CAAFI Perspectives on SAF status and commercialization acceleration!

✈ Opportunities and challenges for woody-based biofuels for SAF

Technical Advisory Committee
of the
BR&DB
BIOMASS RESEARCH & DEVELOPMENT BOARD

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Capitol Skyline Hotel, Washington DC

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COMMERCIAL AVIATION ALTERNATIVE FUELS INITIATIVE

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

SAF - Sustainable Aviation Fuel

19Nov'19

Agenda:

* Aviation background: commitments and progress
* Jet Fuel & SAF: Overview and fundamentals
* Conversion technologies
* Forestry Opportunities
* Forestry Challenges
* Thoughts for TAC consideration
* Discussion

Aviation Background

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 need to continuously improve aviation's productivity and control operating costs, of which fuel is the highest expense category

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

Aviation takes its environmental responsibility seriously … on GHGs too

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
mes C. Cherry, Chairman
Alexander ter Kuile, Secretary General
Ashley Smout, Chairman
Giovanni Bisignani, Director General & CEO
Fernando Pinto, Chairman
Marion C. Blakey, Chair
Takatoshi Hosoya, Vice Chair
Thomas Enders, President & CEO
Scott Carson, President & CEO
Steve Ridolfi, President Regional Aircraft
Eric Bachelet, CEO
Frederico Fleury Curado, President & CEO
Scott C. Donnelly, President & CEO GE Aviation
Stephen Finger, President
Mark King, President Civil Aerospace
Philippe Rochat, Executive Director

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

Industry commitments in 2009, 2012, 2015, 2019

Nearly identical commitments from Business Aviation

BUSINESS AVIATION AND CLIMATE CHANGE

Advocating for a global aviation sectoral approach in a post-Kyoto global framework

The global business aviation operating and manufacturing communities support the International Civil Aviation Organization's (ICAO) proposal for aviation sectoral management of targets and monitoring of greenhouse gas (GHG) emissions in a post-Kyoto Agreement. We support the ICAO Programme of Action on International Aviation and Climate Change and are in accord with the Declaration of the High Level Meeting on International Aviation and Climate Change convened by ICAO in Montreal on 7-9 October 2009.

Our record of achievement

Business aviation has established an excellent record of consistently improving fuel efficiency, delivering 40% improvement over the past 40 years. Business aviation's global CO_2 emissions are approximately 2% of all aviation and .04% of global man-made carbon emissions. Business aircraft are operated for specific missions and fly efficient, direct routes between airports. Modern navigation equipment, combined with the latest technologies in aircraft and engine design and operational best practices, provide for ever-improving fuel efficiency and reduced GHG emissions.

Our commitment

Nonetheless, our community is resolved to do even more. Business aviation manufacturing and operating communities have jointly developed an aggressive programme in support of ICAO targets. Achieving these targets will require not only sustained effort on the part of the entire business aviation community, but also a partnership between industry and government, and the development of realistic solutions that balance economic growth, progress and technology. The business aviation community therefore commits to the following specific targets:

- Carbon-neutral growth by 2020;
- An improvement in fuel efficiency of an average of 2% per year from today until 2020;
- A reduction in total CO_2 emissions by 50% by 2050 relative to 2005.

We will achieve these objectives through expected advances in four areas: technology, infrastructure and operational improvements, alternative fuels, and market based measures.

Consistent with ICAO recommendations and limitations on data availability, business aviation supports the development of an appropriate alternative metric within ICAO to measure and track business aviation emissions on a fleet basis.

Our needs

Given the global nature of aviation, internationally harmonized policies, rules and procedures are critical to ensure safe, efficient and balanced operations. Our community believes that ICAO must be assigned global sectoral responsibility over aviation emissions targets and monitoring.

Our promise

The business aviation sector has made remarkable improvements in its environmental performance over the last half century. The industry believes that if scope is given to the aviation community to manage environmental stewardship in partnership with industry and under the leadership of ICAO, all will enjoy a vibrant and healthy industry that will continue to proactively reduce its impact on the environment even as the demand for business aviation continues to grow.

www.ibac.org www.gama.aero

Industry commitments in 2009, 2019

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

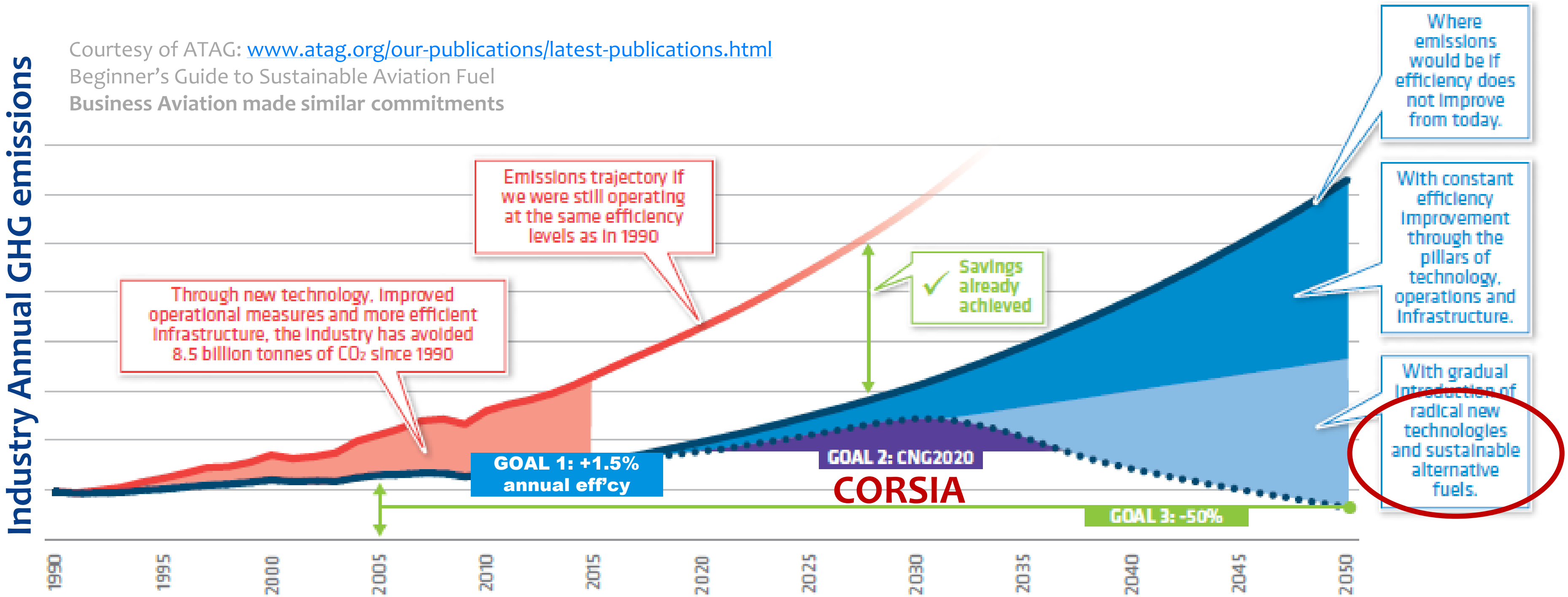
Four Pillars of the Commitment:

