Alternative jet fuel (AJF) LCA for ICAO's CORSIA
&
2050 AJF production potential in the US

Project 1

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AVIATION SUSTAINABILITY CENTER

Carbon Offsetting and Reduction Scheme for International Aviation

- In October 2016, ICAO agreed to mitigate CO_2 emissions from international aviation
- From 2021, airlines will have to buy CO_2 offsets for emissions beyond average emissions p.a. in 2019 and 2020
- Offsets can be bought from the open market – offset eligibility criteria are under development
- Voluntary participation by States until 2026, followed by mandatory participation (with exceptions) from 2027 to 2035
- Use of sustainable AJF reduces airlines offsetting requirements

Alternative Fuels Task Force

AFTF to determine how AJF should be included under CORSIA

>80 international technical experts from academia, government, industry, and environmental NGOs

AFTF method for “core” LCA (non-LUC) emissions for CORSIA:

- Scope
- System boundary
- Emissions species, functional units
- Co-product allocation
- Fossil fuel baseline

Calculation of LCA values

Focus first on ASTM approved, low LUC risk AJF pathways

Technology	Feedstock
Fischer-Tropsch (FT)	Agricultural residues
	Forestry residues
	Municipal solid waste
Hydroprocessed esters and fatty acids (HEFA)	Waste tallow
	Used cooking oil
	Palm fatty acid distillate
	Corn oil
	Tall oil
Alcohol (iBuOH)-to-jet (ATJ)	Agricultural residues
	Forestry residues

AFTF works in a collaborative manner

Argonne NATIONAL LABORATORY

universiteit hasselt

European Commission Joint Research Centre

SENASA

UNIVERSITY OF TORONTO

Calculation of LCA values

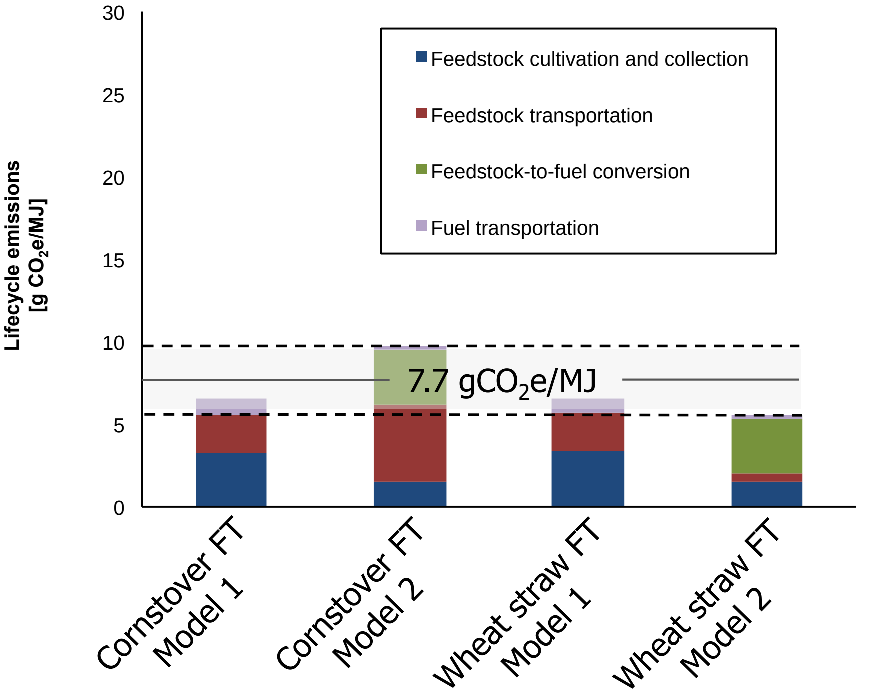
Ex. 1: FT from agricultural residues

Data from 2 models, 2 feedstocks compared

Differences in LCA results due to:

- Greater elec. req'd for FT gasification & synthesis in data from Model 2
- Greater diesel req'd for feedstock collection in data from Model 1
- Differences in feedstock and fuel transp. modes & distances

89-94% reduction in GHGs compared to conv. jet (89 gCO_2e/MJ)



Variability ≤10% of the conv. jet baseline, therefore a single LCA value is selected

Calculation of LCA values

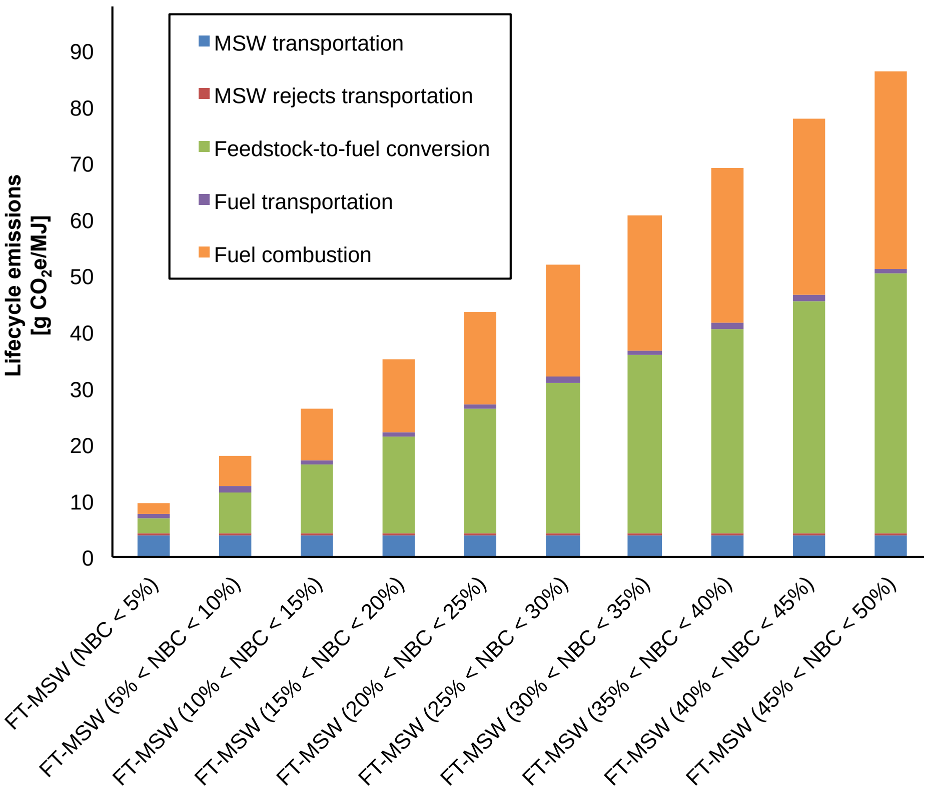
Ex. 2: FT from MSW

Differences in LCA results due to:

