Sustainable Aviation Fuel (SAF):
Aviation needs SAF …
SAF needs your technologies!

tcbiomass*plus* 2019

Day 3, Keynote #1
Steve Csonka
Executive Director, CAAFI

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COMMERCIAL AVIATION
ALTERNATIVE FUELS INITIATIVE

First flight from continuous commercial production of SAJF, 10Mar'16
Fuel from World Energy - Paramount (HEFA-SPK 30/70 Blend).

09Oct'19

Overall industry summary:
Sustainable Aviation Fuel (SAF) activity

- SAF are key for meeting industry's commitments
  - Delivers net GHG reductions of 65-100%, other enviro services
  - Aviation enterprise aligned; 26B gpy US & 90B GPY worldwide opt'y
  - CAAFI and others (e.g. AIREG) are working to foster, catalyze, enable, facilitate, participate
  - Segment knows how to make it; Activities from FRL 1 to 9
  - Pathway identified for fully synthetic (50% max blend today)
  - First facilities on-line, producing SAF at various run-rates
  - Commercial agreements being pursued, fostered by policy and other unique approaches
- Making progress, but still significant challenges – only modest production: focus on enabling commercial viability
- Potential for acceleration a function of engagement, first facilities' success replication, additional technologies

Aviation takes its environmental responsibility seriously …

Decades of progress with:

- *Airport community noise*
- *Tailpipe emissions*
  - *CO, UHC, Smoke, NOx*
  - *PM (recent addition)*
- *Fuel mileage std. (recent)*
  All have ratcheting stringency under ICAO CAEP oversight via global treaty
- *Fuel efficiency*
  Driven by inherent demand to continuously improve aviation's productivity; addressing highest expense category

Now facing the societal pressure of addressing GHGs and growth, while other sectors potentially shrink via incorporation of new technologies

Aviation takes its environmental responsibility seriously … on GHGs too

Industry commitments in 2009, 2012, 2015, 2019

Aviation Industry Commitment to Action on Climate Change

As leaders of the aviation industry, we recognise our environmental responsibilities and agree on the need to:

- build on the strong track record of technological progress and innovation that has made our industry the safest and most efficient transport mode; and
- accelerate action to mitigate our environmental impact, especially in respect to climate change while preserving our driving role in the sustainable development of our global society.

Therefore, we, the undersigned aviation industry companies and organisations declare that we are committed to a pathway to carbon-neutral growth and aspire to a carbon-free future.

To this end, in line with the four-pillar strategy unanimously endorsed at the 2007 ICAO Assembly, we will:

1. push forward the development and implementation of new technologies, including cleaner fuels;
2. further optimise the fuel efficiency of our fleet and the way we fly aircraft and manage ground operations;
3. improve air routes, air traffic management and airport infrastructure; and
4. implement positive economic instruments to achieve greenhouse gas reductions wherever they are cost-effective.

We urge all governments to participate in these efforts by:

1. supporting and co-financing appropriate research and development in the pursuit of greener technological breakthroughs;
2. taking urgent measures to improve airspace design including civil/military allocation, air traffic management infrastructure and procedures for approving needed airport development; and
3. developing and implementing a global, equitable and stable emissions management framework for aviation through ICAO, in line with the United Nations roadmap agreed in Bali in December 2007.

Our efforts and commitment to work in partnership with governments, other industries and representatives of civil society will provide meaningful benefits on tackling climate change and other environmental challenges.

We strongly encourage others to join us in this endeavour.

Robert J. Aaronson, Director General — James C. Cherry, Chairman (Airports Council International)
Alexander ter Kuile, Secretary General — Ashley Smout, Chairman (CANSO)
Marion C. Blakey, Chair — Takatoshi Hosoya, Vice Chair
Giovanni Bisignani, Director General & CEO — Fernando Pinto, Chairman (IATA)
Thomas Enders, President & CEO (AIRBUS)
Scott Carson, President & CEO (BOEING)
Steve Ridolfi, President, Regional Aircraft (BOMBARDIER)
Eric Bachelet, CEO (cfm)
Frederico Fleury Curado, President & CEO (EMBRAER)
Scott C. Donnelly, President & CEO, GE Aviation
Stephen Finger, President (Pratt & Whitney)
Mark King, President, Civil Aerospace (Rolls-Royce)
Philippe Rochat, Executive Director (ATAG)

3rd Aviation & Environment Summit; 22nd April 2008; Geneva, Switzerland

Aviation Industry Commitment to Action on Climate Change: 3 Goal Approach

GOAL 1

PRE-2020 AMBITION

1.5% ANNUAL AVERAGE FUEL EFFICIENCY IMPROVEMENT FROM 2009 TO 2020.

T O I

GOAL 2

IN LINE WITH THE NEXT UNFCCC COMMITMENT PERIOD

STABILISE NET AVIATION CO_2 EMISSIONS AT 2020 LEVELS WITH CARBON-NEUTRAL GROWTH.

T O I + M

GOAL 3

ON THE 2°C PATHWAY

REDUCE AVIATION'S NET CO_2 EMISSIONS TO 50% OF WHAT THEY WERE IN 2005, BY 2050.

