ICAO ENVIRONMENT

ACT-SAF #13 SERIES

SAF Business Implementation studies and TEA models

3 July 2024

ICAO ENVIRONMENT

ACT SAF

Assistance, Capacity-building and Training for SAF

1. Opening

Neil Dickson
Chief – Environmental Standards
ICAO Environment

Objectives

ACT-SAF
#13
SERIES

Provide participants with insights on the SAF Business Implementation studies and techno-economic assessment models

ACT-SAF Series #13 Speakers

Kristin Brandt

CAEP FTG expert,

Adjoint Faculty, Washington State University

Agenda

- Opening remarks by ICAO
- ICAO update on ACT-SAF activities
- ICAO presentation on the Business Implementation Study template
- Presentation of ICAO Rules of Thumb and TEA tools
- Questions and answers with the audience
- Closing remarks by ICAO

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ACT SAF

ACT SAF

Assistance, Capacity-building and Training for SAF

ICAO update on ACT-SAF programme

ACT-SAF platform of implementation support initiatives

- **ACT-SAF tracks implementation support initiatives from our partners**
  - Easy to access resource in ICAO ACT-SAF website, with information on feasibility studies, training/outreach, and events
  - Reduces duplication of efforts across partners/stakeholders
  - Reach out to ICAO to have your initiative reflected in the platform

Latest news

- **ICAO-EU ACT-SAF projects**
  - Project implementation for 10 States, starting with Ethiopia, India, and South Africa. Potential start in July 2024.
  - Kick-off meeting - 29 April
  - Job descriptions for projects have been published
  - **Ongoing work - interviews and evaluation of prospective consultants**
- **Ongoing coordination to start other ACT-SAF projects (funded by Netherlands, France, United Kingdom)**

- **Ongoing engagement with ACT-SAF partners to define new projects and capacity building activities** (Airbus, Cote d’Ivoire, Kenya, Mexico, Fedebiocombustibles, SAF futures)
- **Initial engagement with new ACT-SAF Partners** - Honduras, Costa Rica, Ecuador, Panama, Kazakhstan

Recent initiatives from ACT-SAF Partners

Airbus, Boeing, Rolls-Royce and Safran leading industry work group

- Collaboration across leading aerospace companies in Work Group under the International Aerospace Environmental Group (IAEG) to evaluate technical issues regarding compatibility of 100% SAF with airplane systems
- Objective- to assess impacts of 100% SAF on airplane systems
- To coordinate 100% SAF testing efforts for voluntary and unilateral consideration and use by its members
- Test results to inform ASTM International as it develops specifications for 100% SAF

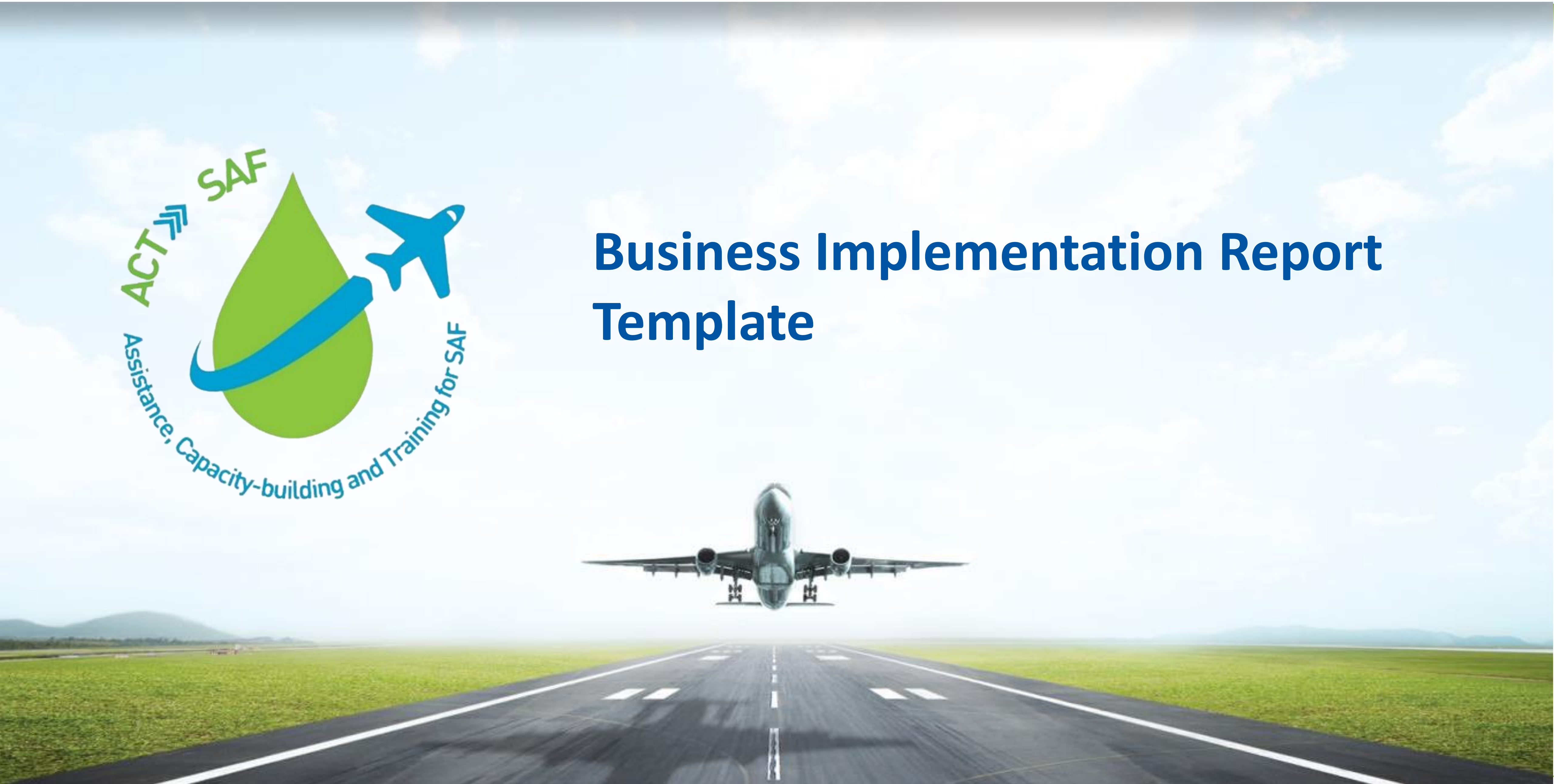
2024 Boeing Sustainability & Social Impact Report

The Boeing 2024 Sustainability & Social Impact Report outlines progress made on environmental efforts, including various initiatives related to SAF

https://www.sae.org/news/press-room/2024/05/leading-aerospace-companies-collaborate-regarding-100-saf-compatibility

Boeing: Sustainability

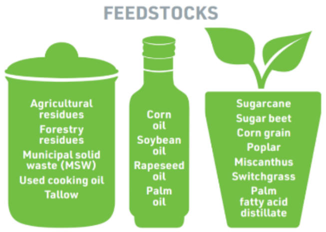
Business Implementation Report Template

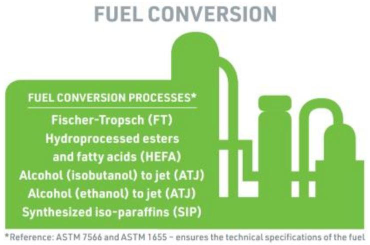


Background: SAF business implementation report template

- **As a follow up to the SAF feasibility study template/guide, ICAO has prepared a draft template to support SAF business implementation**
  - ➢ Provides follow up support to States where preceding studies have already identified SAF feedstock/pathway prospects