- Biogenic C content of MSW feedstock
- Avoided landfilling and recycling credits (not reflected here)

Variability >10% of conv. jet fuel baseline (8.9 gCO_2e/MJ)

Therefore, multiple LCA values are defined on the basis of technology or operational decisions



Methodological challenges

System boundary definition for ag. residues

Ag. residue removal may require additional N fertilizer to be applied, leading to N_2O emissions

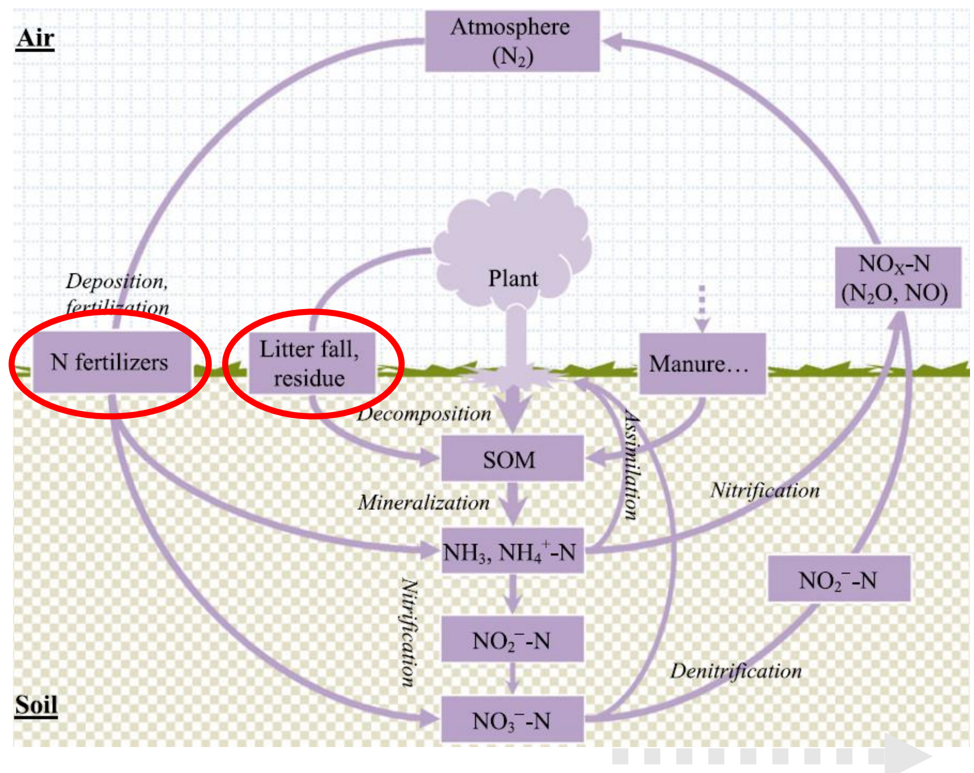
Emissions from nutrient replacement treated inconsistently in AFTF data

AFTF approach

Exclude N replacement emissions:

- Consistent with AFTF attributional LCA method
- Fertilizer over-application means N replacement is not always req'd

Nitrogen cycle



Methodological challenges

System boundary definition for co-products & by-products

<u>Co-products:</u> feedstock generation is intentional, therefore upstream emissions **are** included in LCA

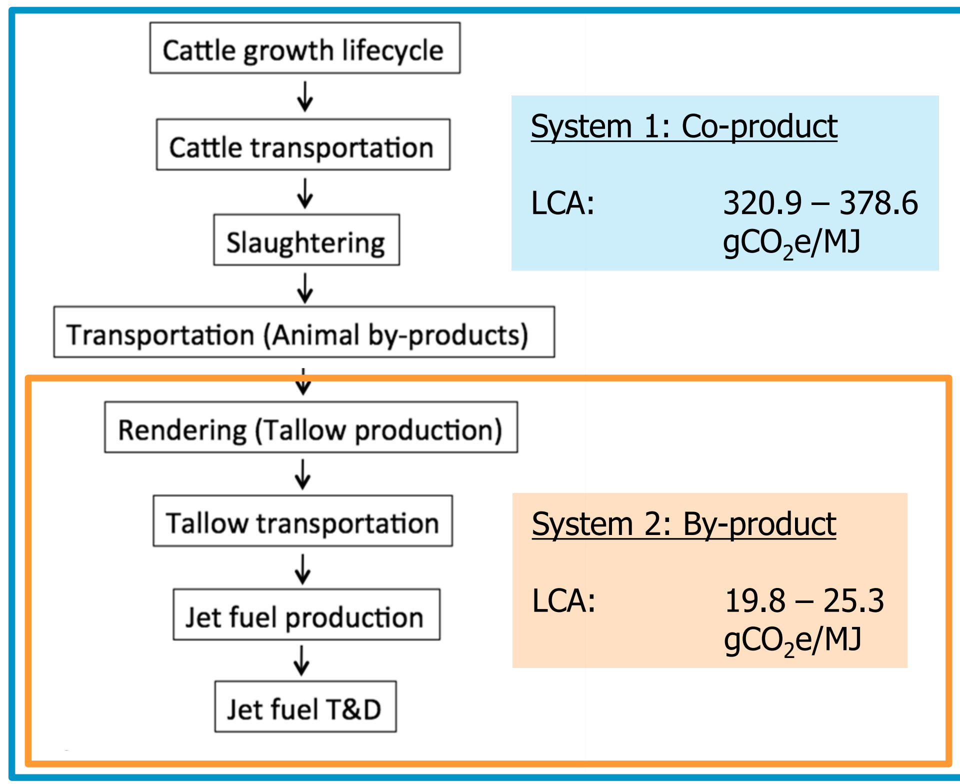
<u>By-products:</u> feedstock generation is incidental, therefore upstream emissions **are not** included in LCA