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

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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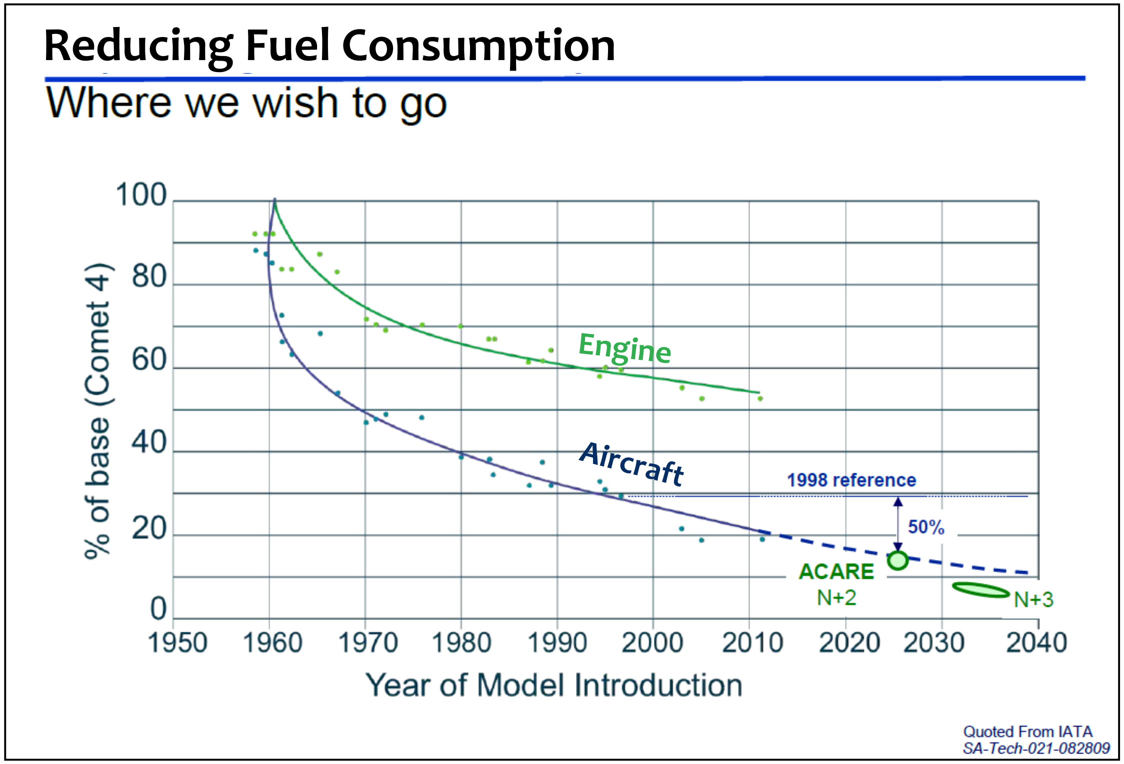
Why not simply aircraft / engine technologies?

* **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)

Aviation background summary

- ICAO regulates international aviation emissions via treaty (Chicago Convention)
  - Regulations become individual country regulations upon adoption by individual States
  - Establishes non-taxation of jet fuel for international use
    - Invokes ire of many suggesting aviation somehow gets a "free ride"
- Aviation was the first world-wide industrial sector to make voluntary GHG commitments (even as a "hard-to-abate sector"), and called for ICAO to promulgation
  - Key interest was to avoid patchwork of regulation that runs counter to treaty intent
  - Key challenge is continued expected growth (especially in developing countries), of 4-5% aagr
- ICAO recognizes "basket of measures" to address GHG reduction need
  - Certification-based Fuel Mileage Standard going forward
  - Established CORSIA – enables CNG2020 via use of SAF and Offsets
    - Could set the stage for domestic approaches
  - Domestic emissions expected to be addressed via Paris commitments
- Aviation efforts attract attention, positive and negative (active protagonists)
  - Aviation lauded to spur others to action (e.g. IMO)
  - Aviation demeaned as result of Paris commitments, and for not being more proactive
- Aviation engaged! Maybe not to the level of some expectations, but tangibly!

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, Finnair, SAS, KLM, Shell	=	Misc Flights, e.g. SFO
+ air bp, Oslo Airport, Lufthansa Group, KLM	=	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)

RED ROCK BIOFUELS + FedEx = 3 M gpy each, 7 yrs (Bay Area, CA)

SG Preston + jetBlue = 10M gpy, 10 yrs (JFK)

SG Preston + QANTAS = 4M gpy, 10 yrs (LAX)

SkyNRG NORDIC + KLM = 24M gpy, 10 yrs

SkyNRG NORDIC + Shell = SAF Supply collaboration

LanzaTech* capturing carbon fueling growth + ANA = Supply from 2021

LanzaTech* + virgin atlantic = UK DfT F4C Funding: ATJ Development

* 100M gpy by 2024 from 4 facilities

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

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Other recent announcements

effort

VELOCYS	+ BRITISH AIRWAYS, Shell	=	MSW-based FT-SPK evaluations
	+ In negotiation	=	BTL #1, Natchez, MS 1,400 bpd
NESTE	+ DFW DALLAS FORT WORTH INTERNATIONAL AIRPORT, American Airlines, Alaska, air bp, Lufthansa	=	SAF Supply explorations SAF Q4'18 restart at Porvoo, ~33M gpy rate, 330M gpy with Singapore by 2022
AGRISOMA	+ QANTAS	=	Carinata supply development
gevo	+ AVFUEL / AIR TOTAL	=	Up to 1M gpy, 5 yrs+ / France & EU supply
	+ Virgin australia	=	Brisbane Supply Demonstration

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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, Delta, ANA, 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

Commitments of Greater Ambition

Multiple airlines additionally committing to net zero by 2050

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. $40M SAF Investment Fund; 27Oct'19
	Norway's government introduces 0.5 % blending mandate for advanced aviation biofuels from 2020; 04Oct'18 Sweden, Spain, … to follow?
world energy Paramount	Moving forward with $350M expansion to enable 306M gpy total capacity & jet capacity of 150M gpy; 24Oct'18
	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 CO2 from 2020; reduce 2030's CO2/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

Intent to help close price premiums

ROCKY MOUNTAIN INSTITUTE + WORLD ECONOMIC FORUM

THE GOOD TRAVELER LEAVES NO TRACE

Resilient and Sustainable Aviation Fuel (RSAF) credit

Clean Skies for Tomorrow Program

SkyNRG NORDIC

Fly Green Fund → BOARD NOW coalition for sustainable flying

Microsoft

AIRFRANCE KLM

DELTA

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

Energy for Airlines

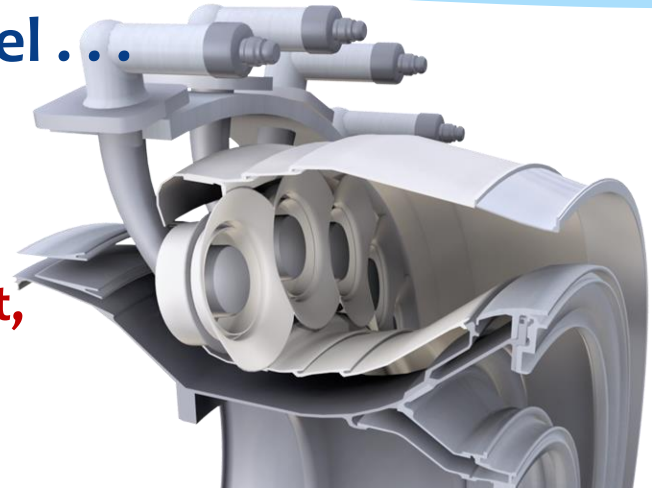
SAF Now Consortium launch, 15Nov'19

Jet Fuel and SAF

Turbine fuel functional requirements
Foundation for aircraft's 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

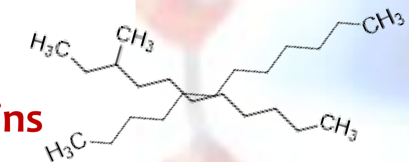
Typical jet fuel composition

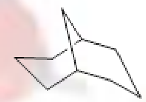
Definition around which aviation enterprise is optimized

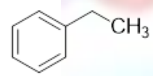
A middle distillate refinery stream is used for jet fuel

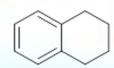
- Comprised of mixtures of aliphatic and aromatic hydrocarbons with carbon numbers predominantly in the range of C_7-C_{17}, which is typically a mixture of:
  - ➢ ~25% / 11% normal / branched paraffins
  - ➢ ~30% / 12% / 1% mono- / di- / tri-cycloparraffins
  - ➢ ~16 / 5% mono- / di-nuclear aromatics