Feedstock availability	Production pathway	SAF market



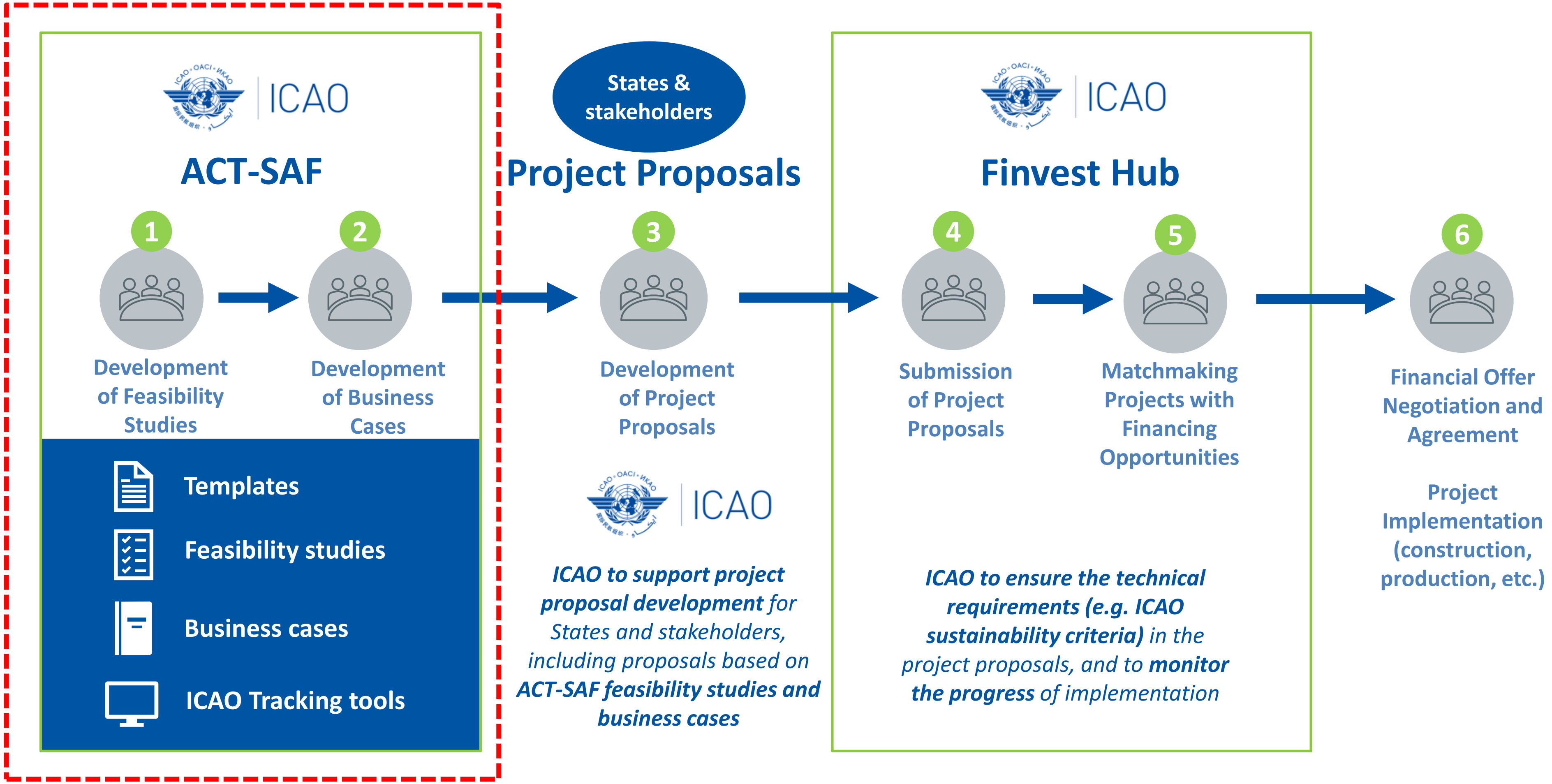


  - ➢ Received support from Kenya, Spain, Airbus, IATA, Oneiros Aerospace Limited, SAF Investor, SFS Ireland, and other individual contributors who participated in calls, and/or provided written inputs to progress the template

Background: SAF business implementation report template

- **As a follow up to the SAF feasibility study template/guide, ICAO has prepared a draft template to support SAF business implementation**
  - Template forms the reference for the implementation several ACT-SAF business implementation studies that will be developed in the coming months
  - Intended to progress development plans towards potential SAF projects, and facilitate final investment decisions
  - Template will offer useful reference for States
    - Business Implementation studies under ACT-SAF will be required to align with the approach set out in the template
  - Following its presentation at ACT-SAF Series #13, template will be made available in the ICAO ACT-SAF website
  - Final comments on the Template are welcome.

How ACT-SAF supports SAF development, and relationship with other mechanisms

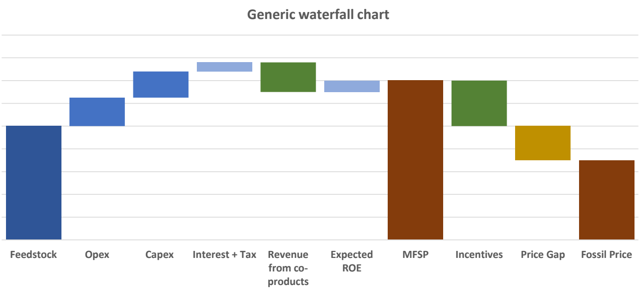


Key elements of the Template:
1) Market analysis (scenario and assumptions)

- Deep dive into at least one shortlisted feedstock / pathway
- Setting out of the valuation model (e.g. discounted cashflow), and key outputs (e.g. NPV, MFSP)
- Provides technical information and assumptions, on SAF production facilities, with explanations
  - Location, supply chain, scale (e.g. energy infrastructure, demand)
  - General facility inputs (e.g. timeframes, capacities, lifespan)
  - Process and energy/utility inputs
  - Financial inputs (e.g. cost of capital, depreciation, IRR)

Key elements of the Template :
2) Techno-economic assessment and results

- **Applies input parameters from preceding section, to assess viability of SAF project in question**
- Typically incorporates a waterfall chart as a visualization tool with key outputs such as MFSP, price gaps, and CO2 abatement costs
- Sensitivity analysis to account for bear/bull variations in each input parameter – deviations from base scenario have to be explained
- At times, different technology providers for the same production pathway, or in different regions may reflect different costs
- Description of potential policies to address the price gap, if necessary



Key elements of the Template :
3) Financial and operational assessment of the project

- **Development of the business case**, defining the economic and operational potential
- Operational assessments may provide information on
  - Facility general plot plans
  - Development timelines
  - Availability of local resources (incl impact on jobs)
- Assessments in cases of positive NPV (most ideal scenario), vis-à-vis negative NPVs (consideration of supporting policy)
- Assessments on potential regulatory issues (e.g. permits, expected timelines)
- Review of sustainability assessments, aligned with CORSIA eligible fuels
- Incorporate feedback from key stakeholders

Key elements:
4) Risk assessment

- **Highlights challenges and barriers** that need to be addressed in order to realizer SAF opportunities, with a focus on risks
- Common challenges include:
  - Scalability
  - Feedstock supply (seasonal variations, regional availability)
  - Technology risks
  - Competition with other refinery outputs
- Challenges may be evaluated in terms of likelihood, as well as impact to project success
- Mitigation means to address risks/challenges
- Useful to consider inclusion of risk monitoring and review plan