<u>AFTF approach</u>

Feedstocks classified as co- or by-products on the basis of economic contribution to value chain

Similar to approach of California ARB

<u>Example:</u> Tallow HEFA



Summary: ICAO AFTF project

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Recent accomplishments

- This month default LCA values proposed by AFTF for 8 waste and residue feedstock-to-fuel pathways will be presented to ICAO Steering Group
- Methodological LCA issues (eg. system boundary issues discussed here) are being addressed as they are identified

Publications

- In July 2017, AFTF analysis that quantified the potential for AJF to mitigate aviation CO_2 emissions was submitted to *Energy Policy*

Next steps

- Calculation of LCA values for non-waste and residue pathways to be included in CORSIA before the end of CAEP/11 cycle

2050 AJF potential in the US

During ICAO CAEP/10 MIT carried out a "Fuel Production Assessment"

- Assessed potential reductions in global aviation CO_2 emissions from AJF by 2050
- Useful for policy-making, but results are specific to international aviation

Goal: Quantify the potential to mitigate aviation lifecycle GHG emissions through the use of AJF in the *US context*

Scope: 2050 US production potential and associated GHG emissions of AJF derived from:

- Cultivated energy crops
- Agricultural and forest residues
- Waste fats, oils & greases (FOG)
- Municipal solid waste (MSW)

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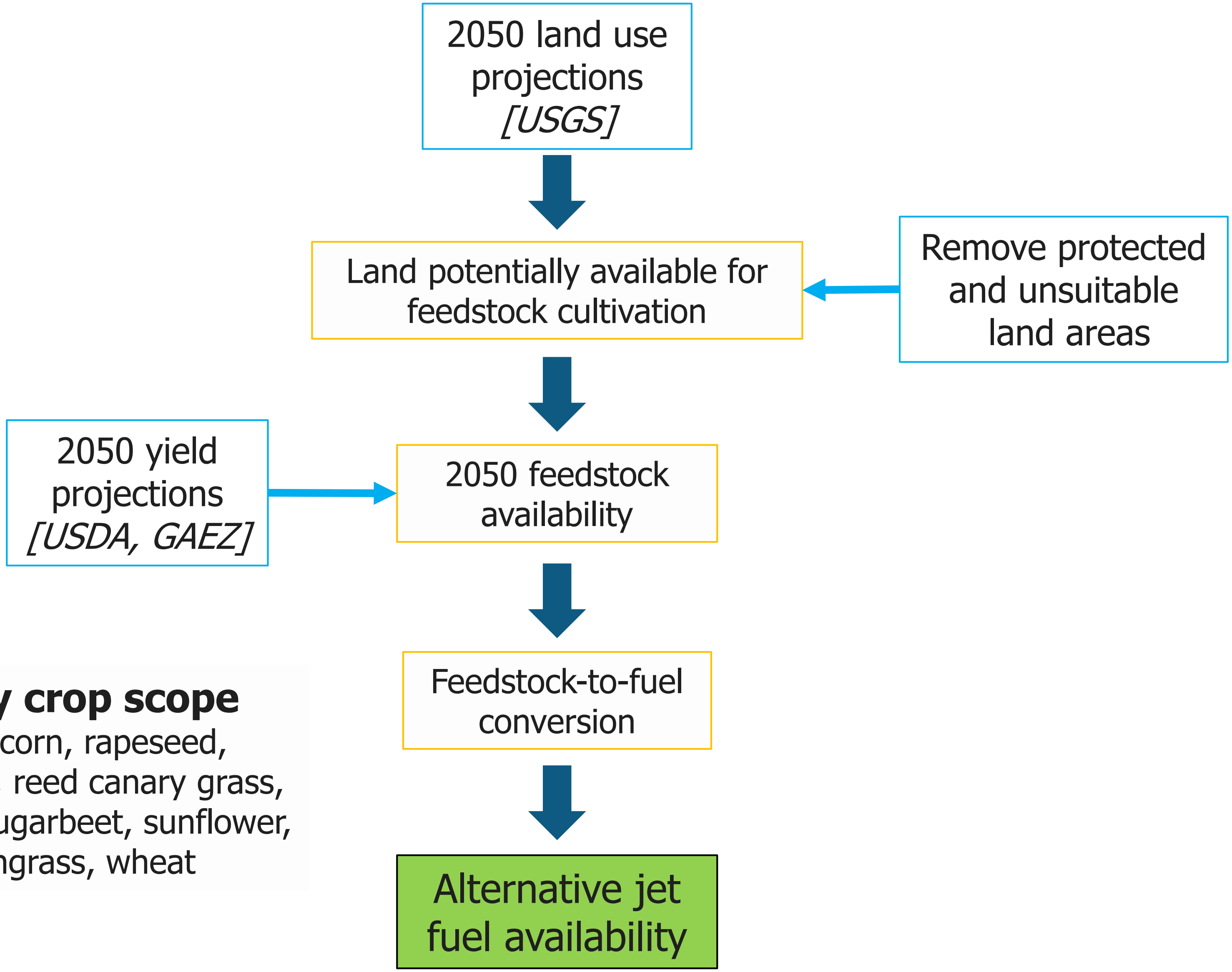
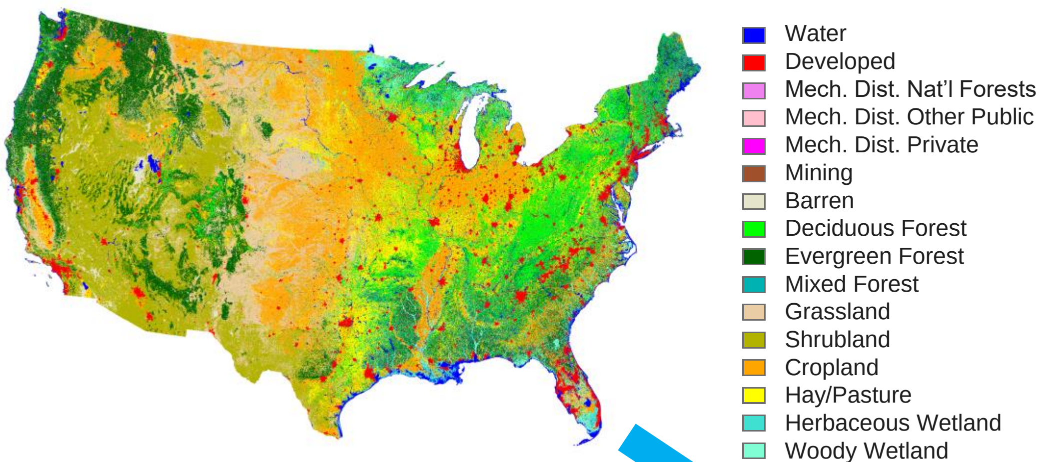
Cultivated energy crops

