Sustainable Aviation Fuel from Isobutene

CAAFI Webinar - November 4th 2020

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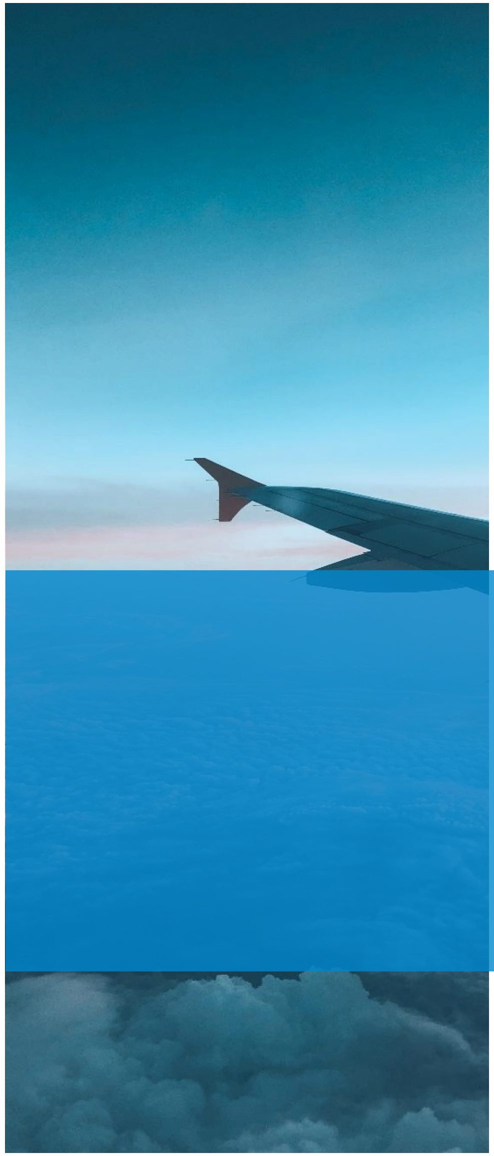
SkyNRG

GLOBAL BIOENERGIES



1 Production Pathway and Fuel Quality

Introduction Global Bioenergies and SkyNRG

Global Bioenergies	SkyNRG
EU-based SME founded in 2008 (public company on Euronext) Around 60 persons operational Coordinator of EU H2020 Project REWOFUEL	EU-based SME founded in 2010 Around 30 persons Partner in EU project REWOFUEL

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Conversion of renewable resources into hydrocarbons through fermentation

Laboratory facilities and pilot plant in France (8 gallons per day)

Fermentation demo plant in Germany (50 gallons IBN per day)