Key elements:
5) Business implementation recommendations

- **Explores final recommendations for the business case**
- Should aim to identify interested project partners – support towards setting out implementation structure
- Identification of potential financing, together with strategies for securing project finance
- Action plan to be aligned with the State's existing and planned policies related to clean energy/SAF development, as with linkages to the ICAO State Action Plan processes to support LTAG monitoring

Overall flow of the development of a business implementation project

1. Review outcomes from preceding SAF feasibility study
2. Shortlist one or more feedstock / conversion pathways
3. Set out input parameters and perform TEA
4. Review results, apply sensitivity analysis
5. Introduce business case
6. Provide economic, operational, risk assessments
7. Develop business implementation recommendations

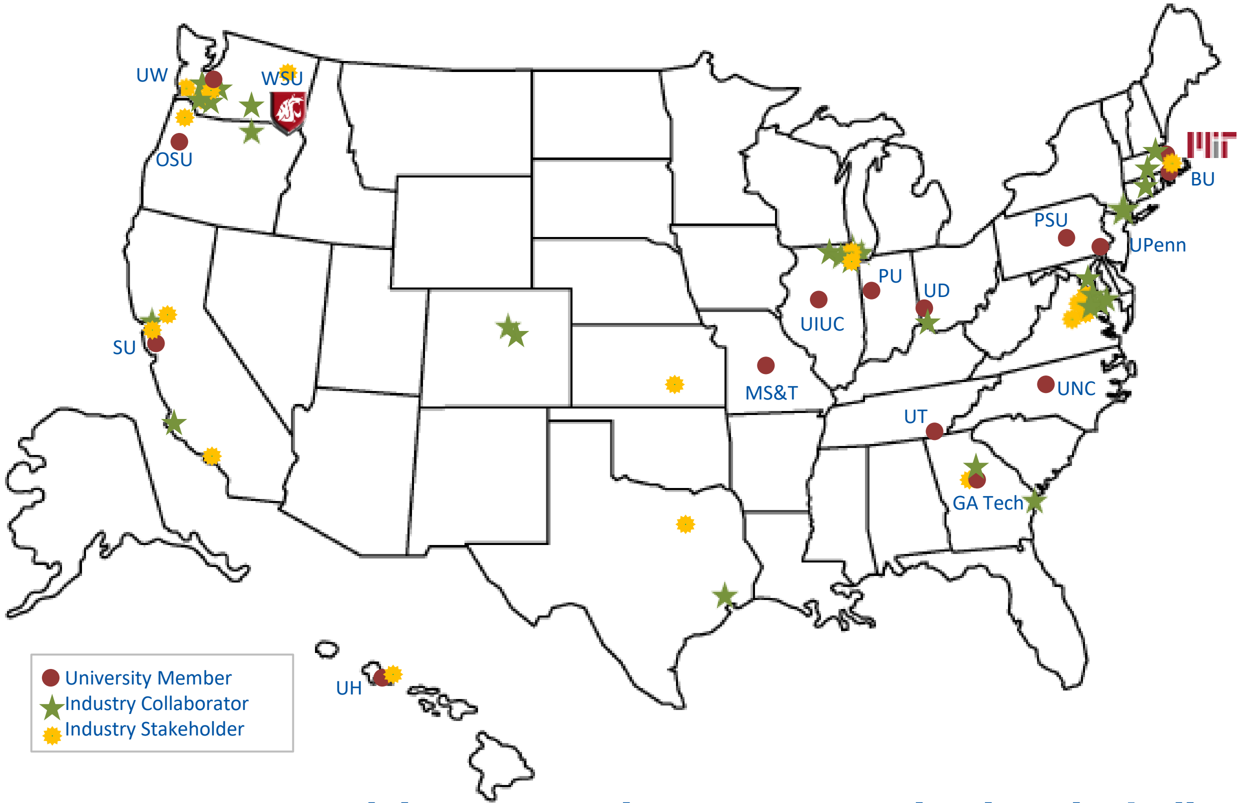
ICAO Rules of Thumb and related TEA tools developed by ASCENT

Outline

- Introduction to ASCENT
- ASCENT Harmonized Techno-Economic Analyses (TEAs)
- ICAO SAF “Rules of Thumb”

ASCENT Center of Excellence (COE)

Lead Universities:
Washington State University (WSU)
Massachusetts Institute of Technology (MIT)
Core Universities:
Boston University (BU)
Georgia Institute of Technology (Ga Tech)
Missouri University of Science and Technology (MS&T)
Oregon State University (OSU)
Pennsylvania State University (PSU)
Purdue University (PU)
Stanford University (SU)
University of Dayton (UD)
University of Hawaii (UH)
University of Illinois at Urbana-Champaign (UIUC)
University of North Carolina at Chapel Hill (UNC)
University of Pennsylvania (UPenn)
University of Tennessee (UT)
University of Washington (UW)



Advisory Committee - 95 organizations including:
- Airports
- Airlines
- NGO/advocacy
- aviation manufacturers
- feedstock/fuel manufacturers
- R&D, service to aviation sector
- government agencies/laboratories

For more information: ascent.aero

ASCENT Support & Coordination

Federal Aviation Administration

Transport Canada

NASA

Environmental Protection Agency

Defense Logistics Agency - Energy

U.S. Dep't of Energy

U.S. Dep't of Agriculture

Air Force Research Laboratory

ASCENT COE:

- In operation: 2013 to present
- $15M+ annual funding level
- $164M funding to date

FAA COE research requires 100% cost share. This has led to significant collaboration among universities, industry, and international research programs