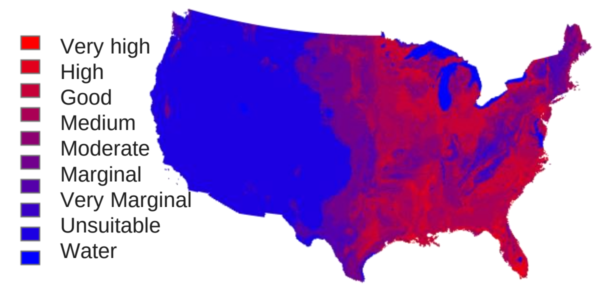


Energy crop scope
canola, corn, rapeseed, miscanthus, reed canary grass, soybeans, sugarbeet, sunflower, switchgrass, wheat

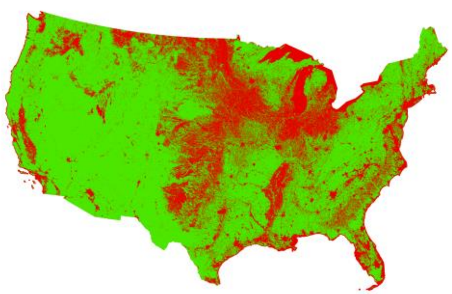
Cultivated energy crop land areas



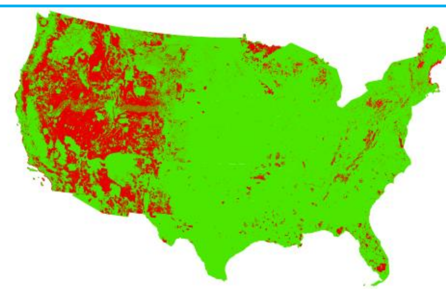
2050 land use projection
(USGS)



Remove areas unsuitable for cultivation on a crop-by-crop basis
[GAEZ]

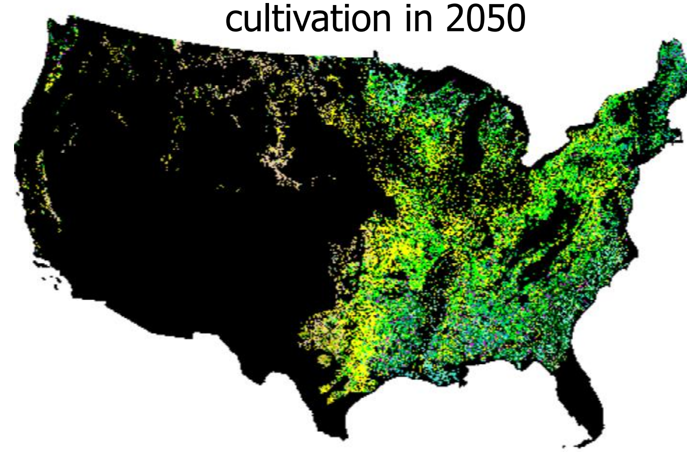


Remove areas projected for other uses
[USGS]



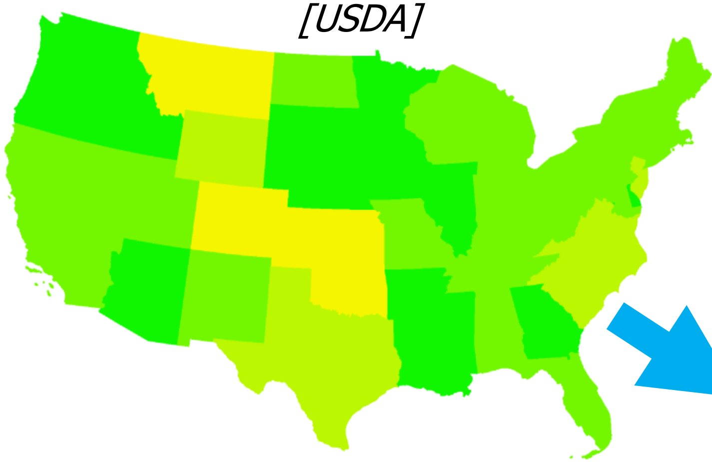
Remove protected areas
[USGS]

