FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Life cycle and techno-economic analysis in support of ICAO's CORSIA policy

Project 1

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Background

- The Carbon Offsetting & Reduction Scheme for International Aviation (CORSIA) policy is designed to achieve carbon-neutral growth of international aviation, beginning in 2021
- In February 2019, CAEP agreed on proposals to enable inclusion of Sustainable Alternative Fuels (SAF) under CORSIA
- The Alternative Fuels Task Force (AFTF) developed the proposals to enable inclusion under CORSIA during the course of CAEP/11 (2017-2019)

Technical work of the Alternative Fuels Task Force (AFTF)

1. Calculating attributional life cycle GHG emissions (core LCA) for various SAF pathways

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2. Estimating consequential, induced land-use change (ILUC) GHG emissions attributable to SAF production

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3. Quantifying the impact of policies on the economic viability of SAF technologies

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4. Defining non-GHG emissions sustainability criteria for SAF eligibility under CORSIA

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Core LCA calculations for CORSIA

How should CO_2 emissions reductions from the use of alternative fuels be accounted for under CORSIA?

AFTF Approach

- Consistent, globally robust, application of LCA
- Multi-model, independent validation of default LCA values
- Mechanism to account for differences from default assumptions

Core LCA calculations for CORSIA

Methodology

- Attributional LCA
- Energy allocation
- System boundary from feedstock generation, to fuel combust.
- Waste, residues, and by-products assumed to be zero emissions during generation
- One-time construc. and manufact. emissions not incl.
- Fossil CO_2, CH_4 and N_2O, using 100-year GWP
- Evaluated relative to petroleum baseline of 89 gCO_2e/MJ

Scope

- 5 ASTM conversion techs:
  - FT, HEFA, SIP, EtOH-to-jet, iBuOH-to-jet
- 18 unique feedstocks
- 25 default core LCA values to-date
- List of pathways is growing

Process for core LCA calculations

- ‘Lead’ and ‘Verifier’ institutions with expertise and data were defined to carry out the LCA for each pathway of interest.

- Discrepancies evaluated to identify opportunities to align key assumptions, in order to reasonably represent commercial-scale production.

- 2 examples to illustrate this process:
  - Sugarcane SIP
  - Palm oil HEFA

Example 1: Sugarcane SIP

Sugarcane SIP data for CORSIA default core LCA values

Conversion technology	Data source	Model	Cultivation	Feedstock transportation	Fermentation and upgrading	Farnesene transportation	Fuel transportation	Total emissions
SIP	MIT	GREET	17.6	2.8	11.4	-	0.3	**32.1**
	JRC	E3db	20.9	1.9	10.4	-	0.3	**33.5**
	~~Unicamp~~	~~CA-GREET~~	~~11.3~~	~~-*~~	~~14.8~~	~~0.2~~	~~0.3~~	~~**26.6**~~

Sugarcane requirements for farnesene production [$t_{sugarcane}/t_{farnesene}$]

MIT	46.6
JRC	65.3
Unicamp	27.2

Differences primarily due to assumed:
- farnesene yield from sucrose
- sugarcane sucrose content