ASCENT Missions

ASCENT
AVIATION SUSTAINABILITY CENTER

FAA
Environment & Energy

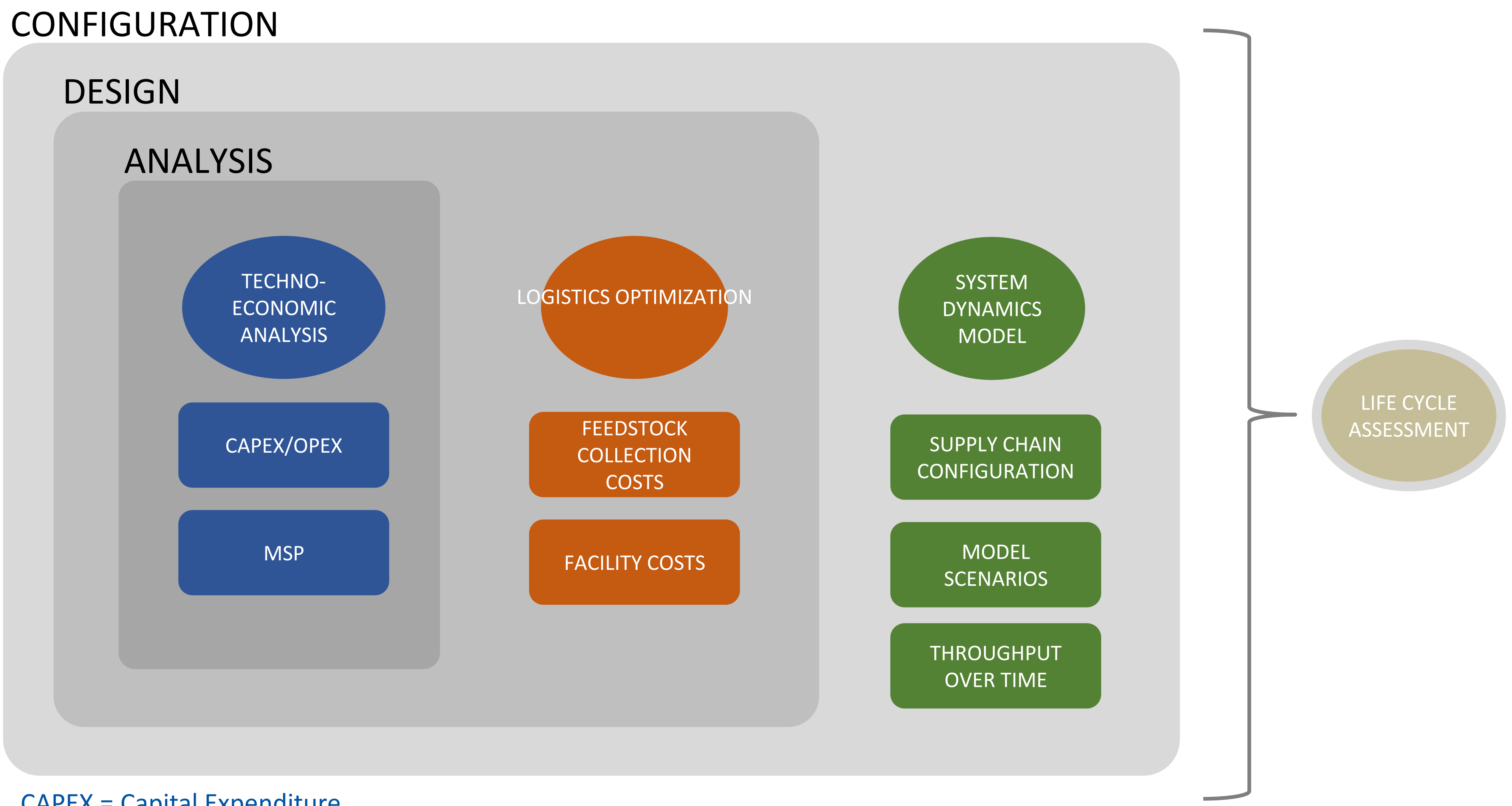
ICAO - International Civil Aviation Organization

NOISE

EMISSIONS

ENERGY

ASCENT Supply Chain Tools



CAPEX = Capital Expenditure
OPEX = Operational Expenditure
MSP = Minimum Selling Price

TEA Explanation

- Techno-Economic Analysis/Assessment = TEA
- Method of quantifying the technical and economic viability of a process
  - Deterministic
  - Stochastic
  - Output is minimum selling price (MSP) or discount rate (return)
- Open sourced (not based on proprietary information)

TEA Harmonization

- Many SAF TEAs have been published each with a specific set of assumptions
- Harmonized TEAs have unified assumptions to allow comparisons
- TEAs can be harmonized for many analysis assumptions including: location, taxes, equipment costs, energy costs, hydrogen costs, cost year, return on investment, plant life, etc.
- TEAs for the same process with different assumptions will create results that do not match

Input - CAPEX

- CAPEX – capital costs, used to cover major costs for items used over a long period of time
- Separated into direct and indirect
  - Direct CAPEX is used to buy and install process operations
  - Indirect CAPEX is used for construction overhead and any non-process operations
- Examples of direct and indirect capital costs

Direct	Indirect
equipment	engineering
equipment installation	construction
buildings	legal fees
land improvements	contractor fees

- Working Capital – amount needed to cover the cost of operation. Covers raw materials and finished goods in stock, payment of bills, payroll and taxes

Input - OPEX

- OPEX – operating costs, used for day-to-day operation of a business
- Divided into fixed and variable costs
  - Fixed operating costs are independent of production rate (or nearly independent)
  - Variable operating costs are directly tied to production rate
- Examples of fixed and variable operating costs

Fixed	Variable
labor	feedstock
taxes	electricity
insurance	chemicals
maintenance	natural gas
overhead	hydrogen

Input – Financial Parameters

- Financial parameters are economic assumptions/choices
  - Need to be consistent between analyses for comparisons
  - Can be based on historical data or future projections
  - Vary with industry

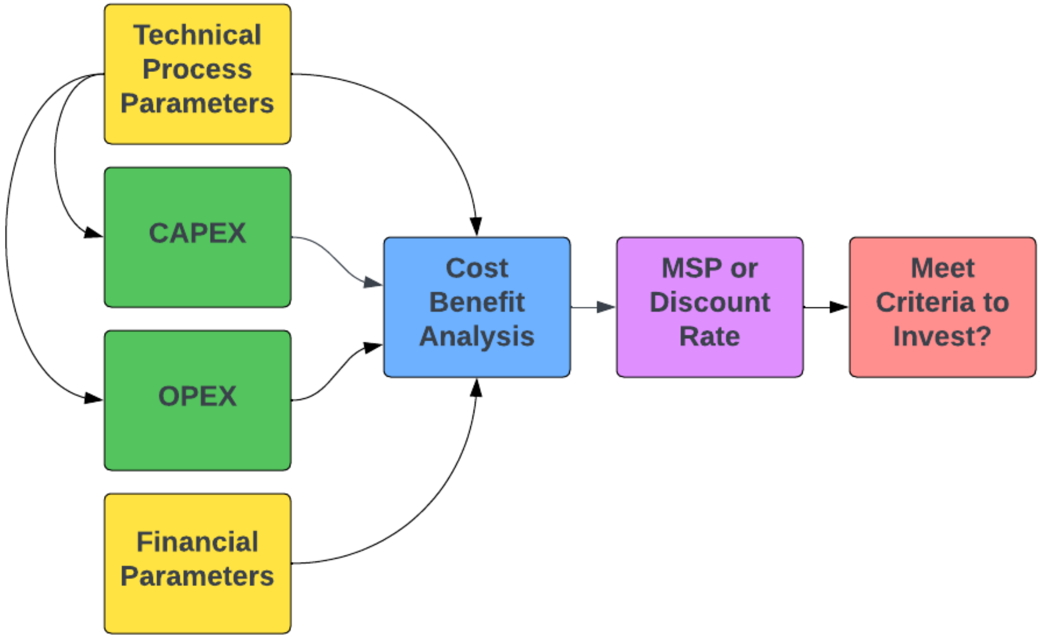
Example Financial Parameters
real discount rate
cost year
working capital rate
equity
loan rate/duration
inflation rate
depreciation schedule

Input – Process Parameters

- Process parameters are technical and operational values
  - from data, assumptions, models or a combination
  - require detailed process knowledge, can be scaled with accuracy limitations
- Examples of technical and operational process parameters

Technical	Operational
yield	uptime
electricity consumption	facility scale
consumables rate	plant life
co-products	maintenance cost rate
technology maturity	

Open-Source, Harmonized TEA Process



- ASCENT harmonized Techno-Economic Analyses (TEAs) are publicly available, including spreadsheets that can be used to estimate fuel minimum selling prices (MSP).
- Users can create financial scenarios using a series of drop-down menus and by entering regional, country, or location specific costs and financial assumptions.
- The impact of policy support is an option for modelers.