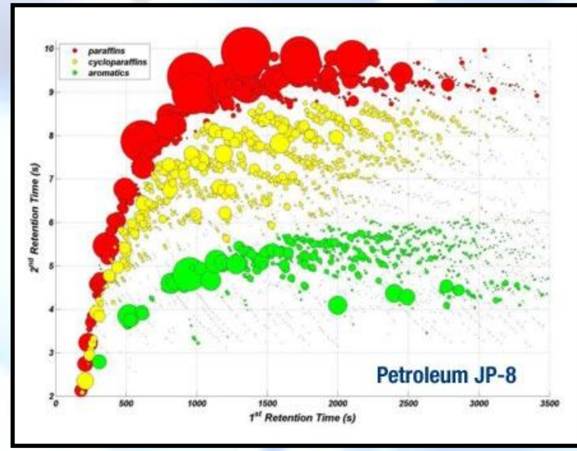
    (25% max aromatics – air quality concern)











- A Gaussian distribution of hydrocarbons, represented as $C_{12}H_{23}$

There is no standard "formula" for jet fuel

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

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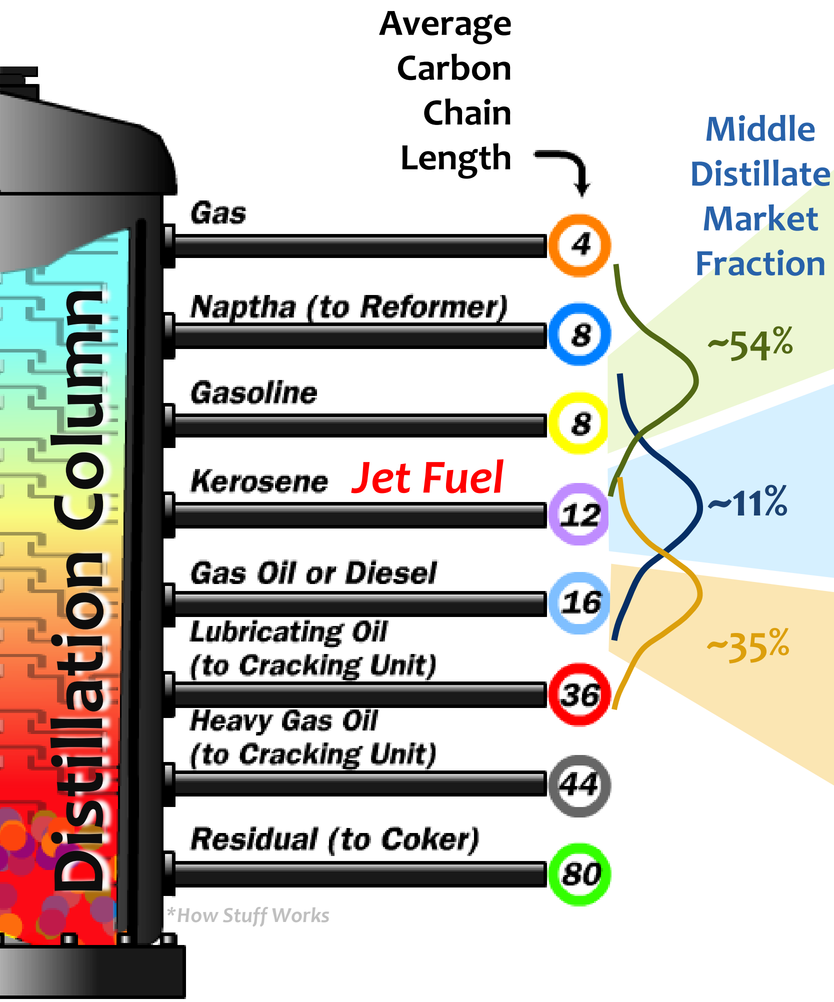
Jet Fuel: a middle distillate refinery product

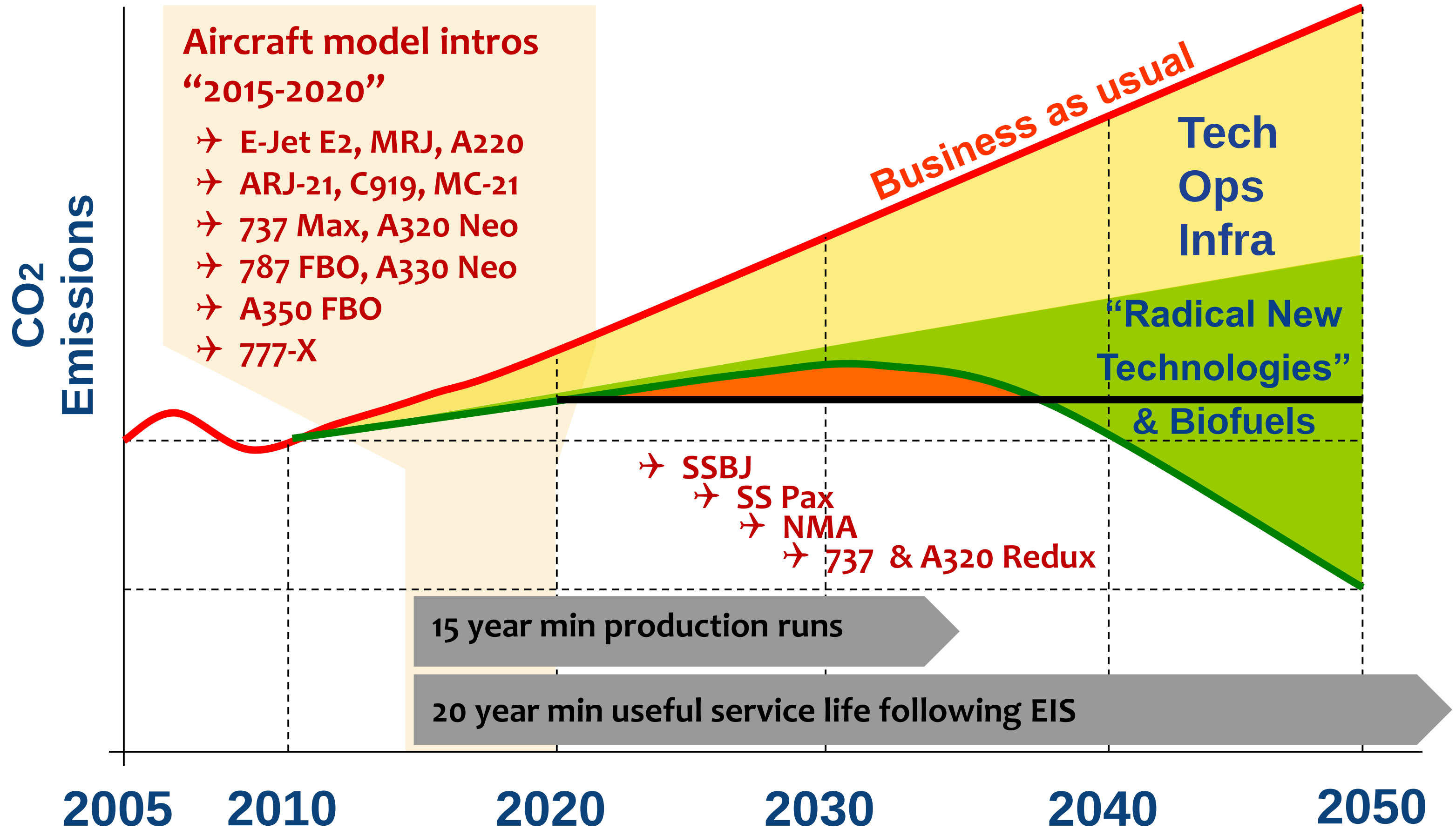


Segment Observations	Energy Options
Cars / Lt. Trucks / Misc. Refineries optimized for gasoline Gas consumption ↓ (CAFE pressure) Future ICE need octane boost ↓ product life, ↓ production runs	**Yes, Too Many!:** • X-OH blends • Hybrids • CNG, LNG, H2 • Fuel Cell, Electric
Jet Aircraft Minority volume; gas/diesel squeeze Jet consumption↑ Fuel requirements stringent – estab. ↑product life, ↑ production runs	**Nothing practical:** • Kerosene, from fossil or renewable H/C sources
Trucks, O/R & HVs, Ships Still need liquid fuels Diesel consumption ?? Future C-IE need cetane boost?	**Yes:** • Biodiesel blends • Hybrids • CNG, LNG, H2