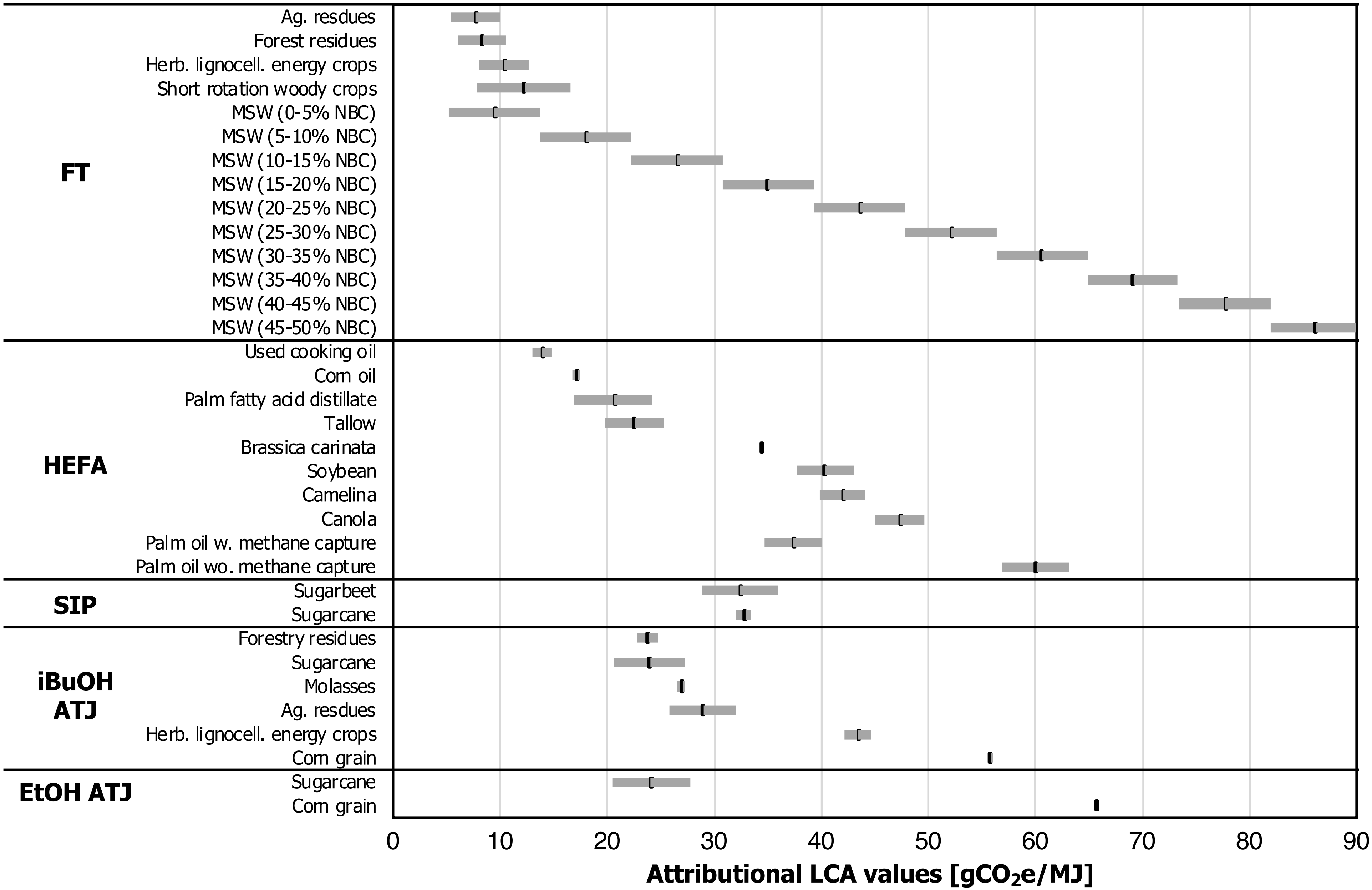
Example 2: Palm oil HEFA

Palm oil mill effluent (POME)

Conversion technology	Data source	Model	Cultivation	Feedstock transportation	Oil extraction	Oil transportation	Feedstock to fuel conversion (isomerization included)	Fuel transportation	Total
HEFA with Methane Capture	JRC	E3db	19.8	1.3	4.7	4.6	9.3	0.3	**40**
	ANL	GREET	11.4	0.5	6	2.9	13.5	0.4	**34.7**
HEFA without Methane Capture	JRC	E3db	19.8	1.3	27.8	4.6	9.3	0.3	**63.1**
	ANL	GREET	11.4	0.5	28.1	2.9	13.5	0.4	**56.9**

Image credit: https://indonesiaexpat.biz/featured/indonesia-looks-toward-palm-oil-sustainability-in-kalimantan/

Default LCA values under CORSIA



Note that **grey bars** indicate the full range of LCA data points considered, and **black hash** represents the mid-point of the range.

Using LCA values under CORSIA

- Airlines using SAF to meet CORSIA obligations can quantify emissions reductions with default LCA values
- Airlines and SAF producers may also compare their data to default assumptions, and calculate producer-specific values
- Where applicable, consequential emissions impacts need to be included as well (ILUC, avoided landfilling emissions)
- Technical report detailing all LCA calculations and input data to be published on the ICAO CAEP website (anticipated 2019)

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TEA policy analyses for CORSIA

- AFTF was tasked with quantifying the impact of different policy options on the economic viability of SAF production
- MIT, Purdue, and Hasselt University undertook this task collaboratively, by implementing a number of policy cases in a stochastic techno-economic analysis (TEA)

Scope of analysis

- Scope was defined to represent technically mature SAF pathways, close to commercialization in regions around the world.