ATJ: https://doi.org/10.7273/000001461

FT feedstock prep: https://doi.org/10.7273/000001463

CH: https://doi.org/10.7273/000002564

FT: https://doi.org/10.7273/000001459

HEFA: https://doi.org/10.7273/000001460

Pyrolysis: https://doi.org/10.7273/000002563

Types of TEAs

- Full detailed analysis
  - requires complete, specific design with detailed information
  - Costs from quotes for
    - Inside battery limits (ISBL), equipment used in the process
    - Outside battery limits (OSBL), equipment that supports the process/infrastructure
  - Accuracy +/- 5%
  - Tactical level analysis
  - Specific data on process, location, products

Types of TEAs

- Ratio Factor Method
  - Uses a ratio factor and ISBL costs to estimate fixed capital investment (FCI), which includes outside battery limit OSBL costs
  - Accuracy +/- 30%
  - Scoping level analysis

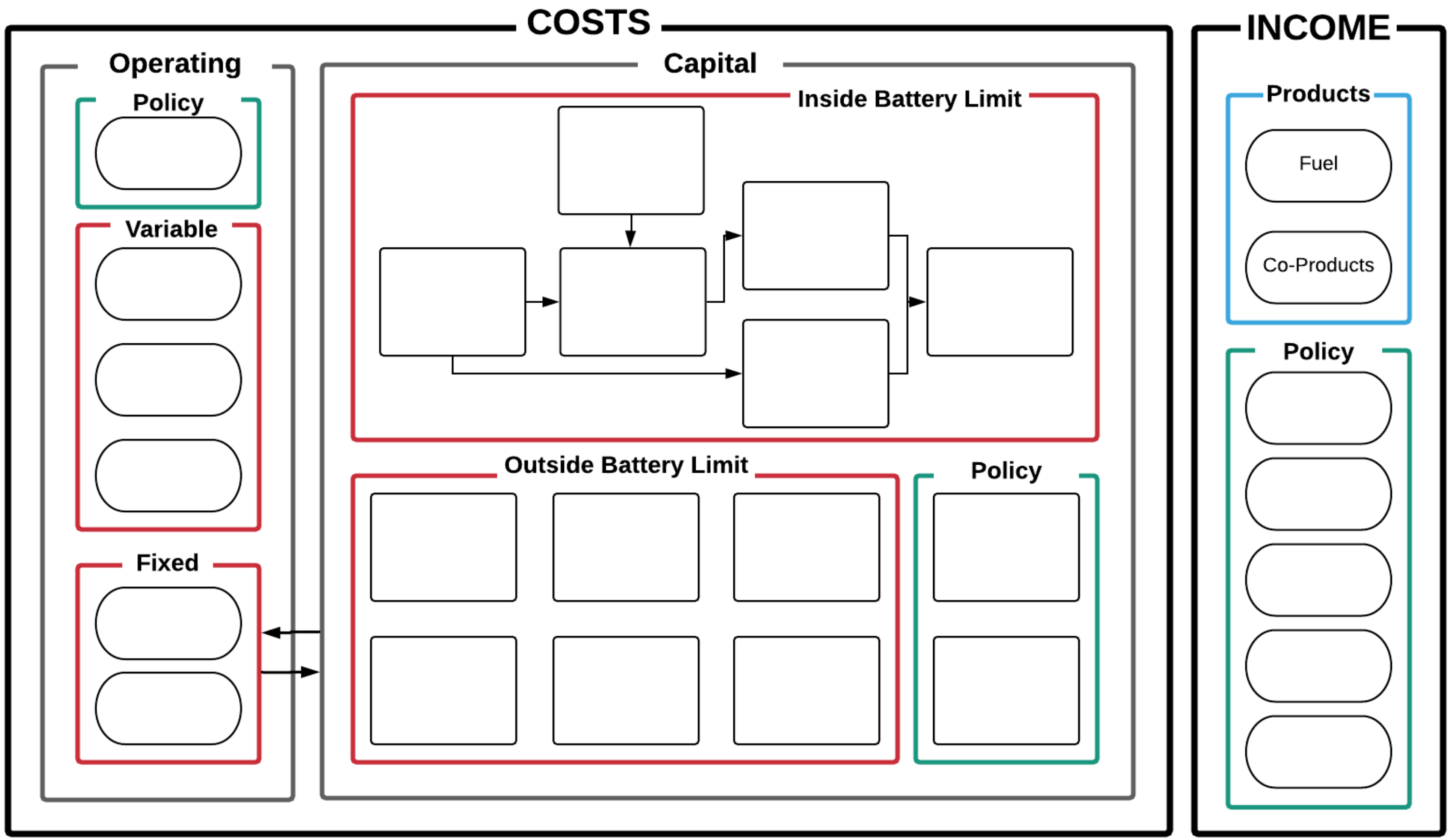
$$FCI = (DC_{rf} + IC_{rf}) \cdot (TDEC)$$

FCI = fixed capital investment

TDEC = total delivered equipment cost

Modified from Peters et al. 2003[1]

Generalized Process Design



ASCENT TEA Spreadsheets

Fischer Tropsch TEA-v2.2unlocked — Saved

D10 =CBA!C25

	A	B	C	D	E	F
2	Revised	1/4/23				
3	Author	Kristin Brandt, Abid H. Tanzil, Lina Martinez-Valencia, Manuel Garcia-Perez, Michael Wolcott				
4	Process	GFT				
5	Feedstock	flue gas				
6	Plant maturity	nth				
7						
8	Annual revenue					
9	Revenue Generating Product	Annual Production	Units	MSP	Units	Total annual revenue, MM$
10	SAF	203.5	MM liter/year	$3.53	$/liter	$718.0
11	Diesel	77.6	MM liter/year	$3.60	$/liter	$279.2
12	Gasoline	718.9	MM liter/year	$3.21	$/liter	$2,310.6
13	Naphtha	0.0	MM liter/year	$3.21	$/liter	$0.0
14	Output Incentives					$0.0
15	Total Revenue					$3,307.7
16						
17	Item	Value			Total delivered equipment cost	MM$
18	Required feedstock (thousand t/year)	3136			Gasification, syngas cleaning, fuel synthesis	$369.1
19	Price of feedstock ($/t)	$50			Hydroprocessing	$69.1
20	Operating hours (hrs/yr)	7884			Air separation	$61.3
21	Analysis year	2017			Total capital investment	**$3,208.8**
22	Plant lifetime (year)	20				
23	Assumed annual Inflation	2.0%			Operational expenditure	MM $/year
24	Equity Percent of Total Investment	30%			Feedstock cost	$157.2
25	**Target Nominal Financial Discount Rate**	**12.2%**	Match by clicking "Run		Other variable OPEX	$2,401.8
26	**Actual Nominal Financial Discount Rate**	**12.2%**	Model" button on Input tab		Fixed OPEX	$248.2
27	Real Discount Rate	10%			Total	**$2,807.2**

ICAO SAF "Rules of Thumb"

- Original request - simple to interpret heuristics for gasification Fischer Tropsch (GFT), alcohol to jet (ATJ), and HEFA
- Updated to include catalytic hydrothermolysis (CH), pyrolysis and high electricity input fuels
- Developed using ASCENT ***harmonized*** TEAs with U.S. centric values

KEY VARIABLES ASSESSED

- Fuel yield
- Feedstock type
- Feedstock cost
- Facility scale
- Technology maturity

https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx

ICAO SAF "Rules of Thumb"