T O I

Four Pillars of the Commitment:

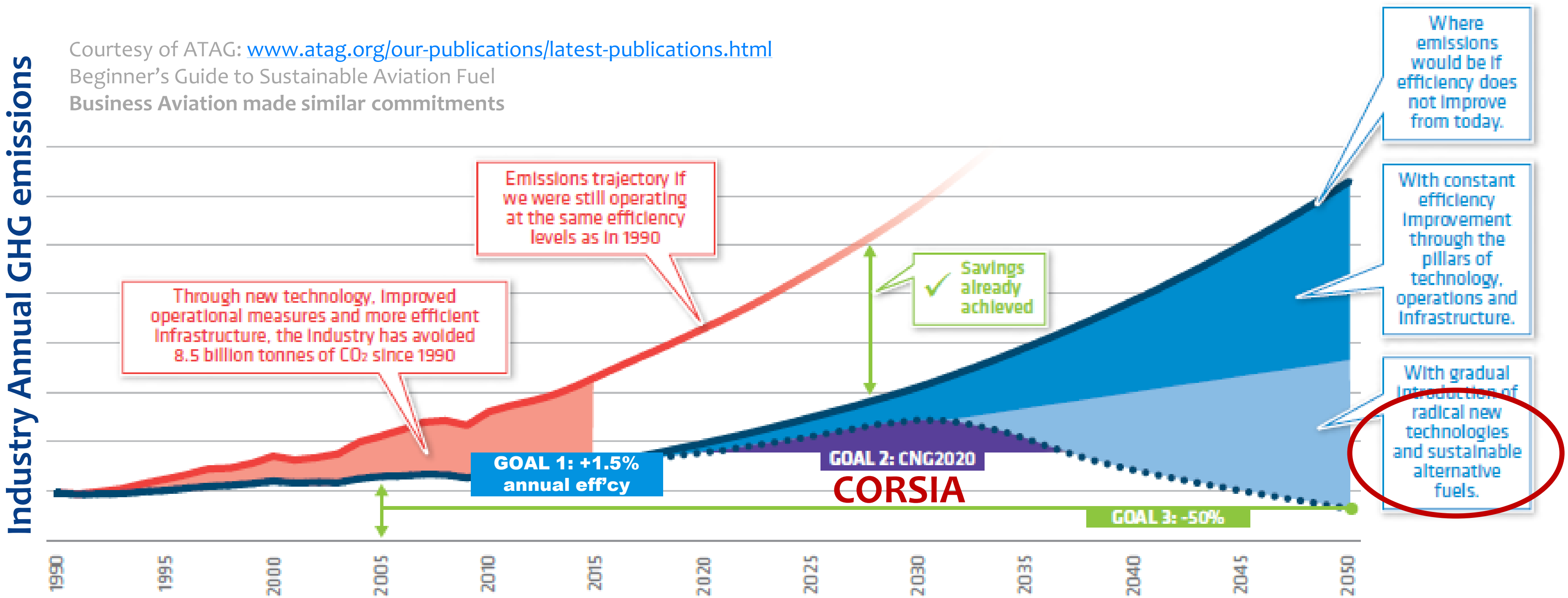
Technology, **O**perations, **I**nfrastructure, and **M**arket-Based Measures

Technology includes the development and commercialization of Sustainable Aviation Fuels

Source: Boyd, Robert (IATA). 2018 CBGM. Policy Panel Discussion. Available at: http://caafi.org/resources/pdf/1.9_Policy_Discussion.pdf

Aviation Industry Commitment to Action on Climate Change: 3 Goal Approach

Courtesy of ATAG: www.atag.org/our-publications/latest-publications.html
Beginner's Guide to Sustainable Aviation Fuel
Business Aviation made similar commitments



SAF a key component of the Technology Pillar; enabler for GHG containment strategy

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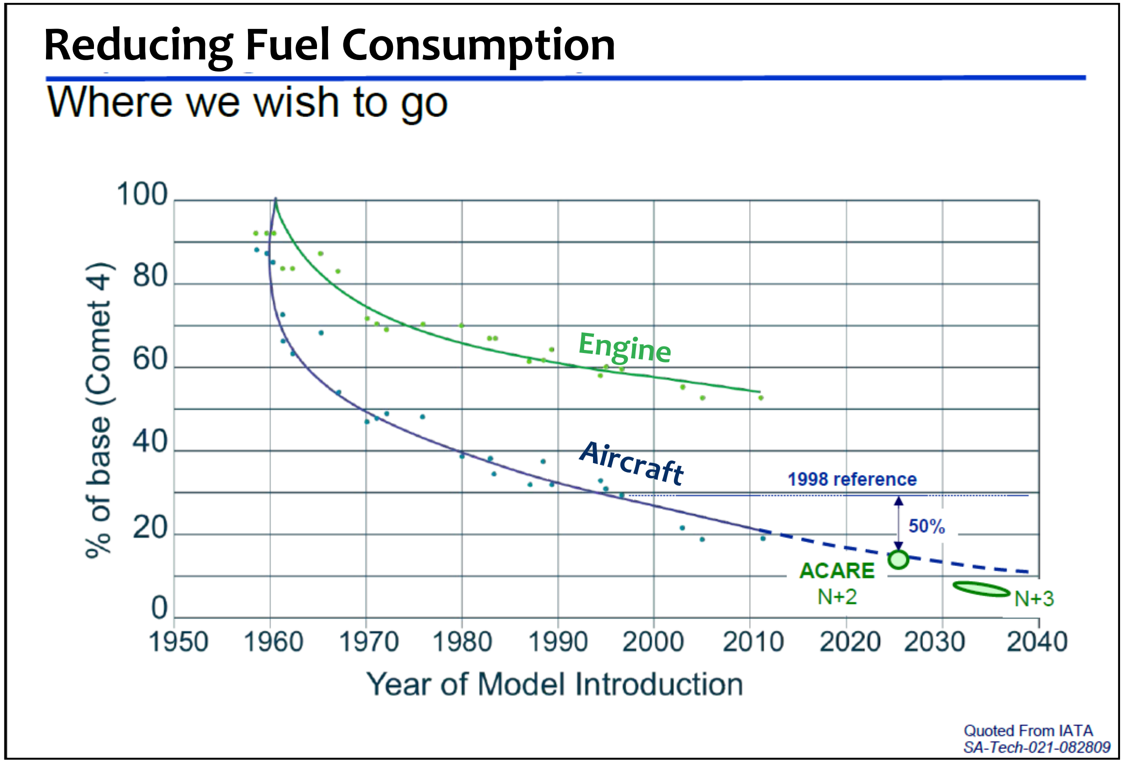
Why not simply aircraft / engine technologies?