2012

R&D in Evry, France

2015

Fermentation pilot plant in Pomacle, France

2017

Fermentation demo plant in Leuna, Germany

2020

Conversion pilot plant in Lyon, France

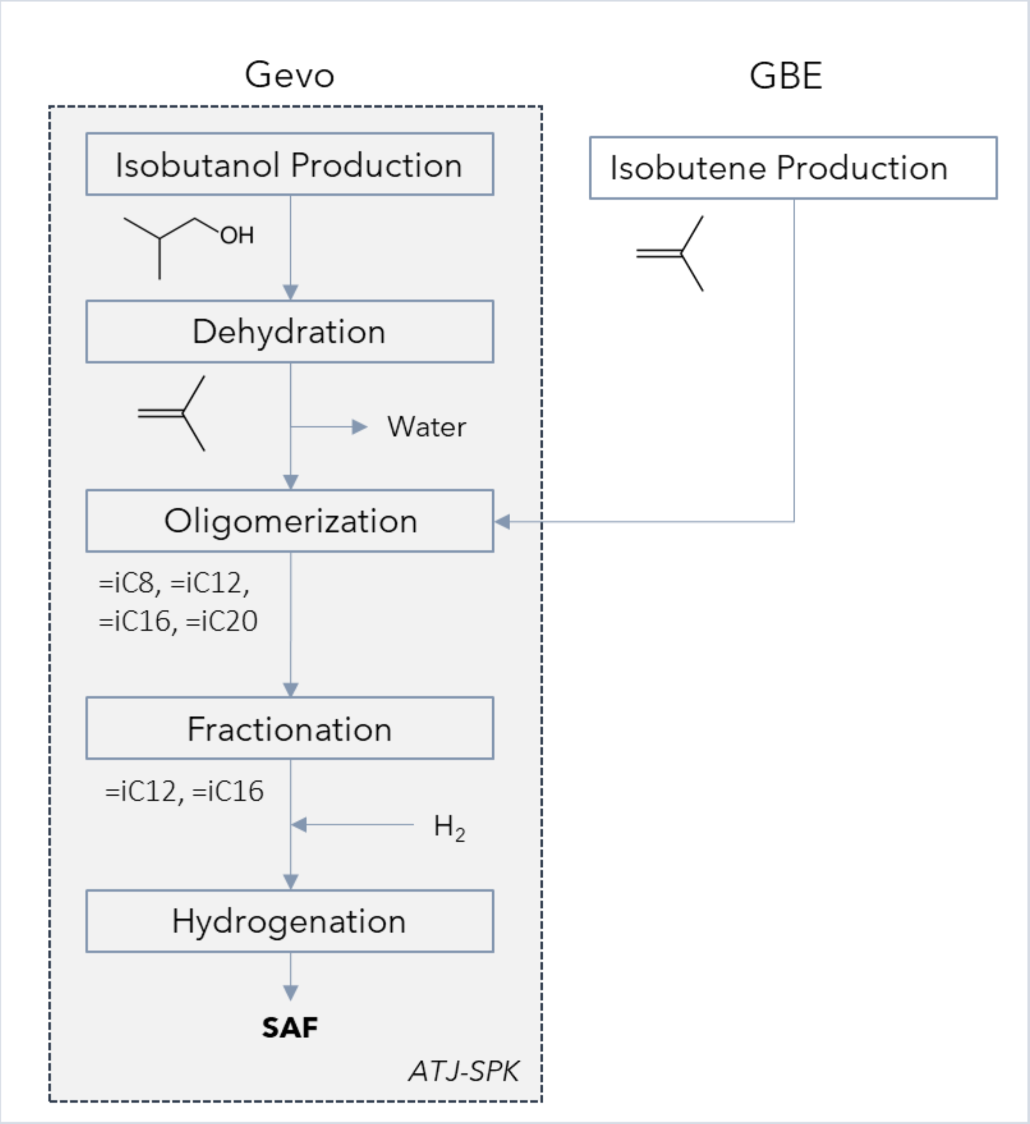
Commercial Plant (>30,000 gallons/day)

GBE's technology ferments sugars into isobutene (IBN) and upgrades the IBN into SAF

Raw feedstock for fermentation is sugar
Sugar can be derived from sugar crops (sugar beet, sugar cane) or 2nd generation feedstock such as wood and agri residues.
In project REWOFUEL the sugars are specifically obtained from residual wood hydrolysate

	Step	Conversion	Description
1	Fermentation	Sugar to Isobutene (IBN) → =iC4	Fermentation of sugars using a GMM, Producing gas-phase isobutene
2	Purification	=iC4 (gas)	Isobutene extraction from the gas phase using a hydrocarbon solvent (petrochemical)
3	Oligomerisation	=iC4 → =iC4, =iC8, =iC12, =iC16, =iC20 etc.	Oligomerisation of isobutene into isooctene (=iC8), isododecene (=iC12) and isohexadecene (=iC16)
4	Fractionation	=iC4, =iC8, =iC12, =iC16, =iC20 → =iC12 and =iC16	Two step distillation to remove light fraction (=iC4, =iC8) and heavy fraction (=iC20+). Light fraction is recycled to increase yield. Final olefin composition rich in C12 and C16
5	Hydrogenation	=iC12, =iC16 → iC12 iC16	Hydrogenation of olefins into paraffins Final SAF composition rich in C12 and C16

Pathway very similar to Gevo's Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)



- Both Gevo and GBE use sugars as a feedstock for fermentation
- Gevo's fermentation yields isobutanol. Isobutanol is converted into isobutene via dehydration, and upgraded to SAF.
- GBE's fermentation directly yields Isobutene, which is upgraded to SAF via the same process as Gevo
- Both GBE's and Gevo's SAF are rich in C12 and C16 hydrocarbons, fully iso-paraffinic
- Gevo's pathway is ASTM approved in D7566 Annex 5, GBE seeks ASTM approval via inclusion in D7566 Annex 5.
  - Extension of existing annexes preferred over adding new ones
  - Fuel composition is very similar to Gevo's ATJ-APK, and less to conventional jet fuel, therefore seeking Fast Track approval is not preferred

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Neat GBE SAF samples closely resemble Gevo's HC composition and distillation profile