Summary Table 1 - Feedstock Information

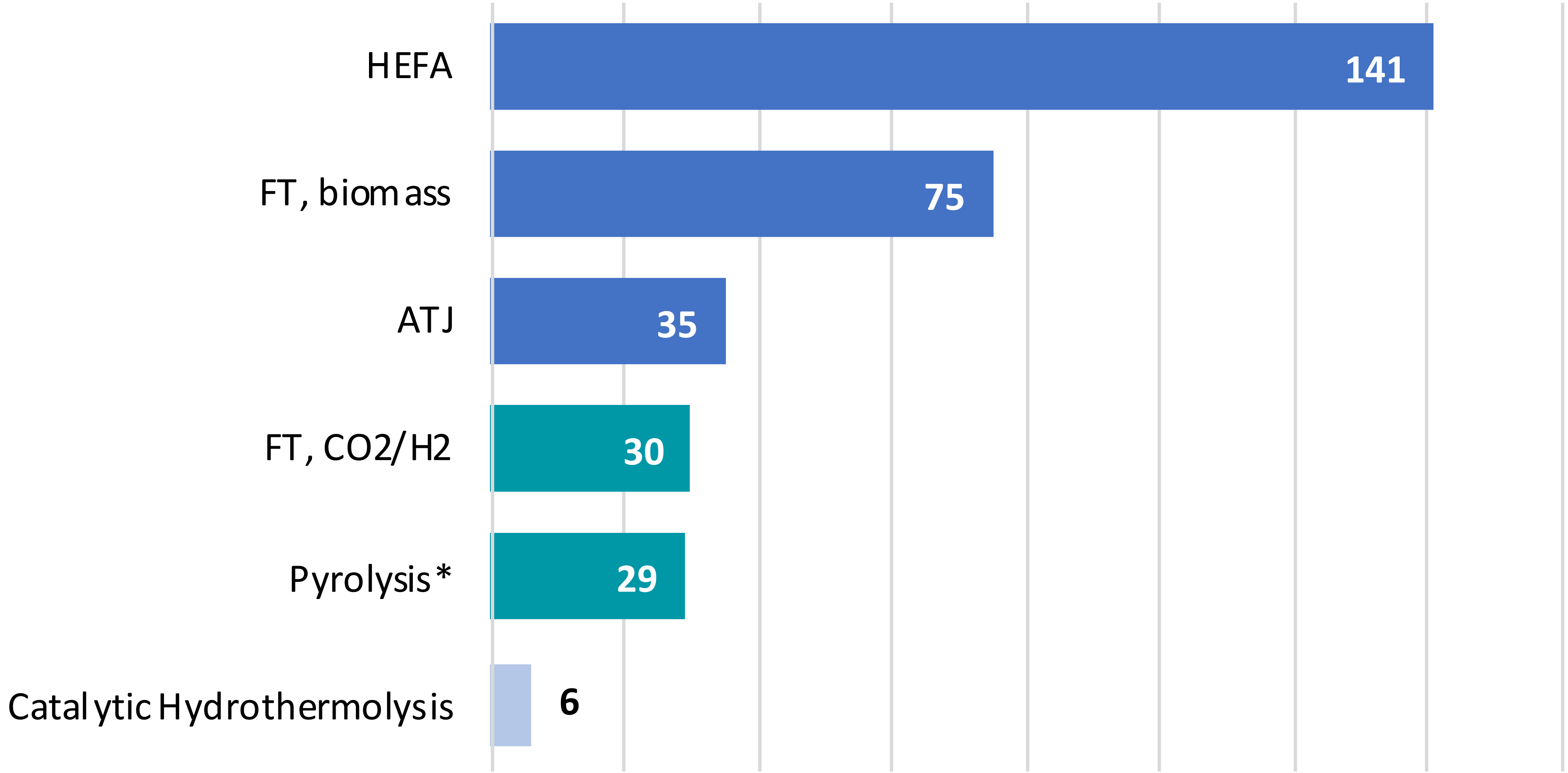
Summary Table 2 - SAF facilities information

Summary Table 3 - CO2 abatement costs

CO2 Abatement costs for nth and pioneer facilities for each pathway (compared with the CORSIA baseline of 89 gCO2e/MJ).

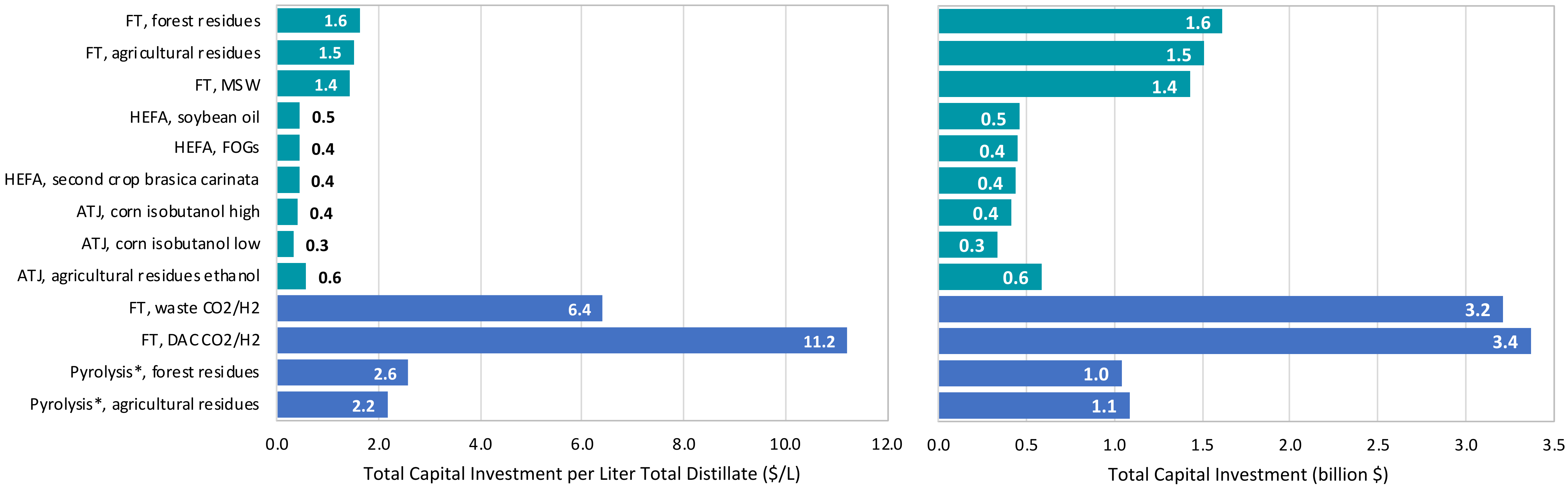
Processing Technology	Feedstock	Life cycle emissions (gCO2e/MJ)*	Abatement Cost ($/t$CO_2$e)	
			nth	pioneer
FT	MSW	32.5*	210	840
FT	forest residues	8.3*	420	990
FT	agricultural residue	7.7*	520	1170
ATJ	corn ethanol	90.8 *, **	no CO2 abatement	no CO2 abatement
ATJ	agricultural residues ethanol, stand alone	39.7*	1020	1190

Technology Announcements



* ASTM approval pending

Total Capital Investment



- Value from harmonized techno-economic models
- Facility scale changes with technology and feedstock combinations
- Assumed mature technology
- 2017 cost year