* **Each major engine OEM spending > $1B per year in R&D and product development to maintain or improve upon an ~ -2%/yr technology introduction trend … a tough task**



Technology alone (~ 1.5-2.0% aair) insufficient to keep up with projected traffic growth (~ 4-5% aagr)

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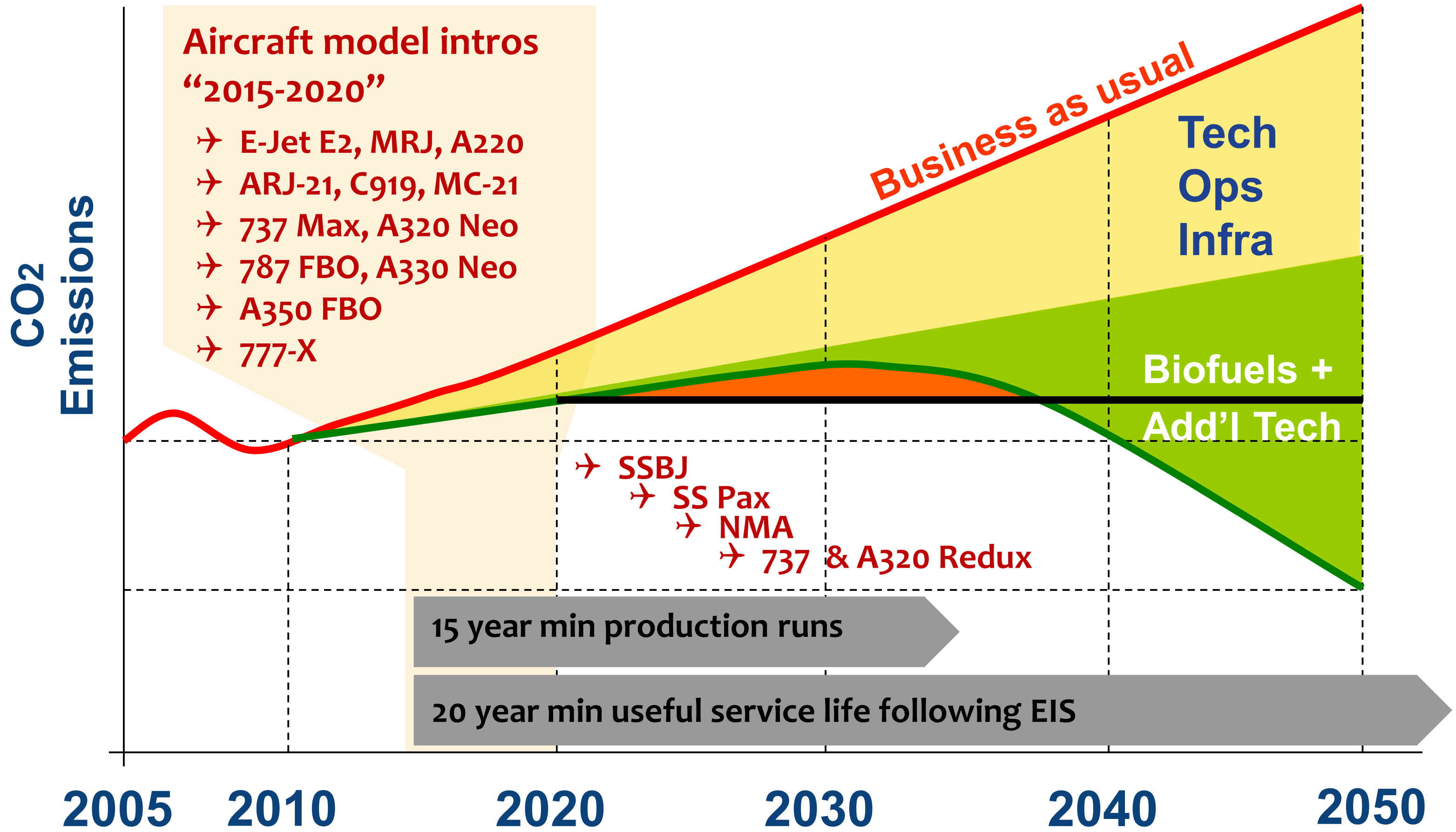
Jet fuel usage will continue …

Through several decades, with tomorrow's technology

CO_2 Reduction Roadmap & Goals



… and into the intro period of "Radical New Technologies"