Jet fuel usage will continue …

Through several decades, with tomorrow's technology

CO_2 Reduction Roadmap & Goals



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

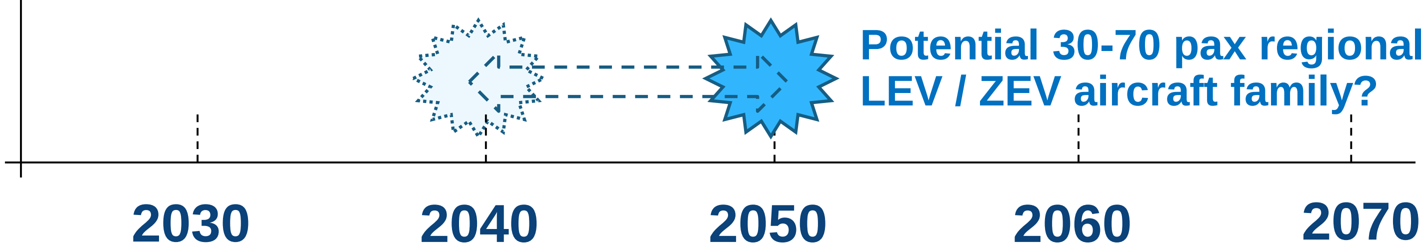
CO₂ Emissions Reduction Concepts Introduction

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



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

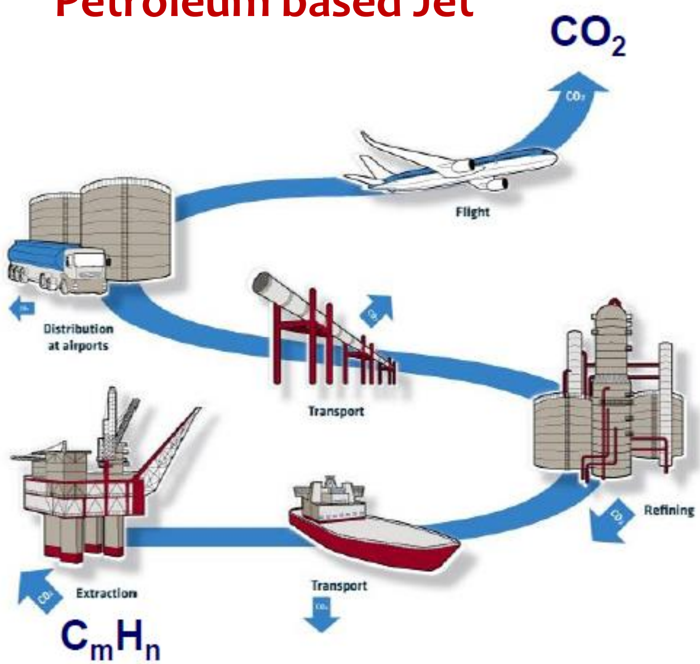
Aviation Fuel: Maintains the certification basis of today's aircraft and jet (gas turbine) engines by delivering the properties of ASTM D1655 – Aviation Turbine Fuel – **enables drop-in approach – no changes to infrastructure or equipment, obviating incremental billions of dollars of investment**

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

How: Creating synthetic jet fuel with biochemical and thermochemical processes 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)**

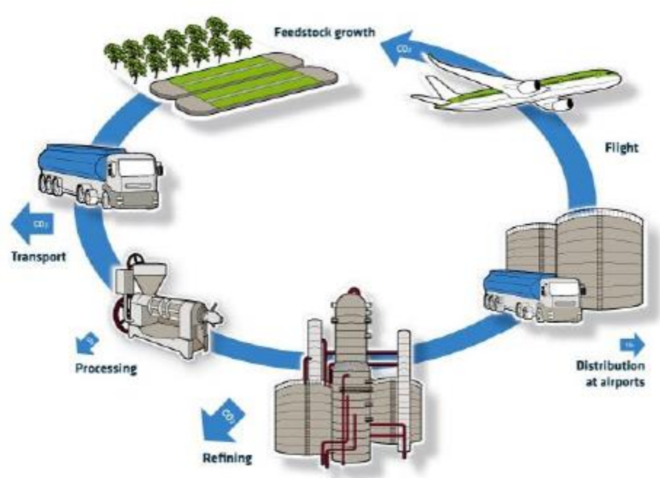
Achieving net Lifecycle GHG Reductions with SAF

Petroleum based Jet



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

Sustainable Aviation Fuel



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

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

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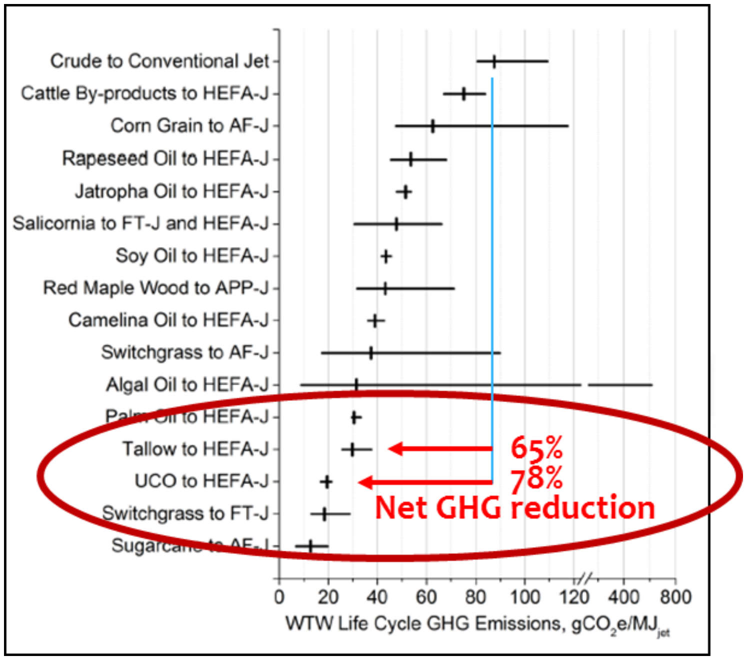
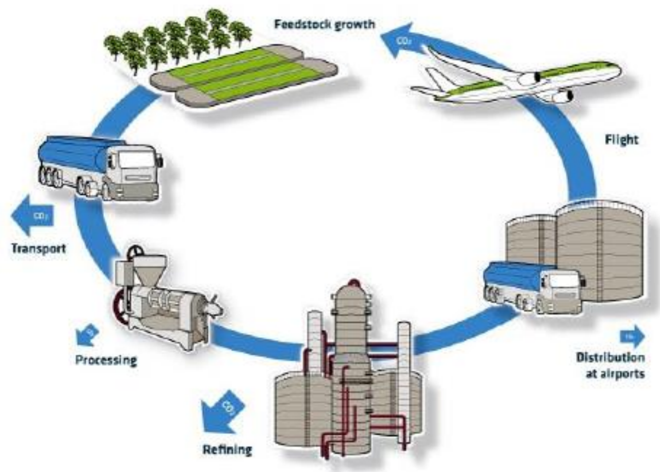
Achieving net Lifecycle GHG Reductions with SAF