Process	Feedstock	Region	Company example
Micro - FT	Forest residues	North America	Velocys
HFS-SIP	Sugarcane	South America	Total-Amyris
HEFA	Waste fats, oils and greases (FOG)	North America/Europe	Altair/Neste
HEFA	Palm oil/palm fatty acid distillates (PFAD)	Asia & Pacific	Pertamina
FT	Municipal solid waste (MSW)	North America	Fulcrum
ATJ (via. iBuOH)	Corn	US	Gevo

Stochastic TEA model

Input distributions for I/O quantities and costs → Pull random values from distributions → Calculate revenues and costs → Evaluate revenues and costs in DCFROR model

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Random variables

<u>Process I/O quantities</u>

- Fuel yield/feedstock input
- Natural gas input
- Power input
- Other inputs (eg. catalyst, make-up water, chemical inputs)

<u>Costs</u>

- Fixed capital investment
- Feedstock cost
- Natural gas, power costs
- Fuel product prices

Stochastic TEA model

Input distributions for I/O quantities and costs → **Pull random values from distributions** → Calculate revenues and costs → Evaluate revenues and costs in DCFROR model

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Revenues

- Fuel sales
- Co-product sales (DDGS, excess co-produced power)

Costs

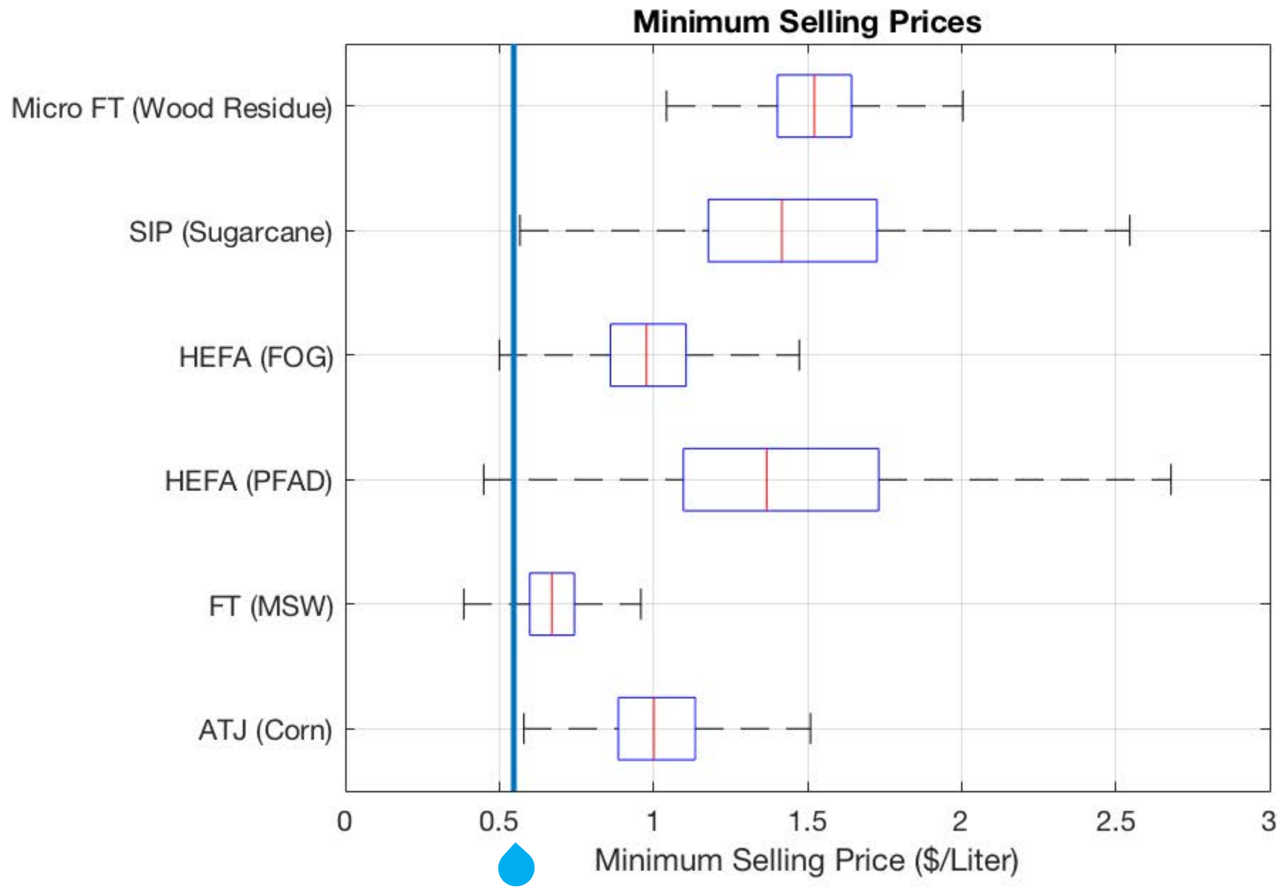
- Fixed capital investment
- Variable operating costs
  - Feedstock & utilities
- Direct operating costs
- Fuel sales
- Co-product sales (DDGS, excess co-produced power)