Land areas potentially available for energy crop cultivation in 2050

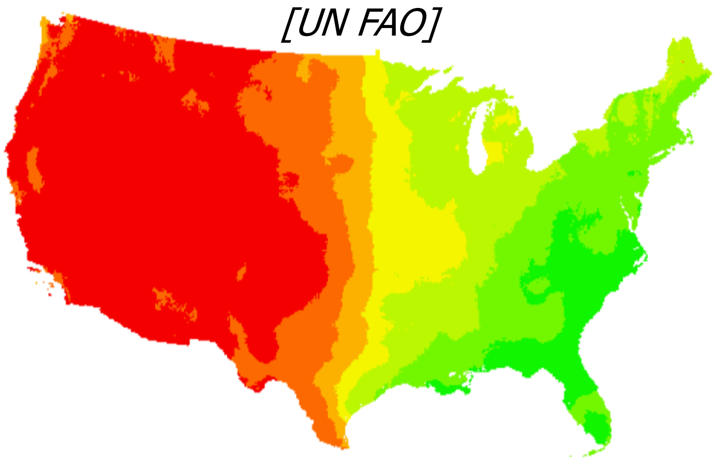


Cultivated energy crop yields

Extrapolated 2050 yield by crop in each state *[USDA]*

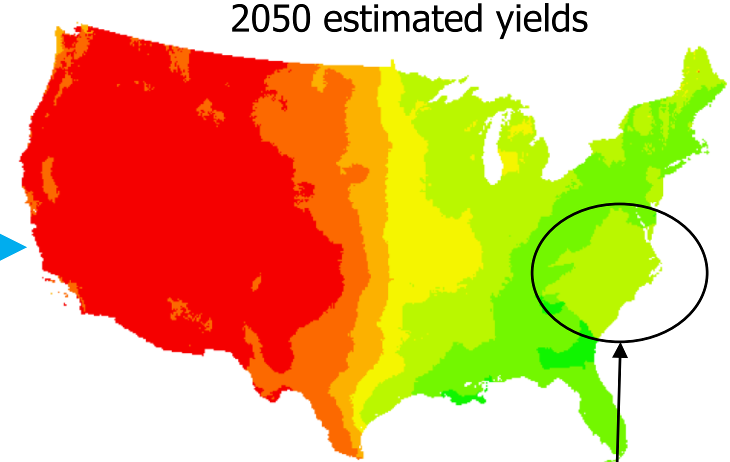


Agro-climatically attainable rain-fed yield *[UN FAO]*



Take lower value

2050 estimated yields



Yield limited by extrapolated data

Corn grain (kg/ha)

0 - 1,206
1,206.000001 - 3,552
3,552.000001 - 6,211
6,211.000001 - 8,539
8,539.000001 - 10,449
10,449.00001 - 12,543
12,543.00001 - 15,193

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- **Waste fats, oils & greases (FOG)**
- **Municipal solid waste (MSW)**

Residues and wastes

	Agricultural & forest residues	Waste FOGs	MSW
Feedstock availability	• Crop production *[USDA, energy crop analysis]* • Forestry and processed wood production *[USFS]*	• Livestock/tallow, waste grease/UCO production based on 2050 population *[USDA]*	• MSW generation based on 2050 population *[IEA ETP]*
Availability for AJF production	• Residue fraction of crops/forestry; scrap portion of wood processing • Sustainable collection rates • Exclude fraction diverted for char/pellets, on-site energy	• Tallow portion of livestock slaughtering & processing • UCO collection rates • Exclude fraction used for feed, oleochemical & other uses	• Landfilled portion by material *[EPA]* • Energy content by material *[IEA]*

Fuel pathways

Pathway	Feedstock category	Feedstocks	Source
HEFA	Oil	Canola, rape, soy, sunflower, tallow, UCO	Pearlson et al. (2013)
Alcohol to Jet	Sugar, starch	Corn, sugarbeet, wheat	Staples et al. (2014)
Fischer-Tropsch	Lignocellulose	Reed canary grass, miscanthus, switchgrass, crop and forestry residues, MSW	Stratton et al. (2011)

Climate impacts

LCA emissions tracked for each feedstock-to-AJF pathway

- CAEP 10 projected 2050 LCA emissions

Soil and plant matter carbon content changes attributed to fuel and amortized over 30 years

- GTAP emissions factor model for land use change emissions

MSW diverted from landfills without gas recovery credited for avoided methane emissions

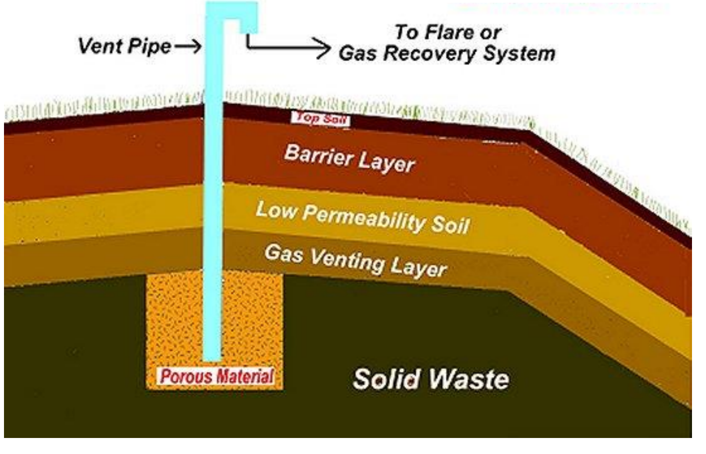


Image: http://www.ohswa.org/facilities/regional-landfill/landfill-plan/landfill-cap/

Scenarios

Economic and population projections based on IPCC Special Report on Emissions (SRES) A1B, A2, B1, B2 scenarios