Sustainable Aviation Fuel



Policy rewards reductions >50%

Many solutions in the 60-80% range

Some solutions achieve >100% via carbon sequest'n or other emission reduction

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

Overall industry SAF summary:

* No opportunities for liquid hydrocarbon replacement in next several decades for majority of worldwide fleet
* SAF are key for meeting industry's GHG commitments – decoupling carbon from aviation's growth
  * Delivers net GHG reductions of 65-100%, plus other enviro services
  * Aviation enterprise aligned; 26B gpy US & 90B GPY worldwide opportunity
  * Many 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
  * CORSIA monetizes carbon specifically to aviation enterprise
  * Commercial agreements being pursued, fostered by policy / other approaches
  * Making progress, but still significant challenges – only modest production
    * SAF Refineries: 2 full time; 2 batch mode; 3 in construction; multiple in FEED
  * Focus on enabling commercial viability - Potential for acceleration a function of engagement, first facilities' success replication, additional technologies

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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 <u>50X</u> 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 for mainstream commercial aircraft
- Even if we see hybrid or electric applications enter service as a regional turbo-prop replacement, this family of aircraft is only responsible for a small fraction of today's GHGs.
- SAF – Maintaining our license to grow!
- SAF – Perhaps maintaining our license to exist!
- SAF – enables radical-new-tech to enter the system as its own natural pace – as it becomes technically and financially viable!

SAF Conversion Technologies

How is SAF made?
Conversion Processes

* Biochemical conversion processes use various microorganisms that convert feedstocks to hydrocarbon chemicals
* Thermochemical processes use heat and pressure, often with various types of catalysts, in various types of reactors. Examples of these reactions include:
  * Deconstruction: Torrefaction, Pyrolysis, Gasification (in increasing energy levels), dehydration
  * Reconstruction: oligomerization, Fischer Tropsch synthesis, hydroprocessing
  * Fuel Finishing: taking H-C molecules, and making them suitable for use as a jet fuel blending agent, in part or in whole, using typical refinery processes: hydrotreating, hydro-isomerization, hydro-cracking

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How is SAF made?
Feedstocks

* Materials that contain hydrogen and carbon are converted to SAF by using biochemical and thermochemical transformation processes to create jet fuel molecules
* These are often referred to as feedstocks
* Nature gives us 3 families of hydrogen and carbon containing compounds by converting atmospheric CO2 and water
  * Lipids - e.g. fats (animal), oils (various plants), greases
  * Sugars - sugar cane, sweet sorghum, sugar beets, tubers
  * Lignocellulose – cellulose, hemicellulose, lignin
* There are several human activities that also produce waste or byproduct streams that also contain hydrogen and carbon

SAF conversion processes
…or, "dispelling the fear of revisiting Chemistry 101"

Start with hydrocarbon / organic building-blocks

Deconstruct & remove extraneous molecules

Process to workable intermediates

Reformulate to appropriate C_8-C_{16} molecules

Utilize standard refinery "finishing" processes

D7566 - SAJF Blending Components

D1655 – from petroleum and D7566 fuel blends

SAF conversion mechanisms

Challenge … doing it at the price of petroleum refining

Fossil HC	Lipids Plant & Animal	Cellulose & Hemi- & Lignin	Sugars & Starch	Wastes & Syngas	CH_4 \ CO_2

$ $?

Gasify Pyrolize Torefy Saccharify Deconstruct Digest

Separate Ferment Dehydrate Catalyze Process

FT CH CC APR HL Oligomerize

Distill Hydrotreat Hydroprocess Hydro-Isomerize

FT-SPK, HEFA-SPK, HFS-SIP, FT-SPK/A, ATJ-SPK, …

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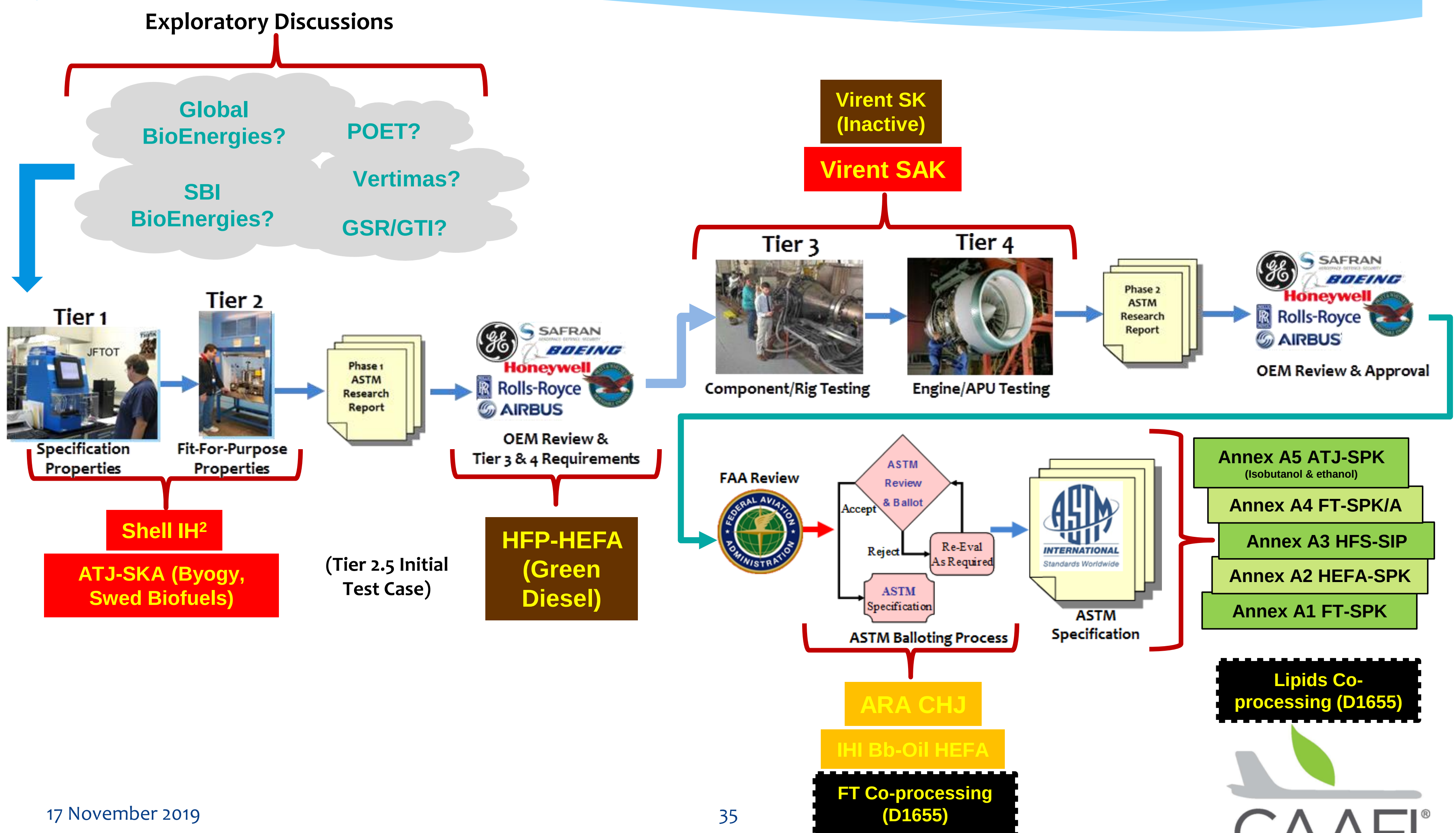
Aviation industry path to SAF

* **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.