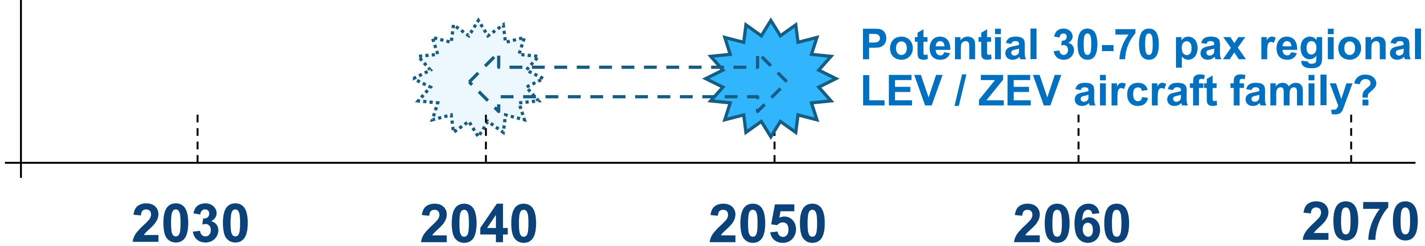
CO2 Emissions Reduction Concepts Introduction

CO_2 Reduction Concepts

- Brayton cycle entitlement (UHBR, GTF, UDF)
  - Hybrid: gas turbine HP augmented w/ electrics
    - Distributed propulsion / Ultra span concepts
      - New thermodynamic cycle concepts / Variable cycle
        - Dual fuel, new fuel (LNG, H_2, …)
          - Cryogenic Fuel - intercooled / variable cycle engines, supercooled conduction, associated tech, …
            - Cryogenic fuels – unconventionally fully-electric
              - Battery/fuel-cells – conventionally fully-electric aircraft
                - Battery powered full electric (off by factor of 50)
                  - Super-/hyper-sonic slingshot aircraft, scramjet
                    - …

Potential Break Points, e.g.:

- Aircraft / engine configuration changes drive terminal / runway changes?
- Duplicate fueling systems
- New hydrant systems / new airports
- Quick charge/change aircraft configs



Between a *Rock and a Hard Place*

- No technology on the horizon to decarbonize current / advanced commercial aircraft (>100 seats)
  - Energy and Power densities of batteries and electrical systems are 50X off the levels needed to replace hydrocarbon fuels
  - No fuel switches (X-OHs, diesel, LNG, CNG, H2, …) appear viable
- So, for the next 3-4 decades, we're forced to look primarily to the fuel to enable carbon reduction.
- SAF - Maintaining our license to grow!
- SAF – Perhaps maintaining our license to exist!

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IATA Recommitment to SAF at 75th AGM
02Jun'19 Resolution Pronouncement

Renewed emphasis on SAF in Resolution

… ENCOURAGES all ICAO Member States to demonstrate climate and aviation leadership;

… URGES all IATA members to take part in the long-term energy transition of air transport towards sustainable aviation fuels; These are key to achieving the industry's 2050 commitment.

… EMPHASIZING that IATA member airlines have consistently considered that meeting aviation's climate goals relies not only on industry action but is also subject to governments incentivizing technological research and development for airframes and engines and the commercial development of sustainable aviation fuels, …

More to follow from Lufthansa and JetBlue Chair IATA appointments for the next 2 years.

Similar statement followed from Aerospace Industries Association.

CAAFI - Public/Private Partnership

A reflection of the unaddressed focus on industry GHGs

An aviation industry coalition established in 2006 to facilitate and promote the introduction of sustainable aviation fuel (SAF), coincident with the industry's commitments

Goal is development of non-petroleum, drop-in, jet fuel production with:

* ***Equivalent safety & performance***
* ***Comparable cost***
* ***Environmental improvement***
* ***Security of energy supply for aviation***

SAF - Synthetic kerosene, primarily from renewable or recycled H-C sources

Enables its diverse stakeholders to build relationships, share and collect data, identify resources, and direct research, development and deployment of alternative jet fuels

AEROSPACE INDUSTRIES ASSOCIATION

FEDERAL AVIATION ADMINISTRATION

AIRPORTS COUNCIL INTERNATIONAL NORTH AMERICA

Airlines for America™ We Connect the World

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SAF (Sustainable Aviation Fuel)
a.k.a. aviation biofuel, biojet, alternative aviation fuel

Aviation Fuel: Maintains the certification basis of today's aircraft and jet (gas turbine) engines by delivering the properties of ASTM D1655 – Aviation Turbine Fuel – enables drop-in approach – no changes to infrastructure or equipment, obviating incremental billions of dollars of investment

Sustainable: Doing so while taking Social, Economic, and Environmental progress into account, especially addressing GHG reduction

How: Creating synthetic jet fuel by starting with a different set of carbon molecules than petroleum … a synthetic comprised of molecules essentially identical to petroleum-based jet (in whole or in part)