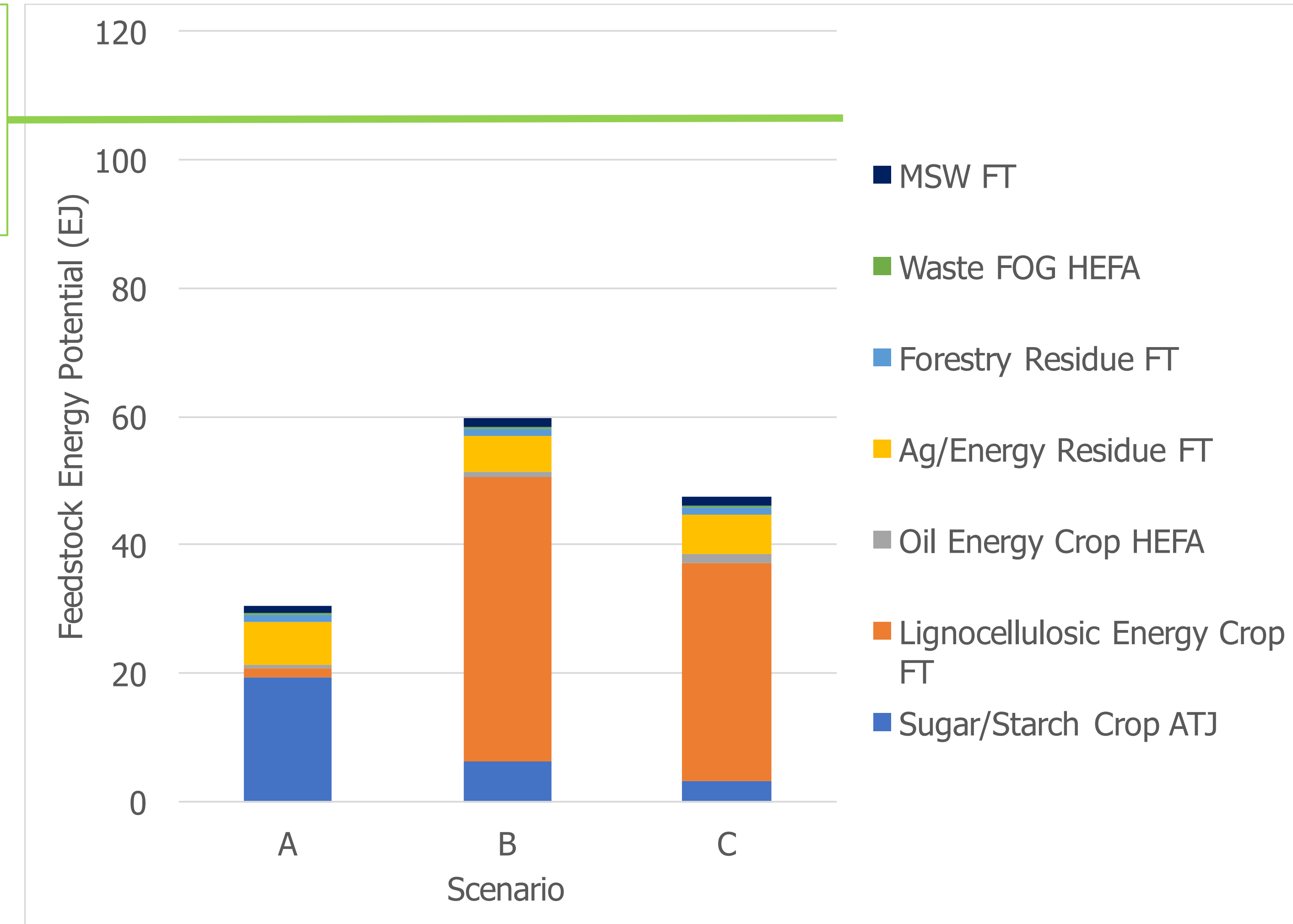
Agro-climatic land suitability thresholds of *'good'* and *'moderate'* studied (as defined in the GAEZ model of agricultural yields)

Two land use decision criteria were studied: maximum AJF production; and maximum total transportation fuel production

Scenario name	Description	Technological/economic development	Agro-climatic suitability threshold	Land use decision criteria
A	Highest AJF potential	SRES B1	Moderate	Max. AJF
B	Baseline AJF potential	SRES A2	Moderate	Max. transp. fuel
C	Lowest AJF potential	SRES A1B	Good	Max. transp. fuel

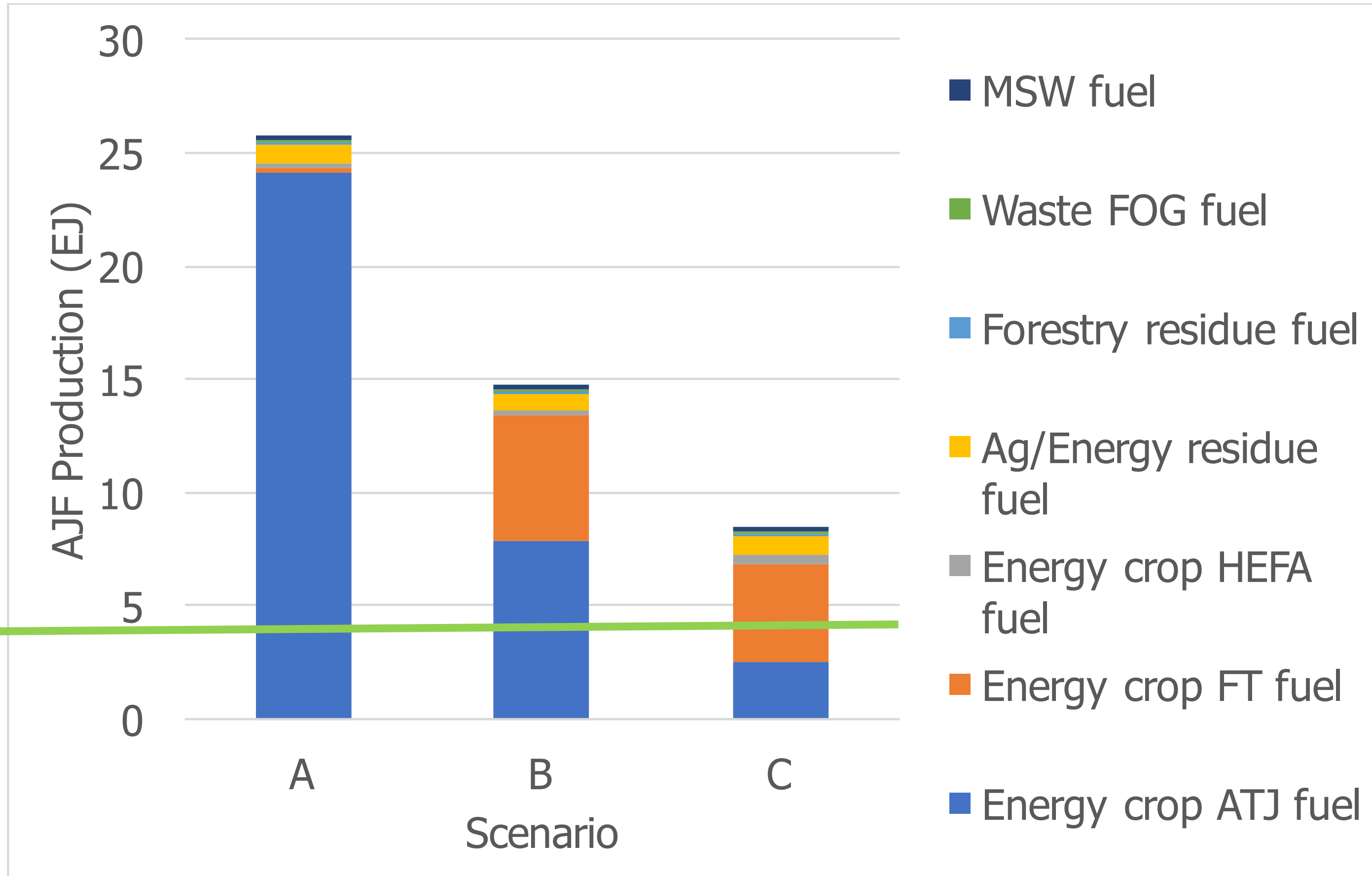
Scenario results: feedstock availability