Stochastic TEA model

Input distributions for I/O quantities and costs → Pull random values from distributions → Calculate revenues and costs → Evaluate revenues and costs in DCFROR model

- DCFROR model calculates **net present value** (NPV) and **minimum selling price** (MSP) over a 20 year facility lifetime
- Process is repeated 10000 times to quantify uncertainty
- DCFROR is based on modified model documented in Bann et al. (2017)

Baseline TEA results



From IATA jet fuel price monitor
($0.56/liter)

Note: these results are for greenfield facilities that do not leverage existing fuel production infrastructure.

Preliminary data, please do not cite or quote.

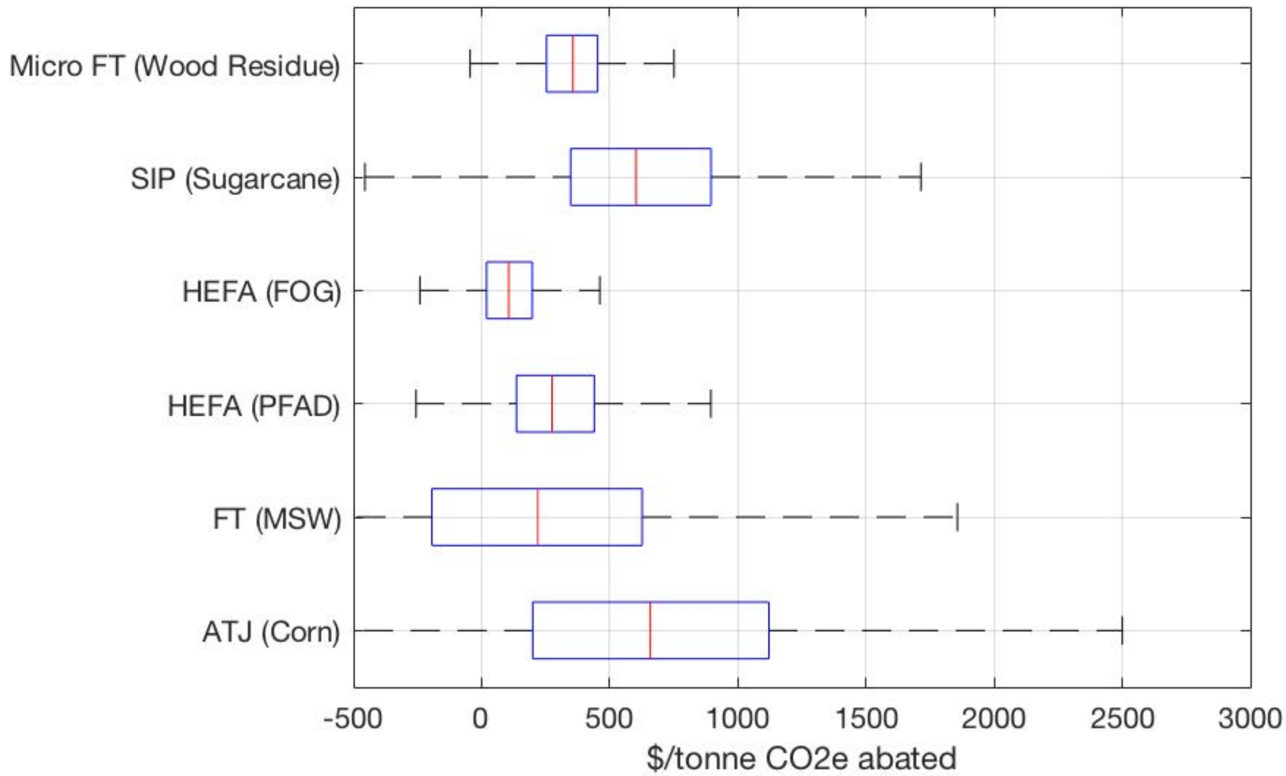
Policy types considered

Policy type	Real world example	Method of modeling
Output based incentive	RFS2 RINs	Credit per liter of fuel produced. All fuel products (not only jet) are assumed to benefit from this policy.
Input subsidy	Subsidized feedstock price	Feedstock costs reduced by a fixed percentage.