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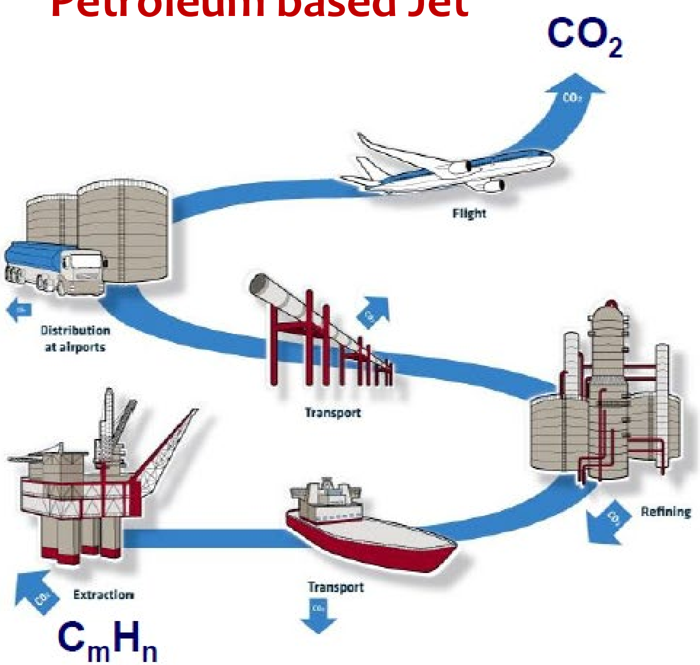
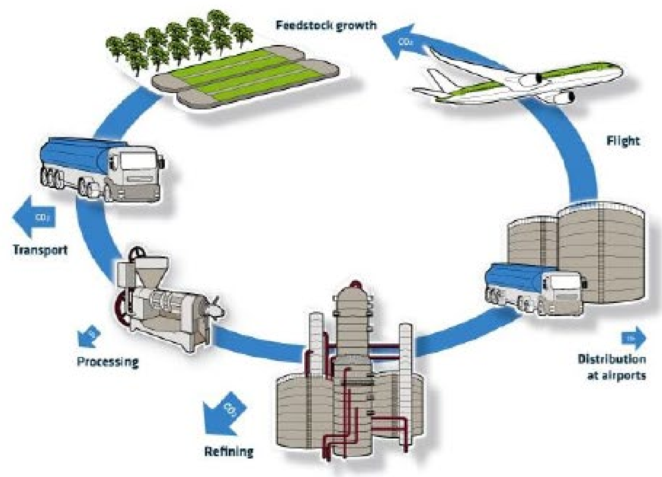
Achieving net Lifecycle GHG Reductions with SAF

Petroleum based Jet



Sustainable Aviation Fuel



Result is a net reduction of additional carbon being introduced into our biosphere

Continuing to pull additional carbon from the ground and releasing it into the atmosphere as CO_2

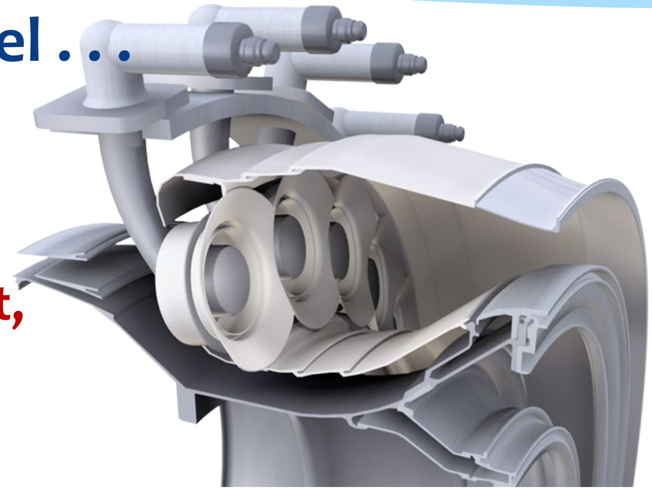
Acquiring the majority of our carbon from the atmosphere, via biology, turning it back into fuel

Turbine fuel functional requirements

Foundation for certification basis

How does the aircraft use fuel . . .

- As a coolant
- As a lubricant
- As a hydraulic fluid
- As a ballast fluid, swelling agent, capacitance agent, …
- And finally, as an energy source



ASTM D-1655
- Acidity
- Aromatics, max%
- Sulfur
- Distillation
- Flash Point
- Density
- Freeze pt
- Viscosity
- Heat of Combustion
- Copper strip corrosion
- JFTOT
- Existent gum
- MSEP
- Electrical conductivity

Need: Efficiency and safety paramount

- High energy content: volumetric & mass
- Stable: high flash point (no explosions), low freeze point (liquid at -40C)
- Unique properties enable required Operability

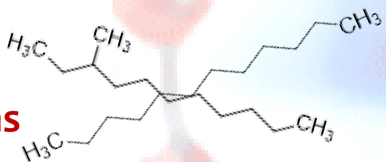
Turbine fuel used for multiple purposes… So its creation has to be carefully controlled to get the right fit-for-use properties

Typical jet fuel composition

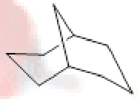
Definition around which aviation enterprise is optimized

A middle distillate refinery stream is used for jet fuel

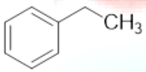
- Comprised of mixtures of aliphatic and aromatic hydrocarbons with carbon numbers predominantly in the range of C7-C17, which is typically a mixture of:
  - ~25% / 11% normal / branched paraffins

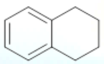


  - ~30% / 12% / 1% mono- / di- / tri-cycloparraffins

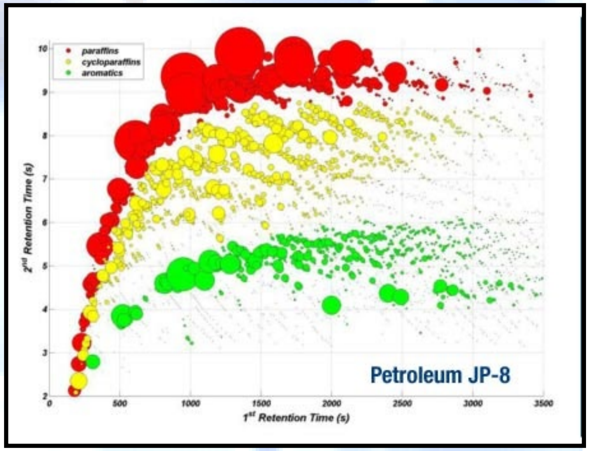


  - ~16 / 5% mono- / di-nuclear aromatics





(25% max aromatics – air quality concern)



- A Gaussian distribution of hydrocarbons, represented as C12H23

There is no standard "formula" for jet fuel

- Composition that delivers the physical properties and performance-based requirements / characteristics of ASTM D1655 specification

Aviation industry path to SAF

* **ASTM D1655 - Standard Specification for Aviation Turbine Fuels**
  * **A1.1.2 …** Aviation turbine fuels with synthetic components produced in accordance with Specification D7566 meet the requirements of Specification D1655.