Projected US primary energy demand in 2050: 106 EJ (EIA)



- Scenario A selects for high-AJF yielding pathways, but lower overall feedstock LHV

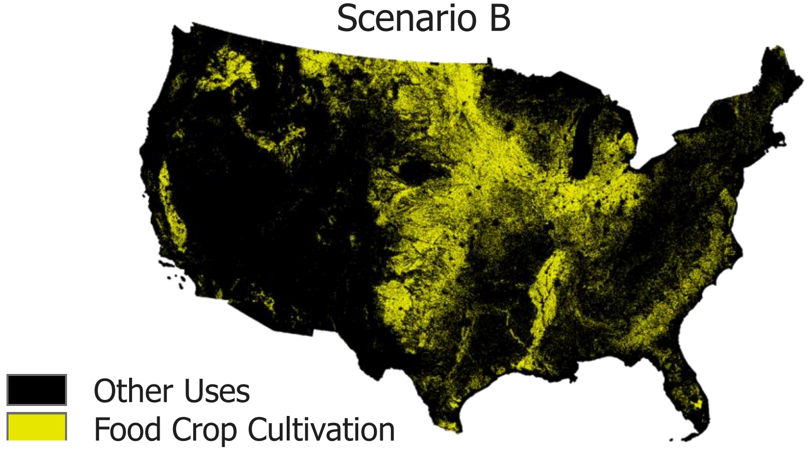
Scenario results: AJF availability



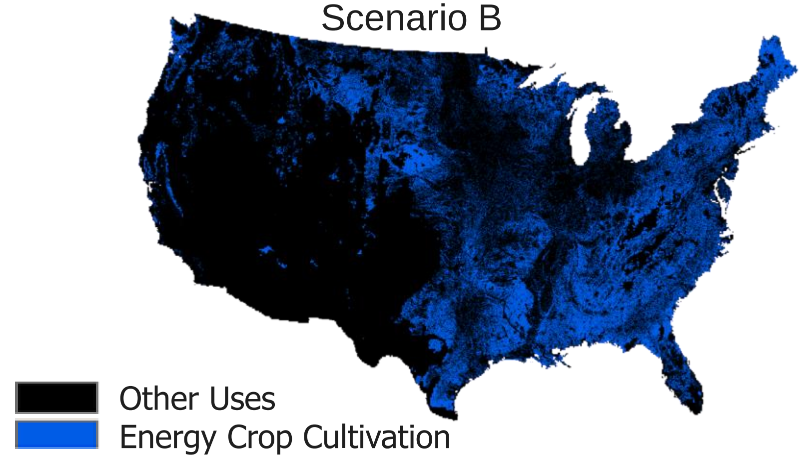
Projected US jet fuel demand in 2050: 4.2 EJ (EIA)

Scenario results: energy crop area

Projected 2050
BAU cropland area
Scenario B



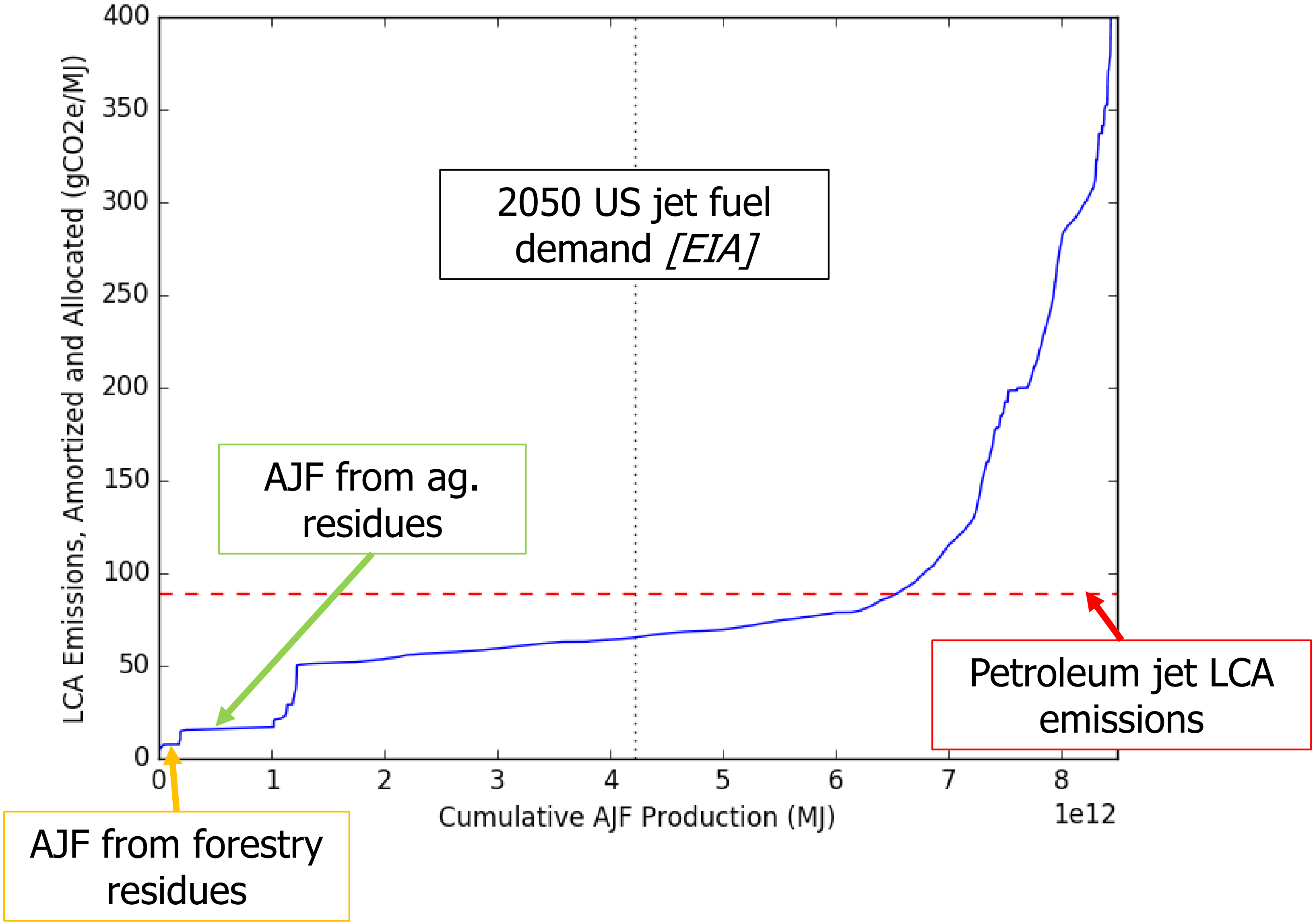
Area required for calculated
2050 energy crop quantities
Scenario B