ASTM D4054 SAF Qualification Status



ASTM D4054 pipeline examples

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 Deoxygenation	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	C_1-C_4 Gas / Syngas	
Ionic Liquid Decon.	Lignocellulose	
Metal Catalytic Conversion	Lignocellulose	
Enzymatic Conversion	Lignin	
PtL	H_2, point source CO_2, low carbon power	

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

Why we care about the pipeline

* We need expanded SAF affordability
  * Processes applicable to lower cost, available feedstocks, low CI
  * R&DDD applicable to CapEx, OpEx
* We need expanded SAF availability
  * Available for processing world-wide, with regionally available sustainable feedstocks
* We need commercialization activity / fuels soon, not in 2030+
  * 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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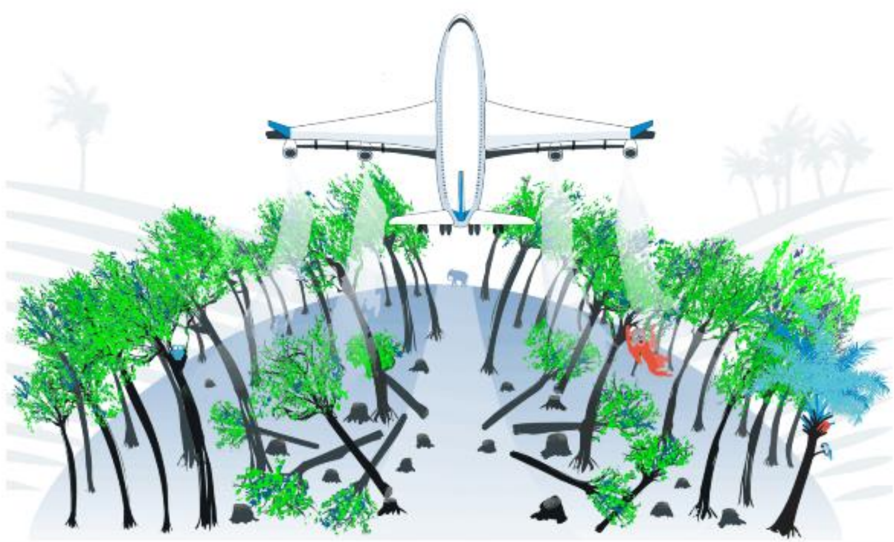
No single feedstock is targeted or sufficient

Aviation climate targets may drive 3 million hectares of deforestation

The aviation industry's climate targets are likely to lead to a dramatic increase in demand for palm oil and soy for aviation biofuels. A new report concludes that this may result in 3.2 million hectares of tropical forest loss – an area larger than Belgium.

Published: 01.10.2019



- **Extrapolation and pet-peeves lead you to extraordinary theories and positions**
- **Aviation has embraced verifiable sustainability and standards, and has shunned some more controversial solutions**

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Forestry Opportunities

Potential for U.S. SAF build-out

SAF from several prevalent waste stream feedstocks

(GPY, using standard conversion efficiencies and viable SAF fractions)

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)**
	Plus, low ILUC purpose-grown crops
	Plus, …

General forest residue opportunities

Advantages

* Relative homogeneity, steadiness of supply
* Some aggregation already occurs
* Timber basins no longer supporting viable paper industry and need economic development opportunities – offer incentives
* Significant acreage: NW, SE, NE

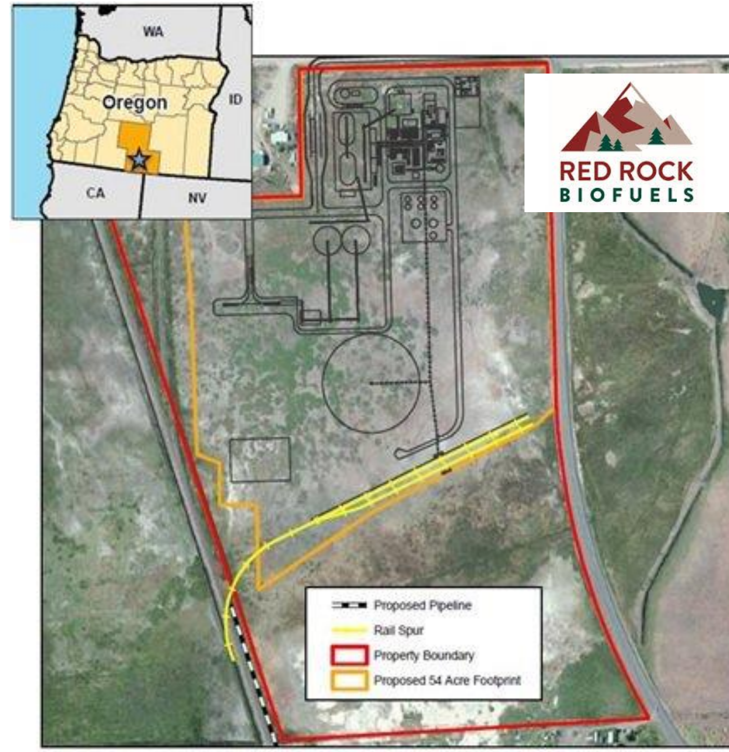
Producers are finding sustainable approaches

* Direct use of residues:
  * FT, Pyro co-processing, IH², HTL,
* Use of hydrolyzed sugars
* Use of lignin
* Use of Tall Oil (from Kraft pulp production)
  * UPM – making diesel today, SAF tomorrow?
* Considering some very unique supply-chain approaches, including densification / intermediates

Red Rock	FT
Velocys	FT
Anellotech	Bio-TCat
Biodico	hybrid
Shell/IH² customers	HTL (e.g. Synsel)
D'Arcinoff	FT
Eco-Options Energy	hybrid biocatalytic
Envergent	Pyro
Expander	FT
Gasosyn	FT
Greenfield	hybrid
Juniper	FT
Licella	HTL
Loring	hybrid
Mercurius	REACH
NuFuels	FT
Proton	hybrid
Renovare	AD-biogas-FT
US Advanced Bio-Fuels	FT
USA Bioenergy	FT
Vertimass	ATJ'
Steeper	HTL

DPA Recipient: Red Rock Biofuels
"Groundbreaking" 18Jul'18, First Fuel YE 2020

* 15.1 M gpy of renewable, liquid transportation fuels – FT process
  * From 167,000 bdtpy of woody biomass (22% of wood waste in 125 mi radius)
  * 3M gpy SAJF offtake agreement from each of Southwest and FedEx
  * $70 million DPA Title III award for ~$320+ million refinery
* Replicable approach targeting 10 additional sites
  * E.g. – timber basins in the Pac NW (see next)