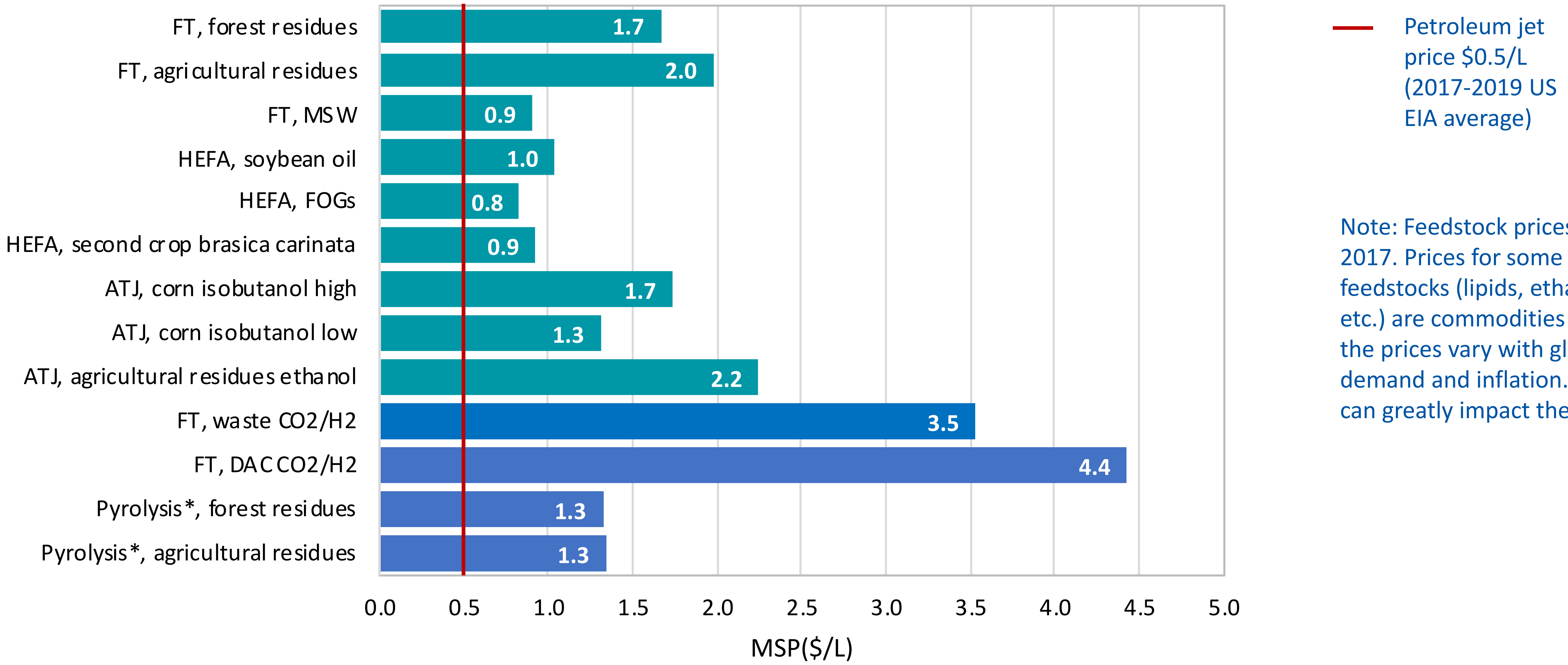
SAF Value

- **Energy value** – value of the energy provided by a fuel (the same as petroleum fuel)
- **Abatement cost** – the cost to remove/reduce GHG emissions by one ton of CO_2e (theoretically covered by policy support and other non-energy funding)

$$Abatement\ Cost\ \left(\frac{\$}{tCO_2e}\right) = \frac{SAF\ MSP - petroluem\ jet\ price}{petroleum\ jet\ LS_f - SAF\ LS_f}$$

- MSP = minimum selling price
- SAF and conventional prices are $/MJ
- LS_f is the emissions tCO_2e/MJ

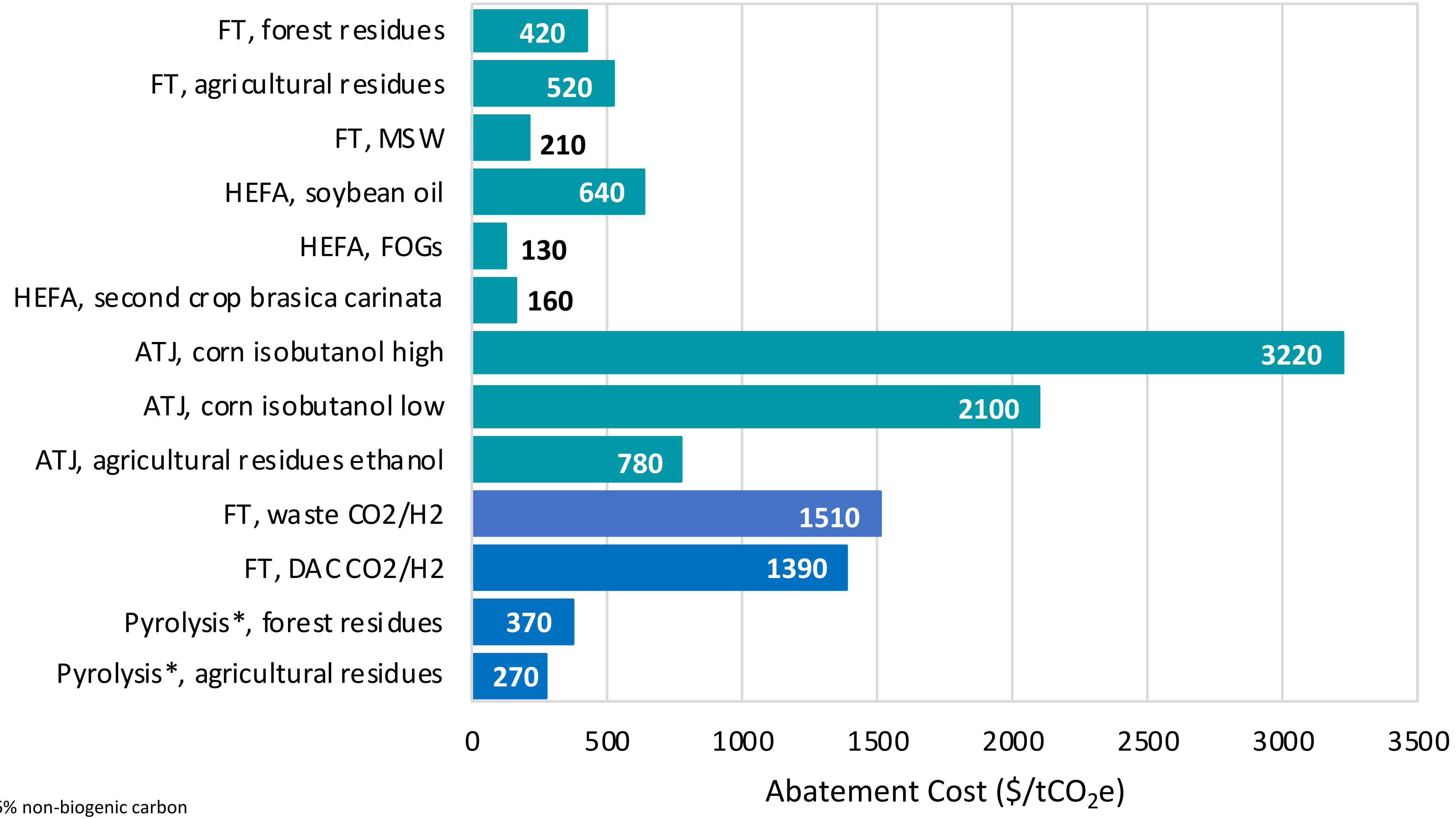
Estimated SAF MSP



Note: Feedstock prices are for 2017. Prices for some feedstocks (lipids, ethanol, etc.) are commodities and the prices vary with global demand and inflation. These can greatly impact the MSP.