- **Sample prepations:**
  GBE's Isobutene and oliogomers
  Several tons of Isobutene produced in lab, pilot and demo.
  Over a ton of oligomers produced via lab and pilot

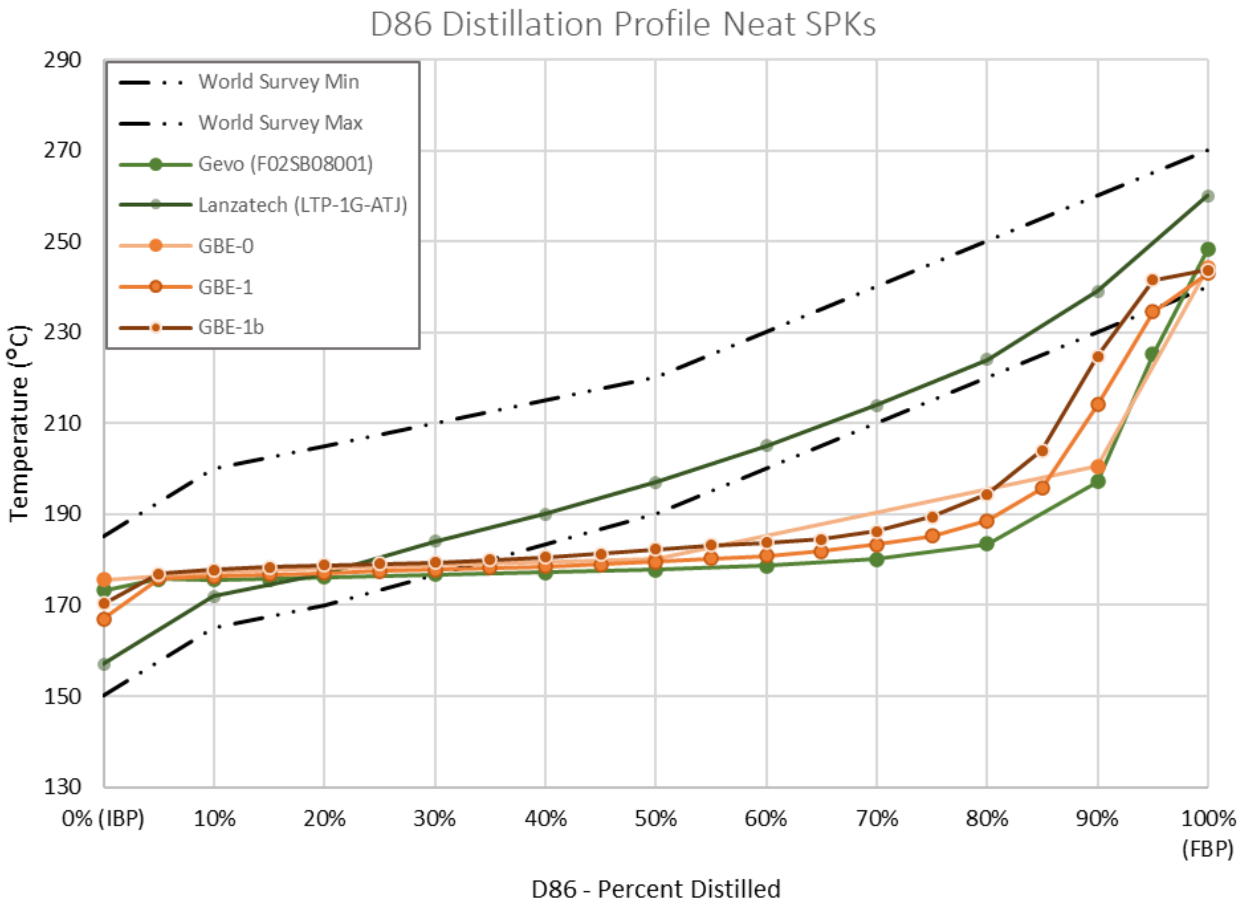
- *GBE's SAF*
  Multiple samples prepared at Laboratory Scale: GBE-0, GBE-1 and GBE-1b

- Approx. 30 Liters of SAF is produced in 3 campaigns via laboratory set-up, all samples are used in ASTM approval process

- **Hydrocarbon (HC) analysis results:**
  Hydrocarbon composition reveals 99,71 wt% iso-paraffins
  Approximately 82% iC12 and 15% iC16

- Gevo: approximately 83% iC12 and 14% iC16

- Resulting in a highly similar distillation profiles for GBE's SAF and Gevo's ATJ-SPK



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GBE's SAF in line with D7566 Annex 5 ATJ-SPK batch requirements

- Chemical Analysis of SAF Samples suggest close resemblance to Gevo's ATJ-SPK
- All parameters within Annex 5 specification limit.
- Except hydrogen & carbon mass. This was due to faulty measurements. D5291 is a very sensitive method.
- Re-testing of the sample via Clearing House yields satisfying result. Slightly on the low side. Possibly caused by anti-oxidant addition.