* **ASTM D4054 - Standard Practice for Qualification and Approval of New Aviation Turbine Fuels**
  * **1.1** This practice covers and provides a framework for the qualification and approval of new fuels and new fuel additives for use in commercial and military aviation gas turbine engines…

* **ASTM D7566 - Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons**
  * **1.2 …** Aviation turbine fuel manufactured, certified and released to all the requirements of this specification, meets the requirements of Specification D1655 and shall be regarded as Specification D1655 turbine fuel.

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Technologies applicable to SAF

Industry approval of SAF via ASTM D4054 Process

Additional Conversion Process Pipeline

Tier 1 &2 testing nearly complete, draft Research Rpt in process, shock tube test at Stanford & initial referee rig test at AFRL completed.

E.g. Vertimas provided initiation plans to OEMs at June ASTM

Phase 1 ASTM Research Report

OEM Review & Tier 3 & 4 Requirements

Virent SAK

Tier 3

Component/Rig Testing

Tier 4

Engine/APU Testing

Phase 2 ASTM Research Report

OEM Review & Approval

Shell IH²

IHI Bb-Oil HEFA

ATJ-SKA (Swed Biofuels)

FT Biocrude Co-processing (D1655)

Fast Track testing at UDRI completed end of April, R'Rpt submitted to OEMs June 12

HFP-HEFA (HDRD or Green Diesel)

FAA Review

ASTM Review & Ballot

Accept

Reject

Re-Eval As Required

ASTM Specification

ASTM Balloting Process

ASTM Specification

Annex A5 ATJ-SPK (Isobutanol & ethanol)

Annex A4 FT-SKA

Annex A3 HFS-SIP

Annex A2 HEFA-SPK

Annex A1 FT-SPK

ARA CHJ

Addressing a couple final concerns with conductivity. Annex likely to be finalized by Q1'20.

Ballot awaiting Q4 release

FOG Co-processing (D1655)

Swedish Biofuels prepared draft R'Rpt, and discussed at Jun'19 ASTM mtg

Working improvements: 4054 Clearinghouse, Quick Entry Annex

CAAFI R&D Team engagement prior to D4054: Tier α, Tier β

FAA assistance with costs

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SAJF Progress - technical

* SAJF are becoming increasingly technically viable
  * Aviation now knows we can utilize numerous production pathways (5 approved, others pending)
  * Enabling use of all major sustainable feedstocks (lipids, sugars, lignocellulose, H&C slip-streams)
  * Following blending, fuel is drop-in, indistinguishable from petro
  * Some future pathways will produce blending components that will need less, or zero, blending
  * Expanding exploration of renewable crude with refiners
* Significant "pipeline" of new production pathways
* Continuing streamlining of qualification – time, $, methods

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SAF progress - commercial

* The path to SAF commercialization has perhaps commenced
  * In production; in construction; in final design; in conceptualization
  * Some will be readily replicable
  * May be able to leverage existing refineries, as well as alcohol and renewable diesel production facilities
* The primary impediments to rapid growth:
  * A production cost delta versus petroleum-jet, and;
  * Competition from diesel (road and maritime), and;
  * A policy environment that may not close cost delta, creates market distortions, and continues to foster uncertainty
* Given a policy framework that addresses the above, SAF is perhaps on the cusp of rapid expansion and replication
  * Many members of entire supply-chains are working to enable such (academia, national labs, entrepreneurs, big oil, fuel suppliers, pipeline companies, farmers and foresters, facilitators, aviation partners)

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ASTM D4054 pipeline

Approach	Feedstock	Companies
ATJ Expansion	Alcohols (via sugars)	Swedish Biofuels*, Byogy
HDCJ (direct or co-processing)	Lignocellulose	Ensyn/Envergent, REC
Microbial conversion	Isobutene (via sugars)	Global Bioenergies*
HTL	Lignocellulose	Steeper, Genifuel, …
Catalytic HTL	Lignocellulose	Licella, Muradel, QUT
Thermal Deoxyg.	Lipids	Forge Hydrocarbons*
SBI CGC PICFTR	Lipids - biodiesel	SBI Bioenergy / Shell
Acid Deconstruction	Lignocellulose	Mercurius
Bio-TCat (thermal catalytic)	Lignocellulose	Anellotech*
CCL	Lipids	
CHyP (syngas, non-FT)	Lignocellulose	
Hydrogenotrophic Conv.	CO_2 / Producer Gas	
Cyanobacterial Prod.	CO_2	
STG+ GTL	c1-c4 Gas / Syngas	
Ionic Liquid Decon.	Lignocellulose	
Metal Catalytic Conversion	Lignocellulose	
Enzymatic Conversion	Lignin	