TCG Global gasifier
Velocys FT reactors
Haldor Topsoe / Valero upgrading
IR1 EPC

Courtesy Biofuels Digest

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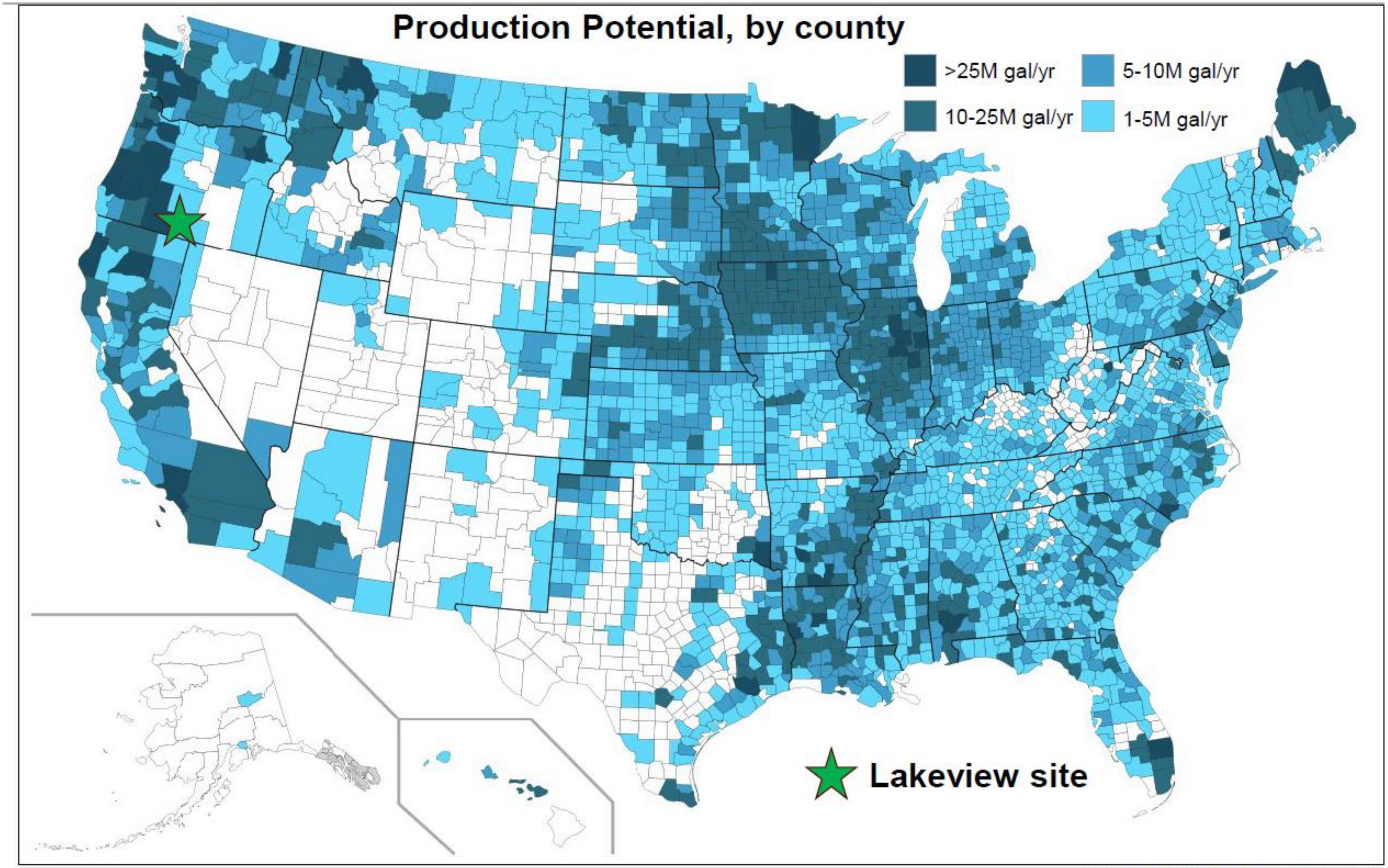
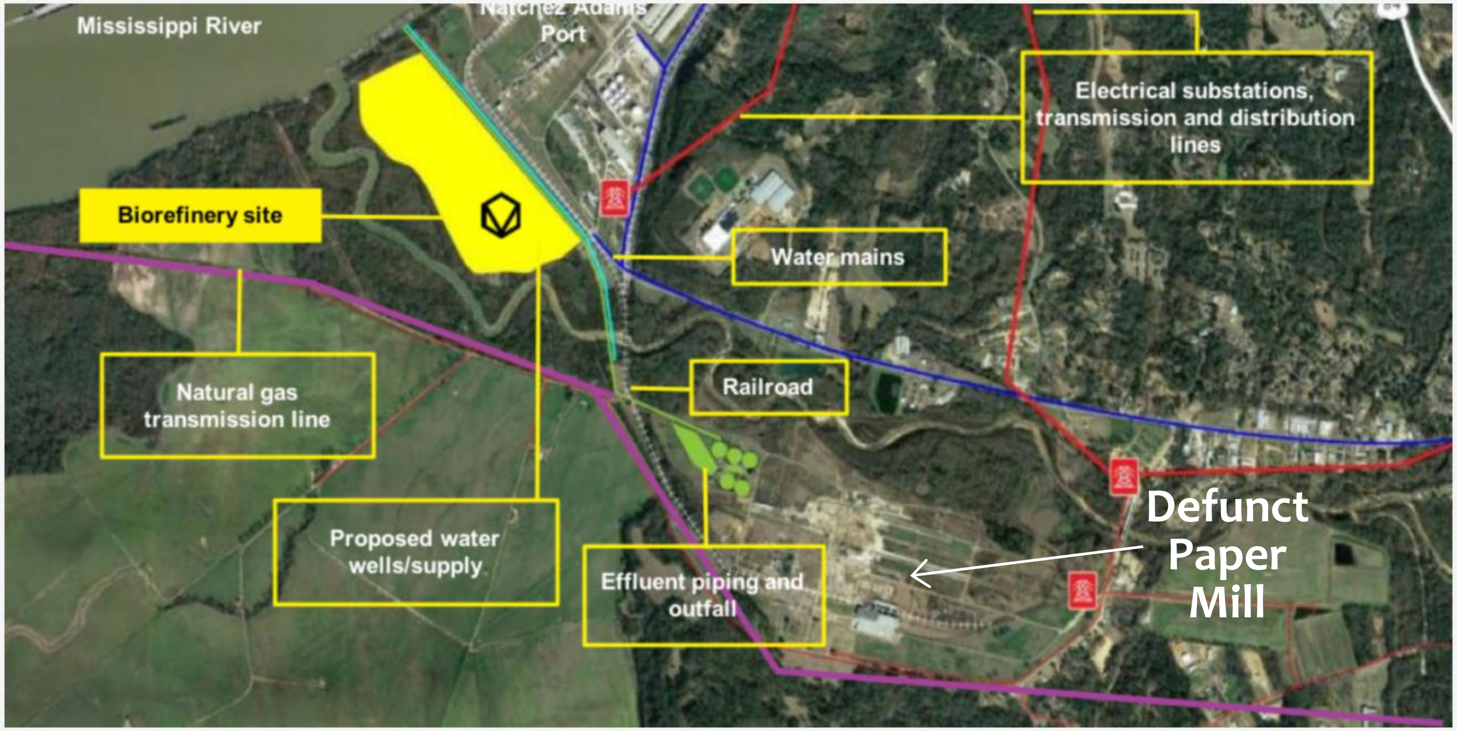
Expansion



Credit: USDA BioSys database, 2015



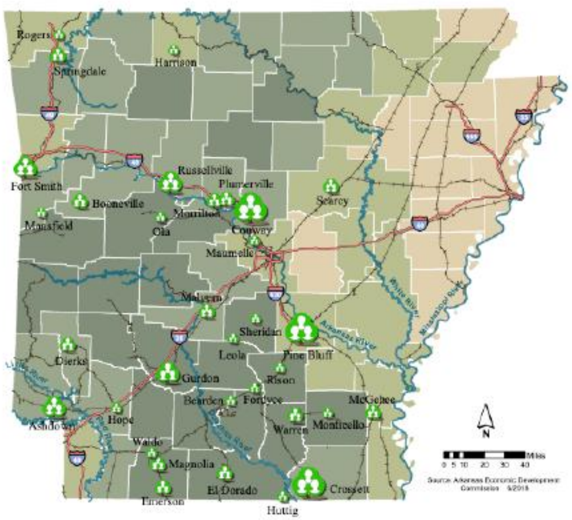
Velocys Mississippi Bayou Fuels project: RFS-2 compliant woody biomass to fuels at full scale