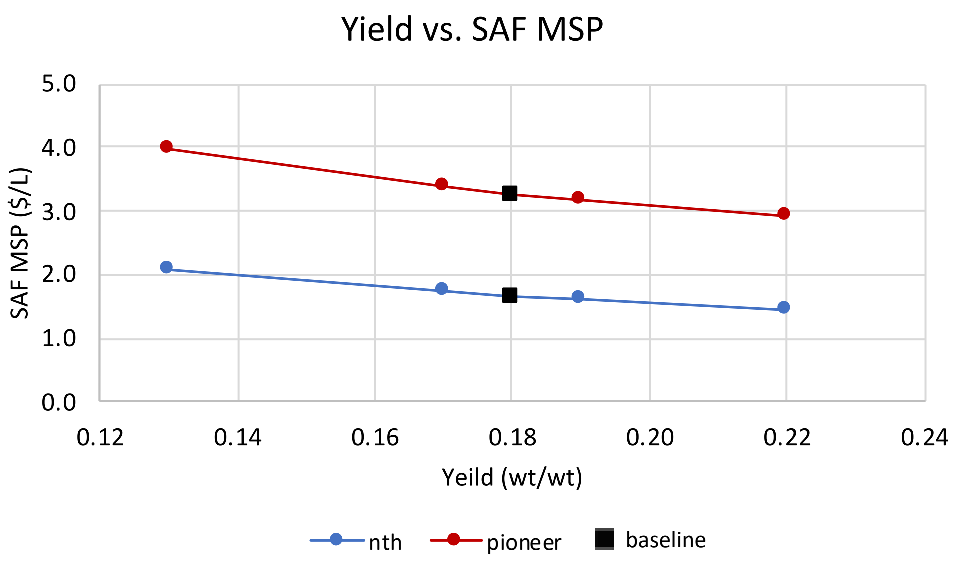
Adapted from ICAO SAF Rules of Thumb (https://www.icao.int/environmental-protection/Pages/SAF_RULESOFTHUMB.aspx)
*not currently through ASTM approval process0

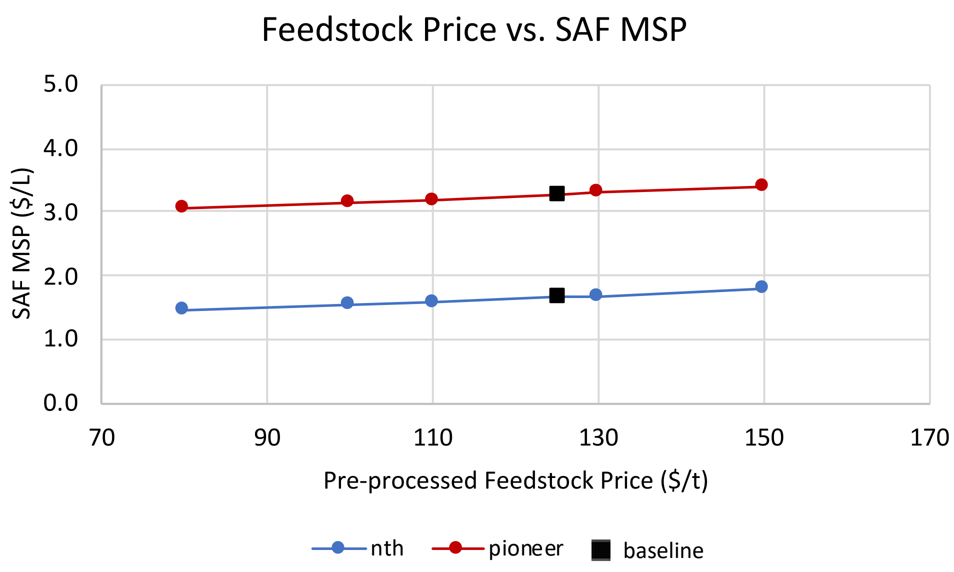
Abatement Cost

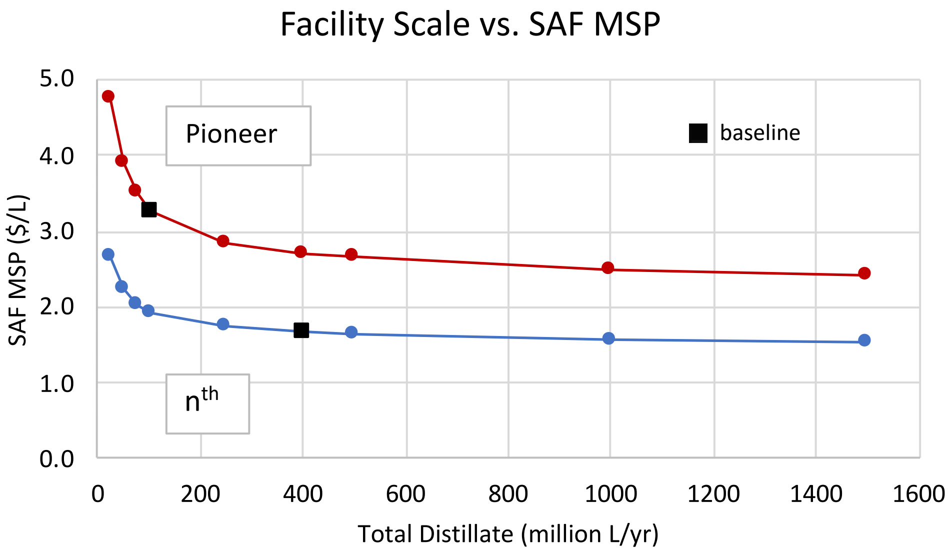


Note: FT, MSW assumes 16% non-biogenic carbon
* ASTM approval pending

GFT with forest residues







Conclusion

- ICAO Rules of thumb, supported by ASCENT TEA tools, provide information on total capital investment needs, SAF minimum selling price, CO_2 abatement cost, etc.
- Such information is provided for various SAF conversion technologies and feedstock combinations, notably Fischer Tropsch (FT), alcohol to jet (ATJ), HEFA, catalytic hydrothermolysis (CH) and pyrolysis.
- ASCENT TEA tools are harmonized, open-source spreadsheets available to ACT-SAF Partners to enhance their modelling, using their own data.
- States can contact ICAO if they wish to bring their data for CAEP consideration.

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ACT SAF

Questions and Answers

ACT SAF
Assistance, Capacity-building and Training for SAF

Closing Remarks

ICAO ENVIRONMENT

Upcoming ICAO Events

ACT SAF

ICAO Symposium on Non-CO2 Aviation Emissions

16-18 September 2024, ICAO HQ, Montreal, Canada

https://www.icao.int/Meetings/SymposiumNonCO2AviationEmissions2024/

ICAO LTAG Stocktaking event

7-10 October 2024, ICAO HQ, Montreal, Canada

https://www.icao.int/Meetings/LTAGStocktaking2024/

Follow up actions

We need your assistance on the following actions:

- Provide any further feedback on the "SAF business implementation template"
  - draft circulated to ACT-SAF partners on 14-June; feedback welcome by 5th July.
- Suggest "latest news" for inclusion in next ACT-SAF series
- Suggest possible consultants with suitable expertise for the upcoming ACT-SAF Projects.
- Contact ICAO if your State is looking for any specific support (e.g. local training)

Responses to officeenv@icao.int will be appreciated

ICAO

THANK YOU