Capital grant	DoE or DoD programs that grant a lump sum to facilities	FCI is reduced by a lump sum at the start of facility construction.
GHG emission reduction incentive	California LCFS, CORSIA	Monetary credit based on the total quantity of CO_2 equivalent reduced. Granted as a lump sum based on annual fuel output.

Policy results

1. Magnitude of each policy-type required for breakeven

Example: GHG reduction incentive [$/tCO$_2$e] required for breakeven



Preliminary data, please do not cite or quote.

Policy results

1. Magnitude of each policy-type required for breakeven
2. Impact of real-world policy examples

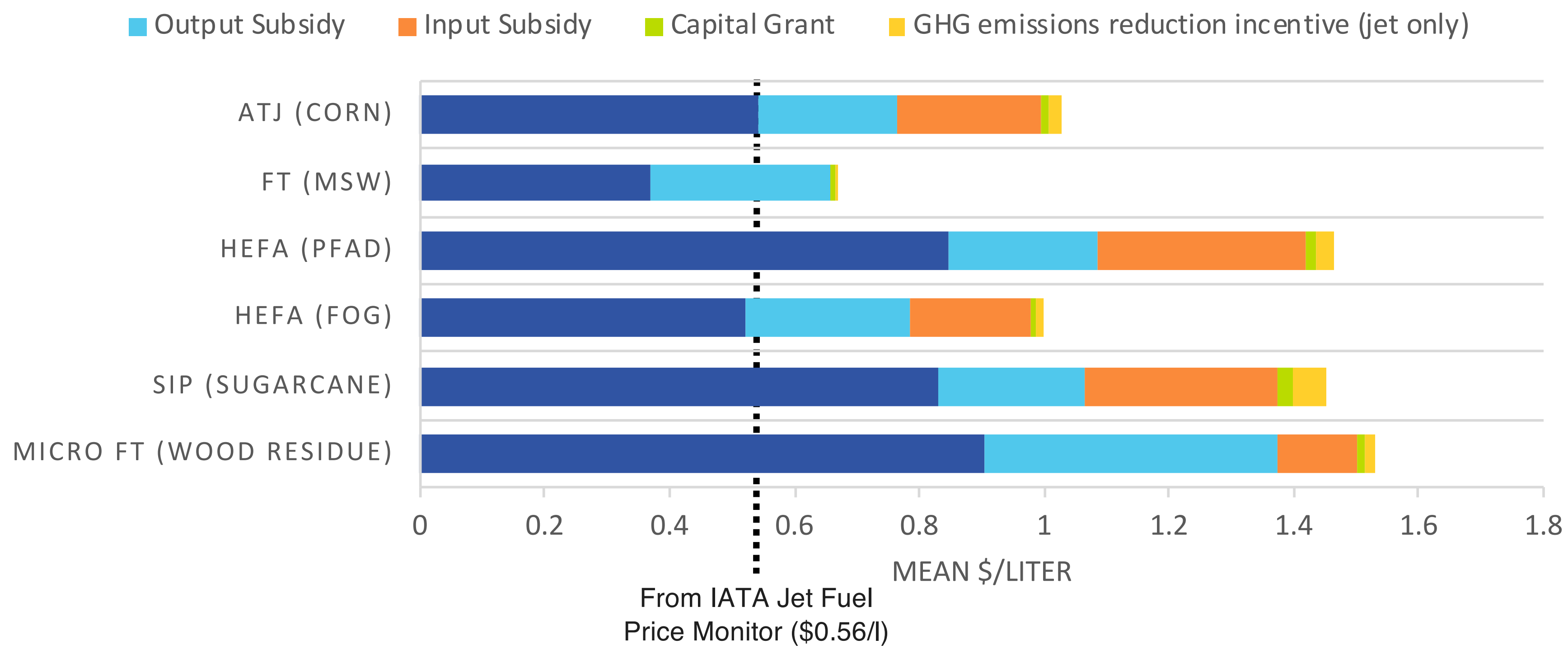
Output based incentive **(Ex. RFS RIN values)**	**Input subsidy** **(Ex. Indonesian palm oil subsidy)**	**Capital grant** **(Ex. CalRecycle grants)**	**GHG reduction incentive** **(Ex. CORSIA)**
0.25 $/liter	27% feedstock cost subsidy	5 mil. USD capital grant	8 USD/t_{CO2} (20 USD/t_{CO2} by 2035)

