment and leveraging of complementarity between the two models.

Thank you!

Kristin.lewis@dot.gov

Current Volpe Team:
Gary Baker, Alexander Oberg (GIS Team)
Olivia Gillham, Scott Smith (Operations Research Analysis)
Matthew Pearlson (SGT Contractor)

Sponsor:
FAA - Office of Environment and Energy
    Nate Brown, Jim Hileman
Dept. of Energy – Policy Office
    Diana Bauer
U.S. Navy - Office of Naval Research (former)
    Sharon Beerman-Curtin

Reference:

Lewis, K., E. Newes, S. Peterson, M. Pearlson, E. Lawless, K. Brandt, D. Camenzind, et al. "U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons." *Biofuels, Bioproducts and Biorefining*, Accepted 2018. https://doi.org/10.1002/bbb.1951.