Input: Waste Biomass
Output: 25 million gallons per year
Permitting complete

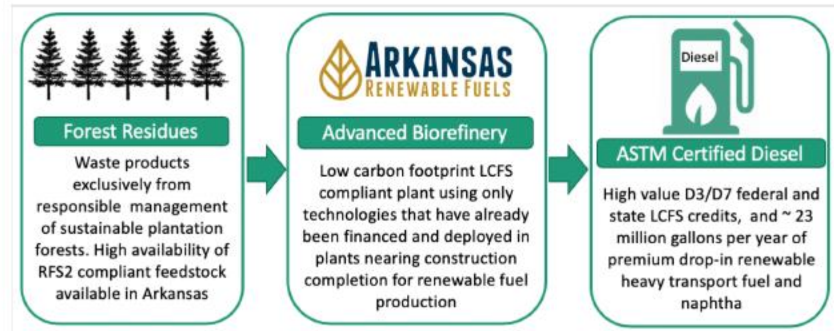
Arkansas Renewable Fuels Plant Summary

The Place

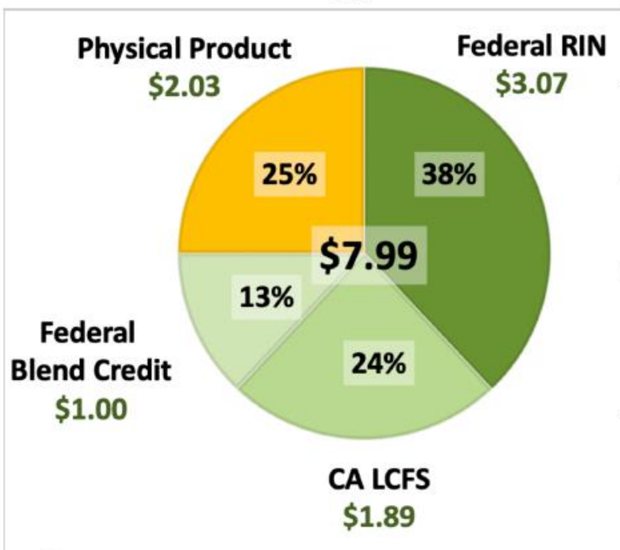
FOREST PRODUCT INDUSTRY IN ARKANSAS



The Project



The Incentives



The Delivery

TRI Gasifier
Johnson Matthey FT & Upgrading

Forestry Challenges

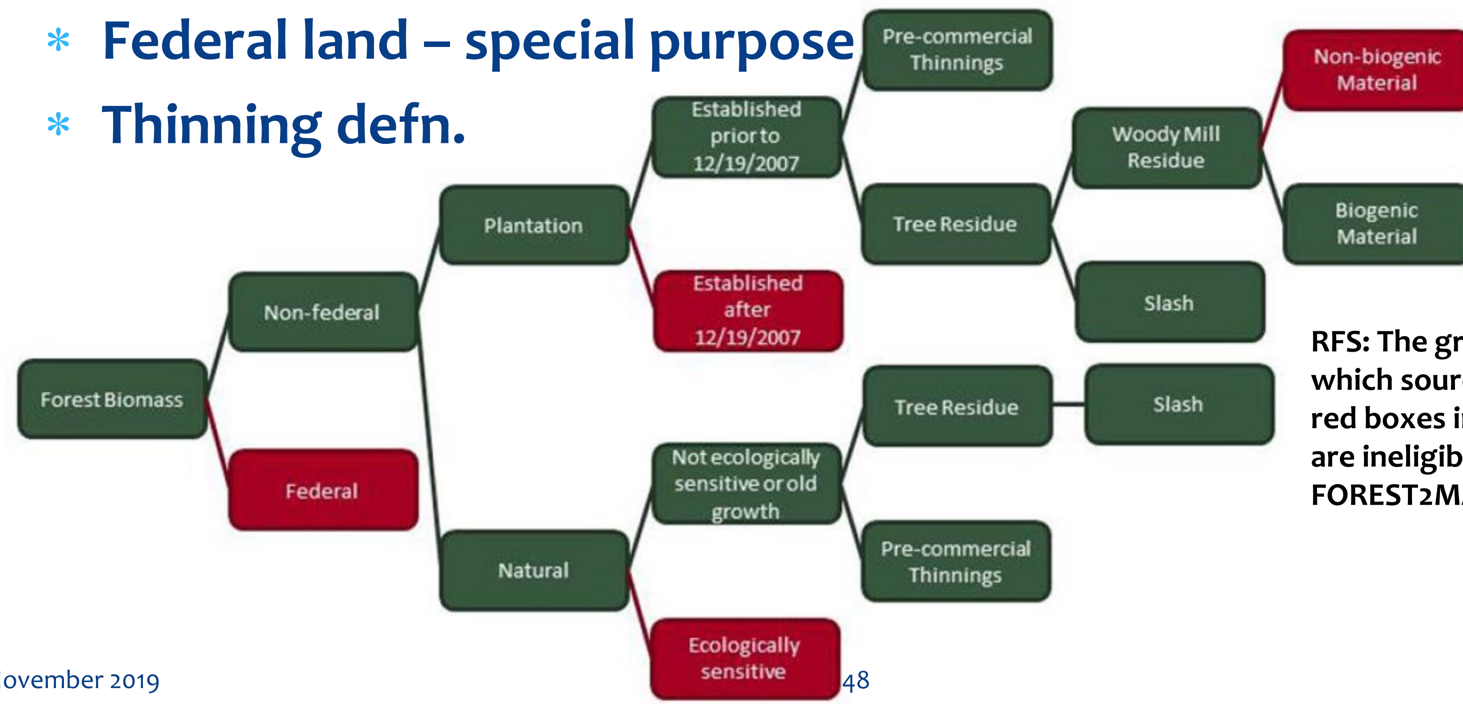
General challenges

* Volumes of policy-viable amounts; without policy, business case difficult
* Aggregation
  * Amounts from processing and mills are not “huge”
  * Collection of thinnings, and allowable thinning, tbd
  * NARA in-depth look at most commonly unused/wasted supply – slash piles
* Hauling (cost of moving air and water, nuisance issues)
* Although desire to use undergrowth (CA fire abatement) or dead material (BANR) is strong, have yet to see full business case pencil-out
* Coppicing plantations
  * Establishment costs and time-to-harvest delay
  * AHB ongoing effort to find workable solutions
* Energy densification technologies unproven or unintegrated – will potentially stay that way with uncertainties above, continued public deification of forests, forests used for “generating offsets,” …
* Competition from pellets, mass-burn, …

Policy treatment inequity

RFS-2 - Vagaries of the definition of allowable biomass

* Issues being worked by ABFA (CARRI), A4A, BIO, et al.
  * Bio-intermediates; Co-processing
  * Blending & Mass allocation
  * Federal land – special purpose
  * Thinning defn.



RFS: The green boxes indicate which sources are eligible; the red boxes indicate sources that are ineligible. Courtesy FOREST2MARKET

Observations for discussion

SAF progress - technical

* SAF 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

SAF progress - commercial

* 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
  * SAF & HDRD Producers – continuous stream of exploration and announcements
  * OEMs have their own fuel needs – another buyer group

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 and/or societal engagement that addresses the above, SAF is perhaps on the cusp of rapid expansion and replication

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Other SAF-linked jeopardies

"Taking a plane is the fastest and cheapest way to fry the planet"

* Calls for punitive measures to truncate demand
  * Calls for renegotiation of Chicago Convention to enable taxing
  * Progressive tax structures on # of trips
  * Elimination of frequent flyer programs
* Calls for reduction in flying (persons and corporations)
  * Fostering of social flight shaming (Sweden - flygskam)
* Calls for conversion of short-haul to trains, or even for elimination of domestic flying (UK)
* Forcing mandates, or potentially in-sector carbon reductions
* Policy schemes (carbon pricing) are not targeting use of funds for in-sector technology development

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Thoughts for TAC Consideration

Thoughts for TAC Consideration

* Although aviation can perhaps be doing more themselves, they need, and merit, assistance to enable commitment:
  * Targeted & improved policies; level/advantaged playing field with diesel
  * Stable policy that encourages funding
    * Jet fuel use continues through 2060, SAF offers GHG reductions now
  * Assistance with R&D, D&D
    * Solid – liquid interface; pumping; reactor introduction
    * Additional catalytic approaches; separation tech
    * Densification concepts (technologies, process/equipment, supply chains)
    * D&D for additional pathways sorely lacking at present
    * The omni-present lignin valorization
  * Brownfield development
* Forestry residues are expected to be part of the solution

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