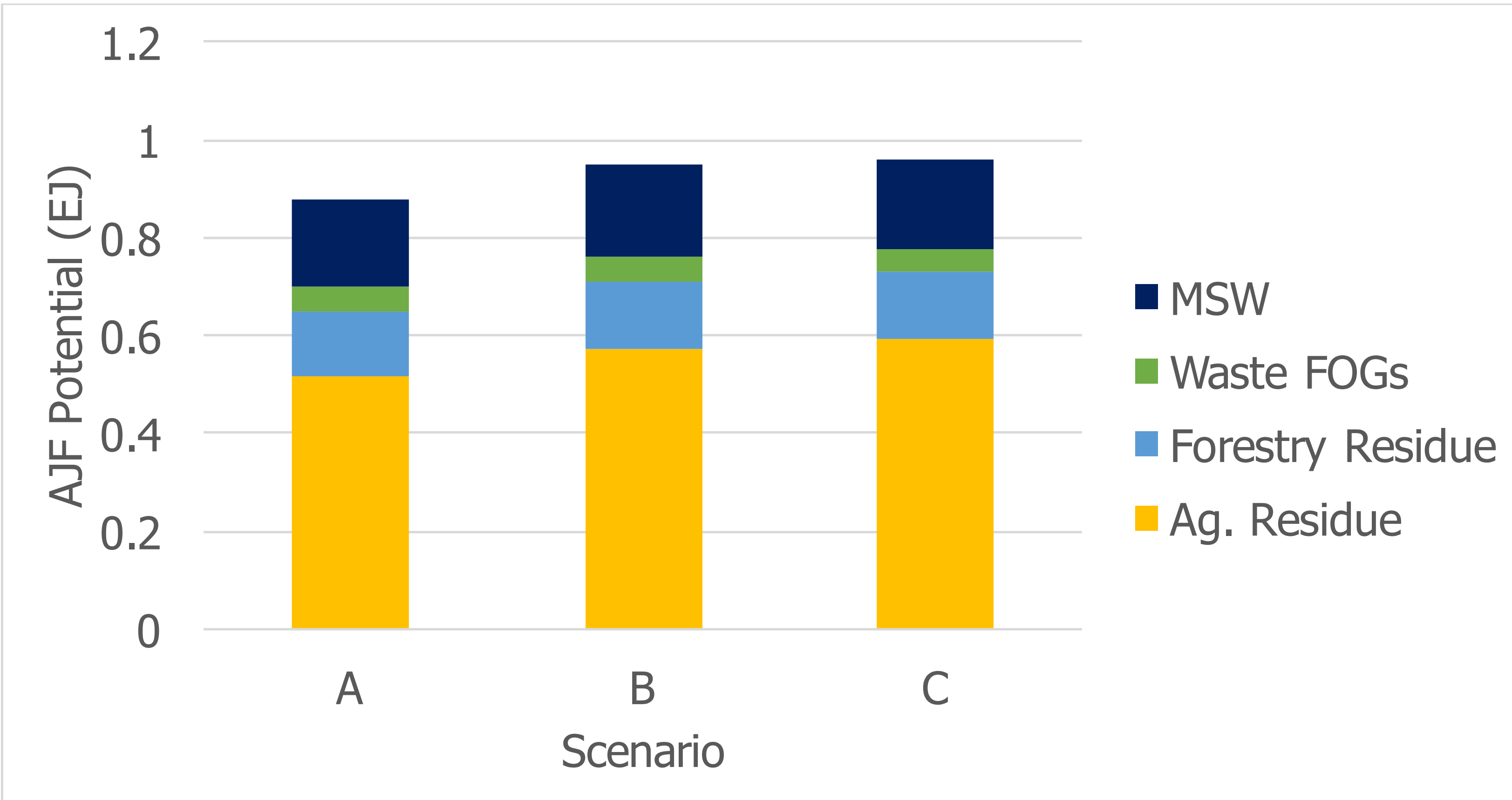
2050 area required for calculated energy crop quantities

Scenario	BAU cropland area (Mha)	Energy crop area (Mha)
A	130	217
B	**145**	**188**
C	150	120

Results: Climate impacts of scenario C



Results: Waste & residue AJF availability



Wastes & residues could satisfy ~20% of expected 2050 US jet fuel demand (4.2 EJ)

Conclusions: 2050 US AJF potential

100% of expected US jet fuel demand 2050 could potentially be satisfied by AJF

- Corresponds to a 56% reduction in GHGs compared to petroleum-derived jet fuel

However, there may be decreasing LCA emissions benefits of greater AJF production volumes from cultivated energy crops

Up to ~23% of expected US jet fuel demand 2050 could be met using waste- & residue-derived AJF, corresponding to LCA emissions reductions of 16%

Summary: 2050 AJF potential in the US

Accomplishments

- 2050 alternative jet fuel potential in the US quantified
- Reduction in aviation lifecycle GHG emissions associated with AJF production volumes calculated

Publications

- MIT master's thesis to be submitted in December
- Archival publication to be drafted in parallel

Next steps

- Further interpretation of scenario results
- Documentation of methods and findings

Acknowledgements

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Contributors

- Timothy Galligan
- Cassandra Rosen
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- Steven Barrett