	D7566 – A5	Gevo	GBE 0	GBE 1	GBE 1b
Flash Point (°C)	Min 38	47	47	48,5	47,5
Freeze Point (°C)	Max -40	< -80	< -80	< -100	< -100
Density (kg/m^3)	730-770	757	756	755	759
Carbon Hydrogen Mass (wt%)	> 99,5	99,9	99,1	98,3	99,3
Sulfur Content (mg/kg)	Max 15	4	0,9	< 0,5	< 0,5
Nitrogen Content (mg/kg)	Max 2	< 0,1	<0,3	< 0,5	<0,5
Acidity (mg KOH/g)	Max 0,015	0,002	0,002	0,01	0,01

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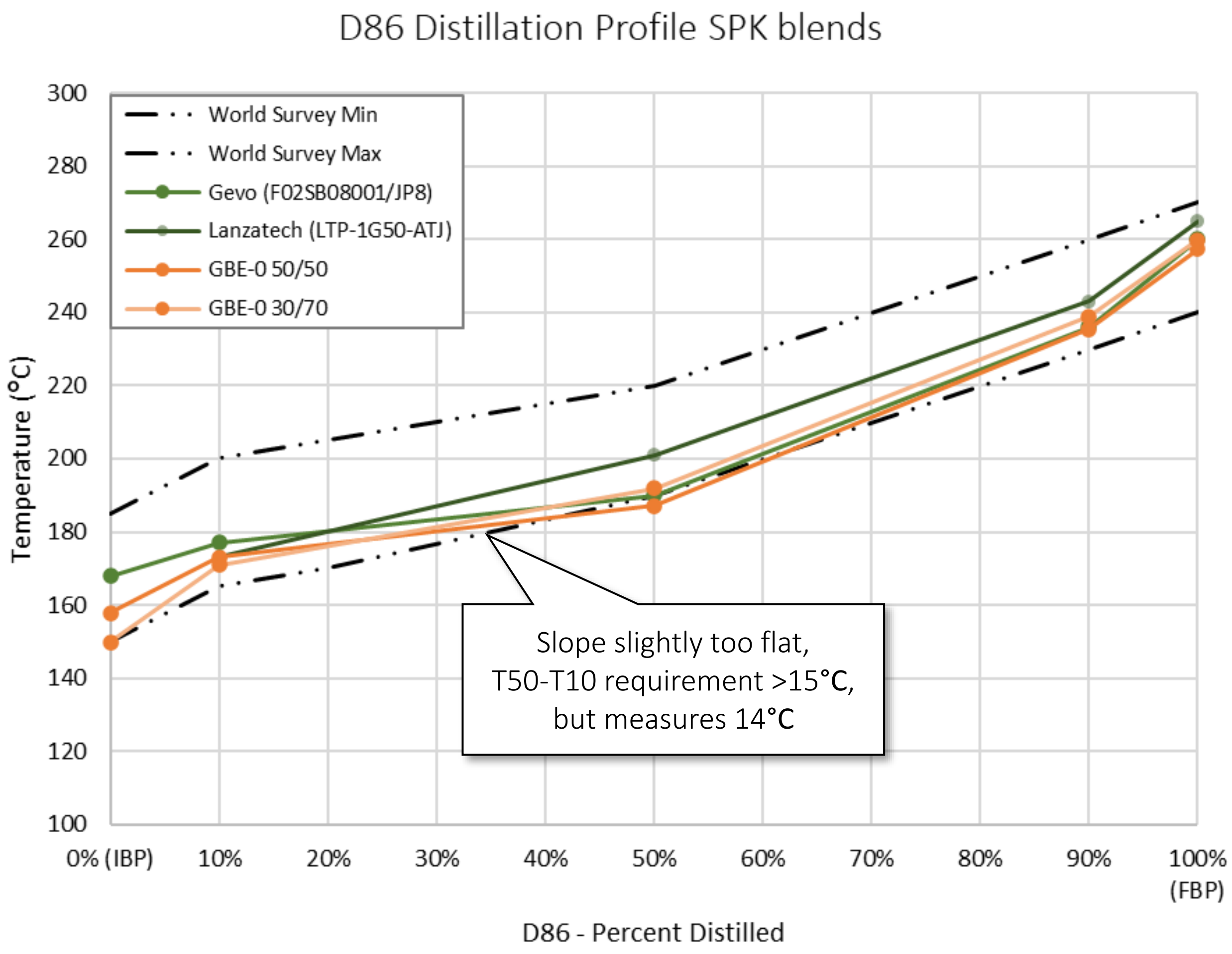
GBE's SAF blended with Jet A1 performs within specifications of D7566 Table 1