* Recent outreach to CAAFI R&D Team, ASCENT C.H. and/or OEMs

Why do we care about the pipeline

* We need expanded SAF affordability
  * Processes applicable to lower cost, available feedstocks
  * R&DDD applicable to CapEx, OpEx
* We need SAF availability
  * Available for processing regionally, world-wide, with regionally available feedstocks
* We need commercialization activity / fuels soon
  * Leverage existing biofuel infrastructure or adjacent production
* Some will shift strategies and may never produce jet fuel (Amyris), or produce compounds of lesser interest (Virent)

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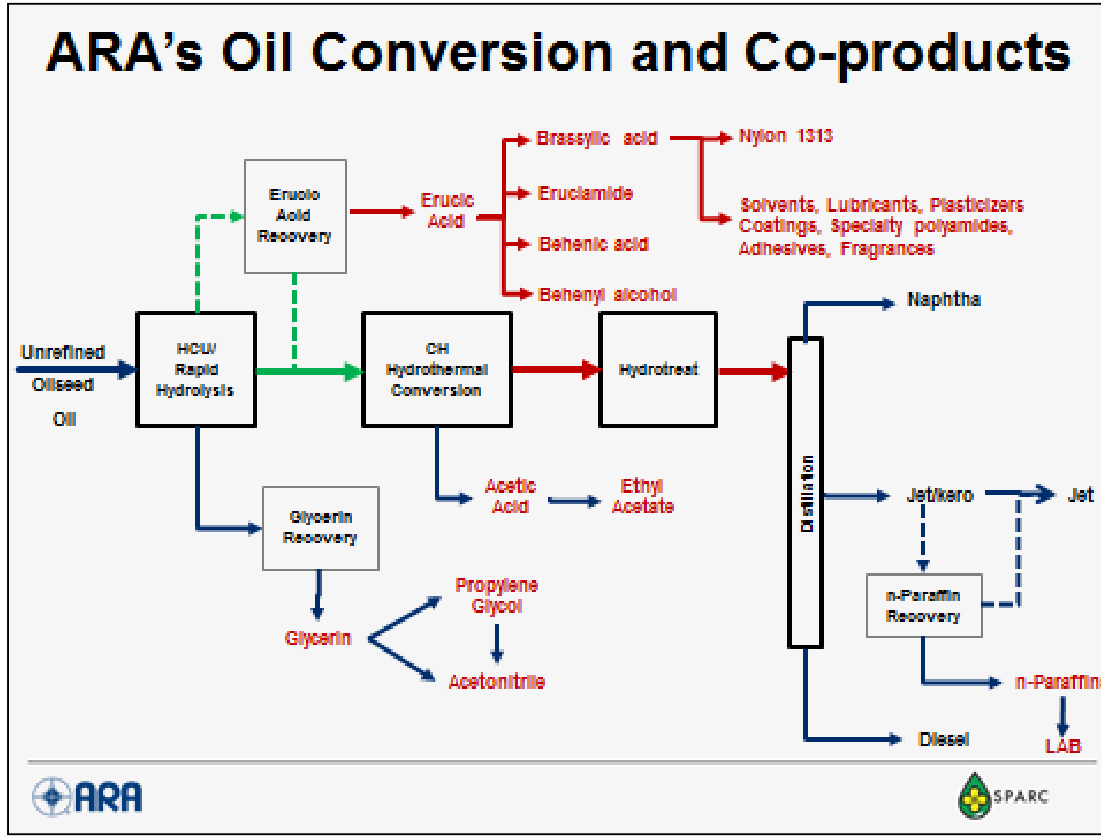
Cost-focus is only part of the need

- Techno-economic assessments don't address total value
- Expectation that viability will be enabled via other revenue, other services, and integration with existing facilities and industries



SAF commercial progress

* Airline engagement continues, strongly with key instigators
  * BizAv and Corporation engagement initiated and expanding
* Other convening activities
  * Fuel Suppliers – new business opportunities
  * Refiners – maintaining markets and meeting policy obligations
    * Co-processing activities
  * NGOs – assisting w/ demand aggregation & market signals
  * Airports – misc explorations, starting w/ infrastructure evaluations
  * Feedstock development – flight demos whet investor interest
  * SAJF & HDRD Producers – continuous stream of exploration and announcements
  * OEMs have their own fuel needs

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SAF offtake agreements

Beyond numerous demonstration programs

neat quantities

World Energy Paramount *

- \+ United = Up to 5 M gpy from 2016 (LAX)
- \+ World Fuel Services, Gulfstream = 3 yr agreement 30/70 blend
- \+ SkyNRG Nordic, Shell, air bp, Finnair, SAS, KLM, Oslo Airport, Lufthansa Group = Misc Flights, e.g. SFO
- = Bioports on demand, et al. (Halmstad, Arlanda, Bromma, Goteborg, Leeuwarden)

Fulcrum BioEnergy

- \+ Cathay Pacific = 37.5M gpy
- \+ United = 90-180 M gpy
- \+ air bp = 50 M gpy
- \+ Japan Airlines, JOIN, Marubeni = Project Development, License, and Offtake

10 yr agreements

* WEP also continues supplying fuel for multiple trial and research activities

SAF offtake agreements

Beyond numerous demonstration programs

			neat quantities
Red Rock Biofuels	+	Southwest	= 3 M gpy each, 7 yrs (Bay Area, CA)
	+	FedEx	=
SG Preston	+	jetBlue	= 10M gpy, 10 yrs (JFK)
	+	QANTAS	= 4M gpy, 10 yrs (LAX)
SkyNRG Nordic	+	KLM	= 24M gpy, 10 yrs
	+	Shell	= SAF Supply collaboration
LanzaTech * (capturing carbon fueling growth)	+	ANA	= Supply from 2021
	+	virgin atlantic	= UK DfT F4C Funding: ATJ Development