Preliminary data, please do not cite or quote.

Policy results

1. Magnitude of each policy-type required for breakeven
2. Impact of real-world policy examples

Cumulative impact of real-world policy examples



Preliminary data, please do not cite or quote.

Policy results

1. Magnitude of each policy-type required for breakeven
2. Impact of real-world policy examples
3. Impact of equivalent cost policies

Impact of equivalent cost policies on HEFA PFAD pathway

Policy type	Output subsidy		
[$/liter]	0.10	0.25	0.75
Total policy cost (mil. USD) [std. dev.]	77 [3]	192 [8]	576 [23]
MSP ($/liter) [std. dev.]	0.97 [0.19]	0.82 [0.19]	0.32 [0.19]
Policy type	**Input/feedstock subsidy**		
[% feedstock cost subsidized]	16%	40%	119%
Total policy cost (mil. USD) [std. dev.]	77 [19]	192 [50]	571 [146]
MSP ($/liter) [std. dev.]	0.98 [0.17]	0.81 [0.12]	$\boxed{0.25\ [0.05]}$
Policy type	**Capital grant**		
[Mil. USD]	77	79*	79*
Total policy cost (mil. USD) [std. dev.]	77 [4]	79 [9]	79 [9]
MSP ($/liter) [std. dev.]	$\boxed{0.88\ [0.19]}$	0.87 [0.19]	0.87 [0.19]
Policy type	**GHG reduction incentive**		
[$/liter]	48	114	343
Total policy cost (mil. USD) [std. dev.]	77 [3]	192 [8]	576 [23]
MSP ($/liter) [std. dev.]	0.97 [0.19]	0.82 [0.19]	0.32 [0.19]

Preliminary data, please do not cite or quote.

* These scenarios are limited by total FCI of the pathway.

Preliminary policy conclusions

- CORSIA, in isolation, is unlikely to be sufficient to bridge the gap between current SAF costs and market prices for jet fuel

- However, a combination of policies (of the magnitude of real-world examples) may be sufficient for some SAF pathways to be competitive with petroleum-derived fuel
  - eg. HEFA FOG, FT MSW cases

- At equivalent total policy cost:
  - Capital grants may be more effective at reducing median MSP
  - Feedstock subsidies may be more effective at reducing variance in MSP

- There are additional measures that could provide significant additional SAF cost reductions that have not been considered here (eg. brownfield developments, or leveraging existing industrial facilities).

Summary & next steps

Major outcomes of this work:

1. Default core LCA values enabling the use of SAF for airlines to comply with CORSIA
2. Actual LCA methodology that can be used by airlines to obtain an LCA value that reflects fuel production practices deviating from default assumptions, including a method to account for MSW emissions credits
3. Data and insight for CAEP Member States considering national or regional policies to support SAF production

Documented in numerous working and information papers presented to AFTF and CAEP. TEA work will be in a MIT Master's thesis to be submitted in May 2019, as well as a journal paper being drafted in parallel.

These tasks will be on-going during the CAEP/12 cycle, beginning with the first meeting of the Fuels Task Group (FTG) in May 2019.

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Contributors

- Mark Staples
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