* 100M gpy by 2023 from 4 facilities

These offtakes/efforts represent >350 M gpy, and account for the total production slate of the first several commercialization efforts

Other recent announcements

effort

VELOCYS + BRITISH AIRWAYS + Shell = MSW-based FT-SPK evaluations

+ In negotiation = BTL #1, Natchez, MS 1,400 bpd

NESTE + American Airlines, DFW Dallas Fort Worth International Airport, Alaska, air bp = SAJF Supply exploration; MOU to design & implement adoption; Collaboration on supply expansion; SAF restart at Porvoo

AGRISOMA + QANTAS = Carinata supply development

gevo + AVFUEL / AIR TOTAL = Up to 1M gpy, 5 yrs+ / France & EU supply

+ Virgin australia = Brisbane Supply Demonstration

Other recent announcements

effort

Multiple Producers, TBA	+	World Fuel Services, AVFUEL	=	Full production slate offtakes
preem Gothenburg Refinery	+	SAS	=	Long-term supply negotiation (from 2023). Fueling all domestic flights by 2030.
TOTAL | AMYRIS Others, TBA	+	Cathay Pacific, Alaska, jetBlue, China Airlines	=	New Aircraft Deliveries from Airbus and Boeing
TBA	+	FINNAIR	=	Customer funding of SAJF purchase from 2019
Multiple Producers & Suppliers	+	Airports and Airline Tenants (Port of Seattle, Seattle-Tacoma International Airport; SFO)	=	Exploration of Greater ambition
NORTHWEST ADVANCED BIOFUELS	+	DELTA	=	$2M for Grays Harbor, WA feasibility study

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Commitments of Greater Ambition

FedEx	Obtain 30% of jet fuel from alternative sources by 2030; 06Nov'17
UNITED	First U.S. Airline to Pledge to Reduce Own Emissions by 50% (vs. 2005) by 2050; 13Sep'18
Norway	Norway's government introduces 0.5 % blending mandate for advanced aviation biofuels from 2020; 04Oct'18
world energy Paramount	Moving forward with $350M expansion to enable 306M gpy total capacity & jet capacity of 150M gpy; 24Oct'18
Netherlands	Netherlands committed to transition all military aircraft to 20/80 AJF blend by 2030 and 70% by 2050; 23Jan'19
SpiceJet	India's SpiceJet commits to flying 100 M passengers on SAF by 2030; 23Sep'19
AIRFRANCE	Horizon 2030: offset 100% of domestic CO_2 from 2020; reduce 2030's CO_2/pax-km by 50% from 2005; R&D for French SAF industry; 01Oct'19

Commitments of Greater Ambition

Airlines using passenger booking options to offset cost

BRA BRAATHENS REGIONAL AIRLINES — Customer option to pay for incremental price of SAF of €29.50 on any flight

SAS — Customer option to pay for incremental price of SAF in 20-min blocks of flight time for €10 / block (up to 80% CO_2 reductions); fuel being allocated to future flights

Lufthansa — Compensaid – calculates specific cost of SAF for specific flights and enables customer to pay for incremental price

FINNAIR — Customer option to pay for incremental price of SAF for 3 categories of flight: intra-Finland (€10), intra-EU (€20), International (€65); fuel being allocated to future flights

Paradigm changing announcements

Corporate intent to help close price premiums

Resilient and Sustainable Aviation Fuel (RSAF) credit

Clean Skies for Tomorrow Program

Purchase of SAF for US-Netherlands flights (beyond offsetting employee travel)

SAF tactical situation

Approaching CNG2020 aviation commitments

* U.S. airlines could use the annual addition of 300-400 M gpy of neat SAJF to enable offset of expected industry init'l growth obligations (total US production at 26B gpy and growing).
* Activity needed in next 2-3 years for SAF to have a material impact against goal and expected carbon monetization

Aviation a willing offtaker, w/ 10-15 yr offtakes available

* Engagement possible, see *Guidance for Selling Alternative Fuels to Airlines*
* Engage with CAAFI for navigation assistance.

Potential for U.S. SAF build-out

Targets of opportunity

SAF from various feedstocks (GPY, using standard conversions)

"Waste" streams

3.8 B	**Wet Waste** (manures, sanitary, misc streams)
3.1 B	**MSW** (municipal solid waste: wood, paper, yard, plastics, textiles, food)
6.1 B	**Agricultural residues** (primary crop residues only, 31% removal)
0.4 B	**Forestry residues** (30% of production uncommitted)
0.8 B	**F.O.G.** (Fats oils and greases: estimates vary significantly, up to 3.0B)
1.3 B	**Industrial off-gases** (steel, aluminum, petroleum)
x.x B	**Other** (C&D waste, telephone poles, rail ties, invasive tree removal)
~ 15.6 B	**Current Total Potential (approx. 58% of 2019 U.S. demand)**

Summary

* Thank you for your interest in SAF-range molecules!! Interest from the industry is real.
  * Multiple feedstock sources / targeted conversion technologies
* Please continue to focus on TEA and LCA driven technology explorations – the industry needs affordable, low-CI jet blending components
* If you are working in the gasoline/diesel space – you are working in the SAF space – please highlight SAF and its focused market-pull
  * Less certainty over the life of the bio-refinery for gasoline and diesel (targeted at road transport or shipping) demand due likely technology shifts – not the same for aviation.

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SECURE & SUSTAINABLE AVIATION