GBE blends produced from GBE-0 and analysed

- 50/50% blend with Jet A1,
- 30/70% blend with Jet A1

All requirements for aviation turbine fuels containing synthetic hydrocarbons according to D7566 Table 1 are met, with a small exception in the distillation profile of the 50/50% blend.

Distillation profile of Gevo's ATJ-SPK blend has similar slope. Extensive combustion testing of Gevo ATJ fuel showed no issues with combustion.

GBE-0 is the first GBE SAF sample produced in laboratory, newer samples have slightly optimized distillation profile and are expected to perform within fuel requirement limits.

More blends containing GBE's SAF will be produced and analysed to confirm meeting D7566 Table 1 specifications.

Other parameters of lab scale blends also 'on-spec' – pilot samples will be analyzed soon

	D7566 – Table 1	Gevo 50/50	GBE 0 50/50	GBE-0 30/70
Flash Point (°C)	Min 38 Max 68	49	42.5	40
Freeze Point (°C)	Max -40	-57	-55	-52.1
Density (kg/m³)	775-840	780	779	789
Viscosity at -20°C (mm²/s)	Max 8	4.5	4.12	4.04
Viscosity at -40°C (mm²/s)	Max 12	8.7	7.9	7.82
Heat of Combustion	Min 42,8	43.6	43.6	43.5

- Next stage SAF samples:
- Currently conversion pilot facility is operational in Lyon, which has produced over 250 Litres of hydrocarbons in multiple runs.
- Large SAF samples (>100L) reserved for ASTM testing expected this and next month.
- Three SAF batches will be available to confirm product quality consistency throughout pilot production
- One pilot batch will be used to validate that GBE's SAF meets all requirements for ATJ-SPKs, essential for ASTM approval.

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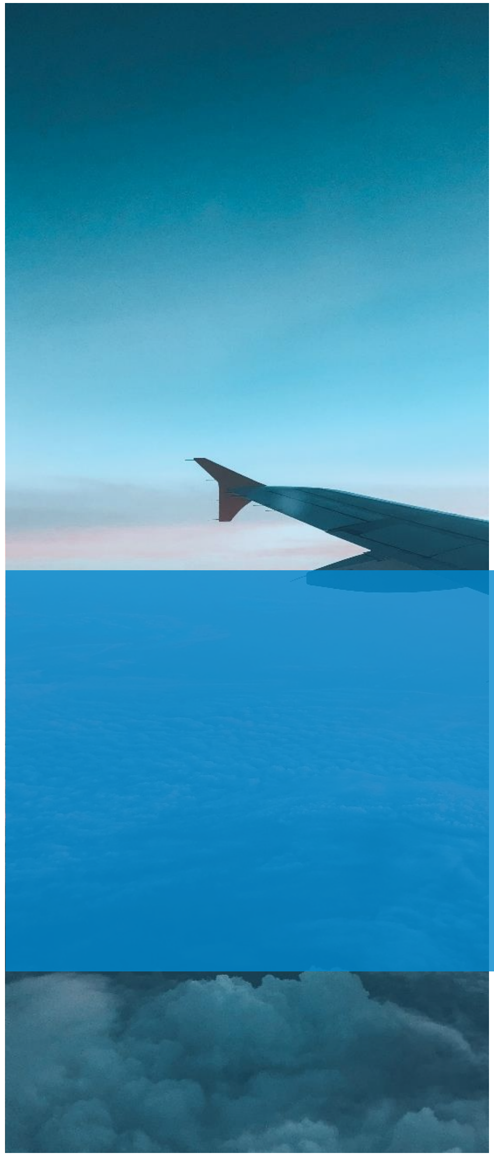
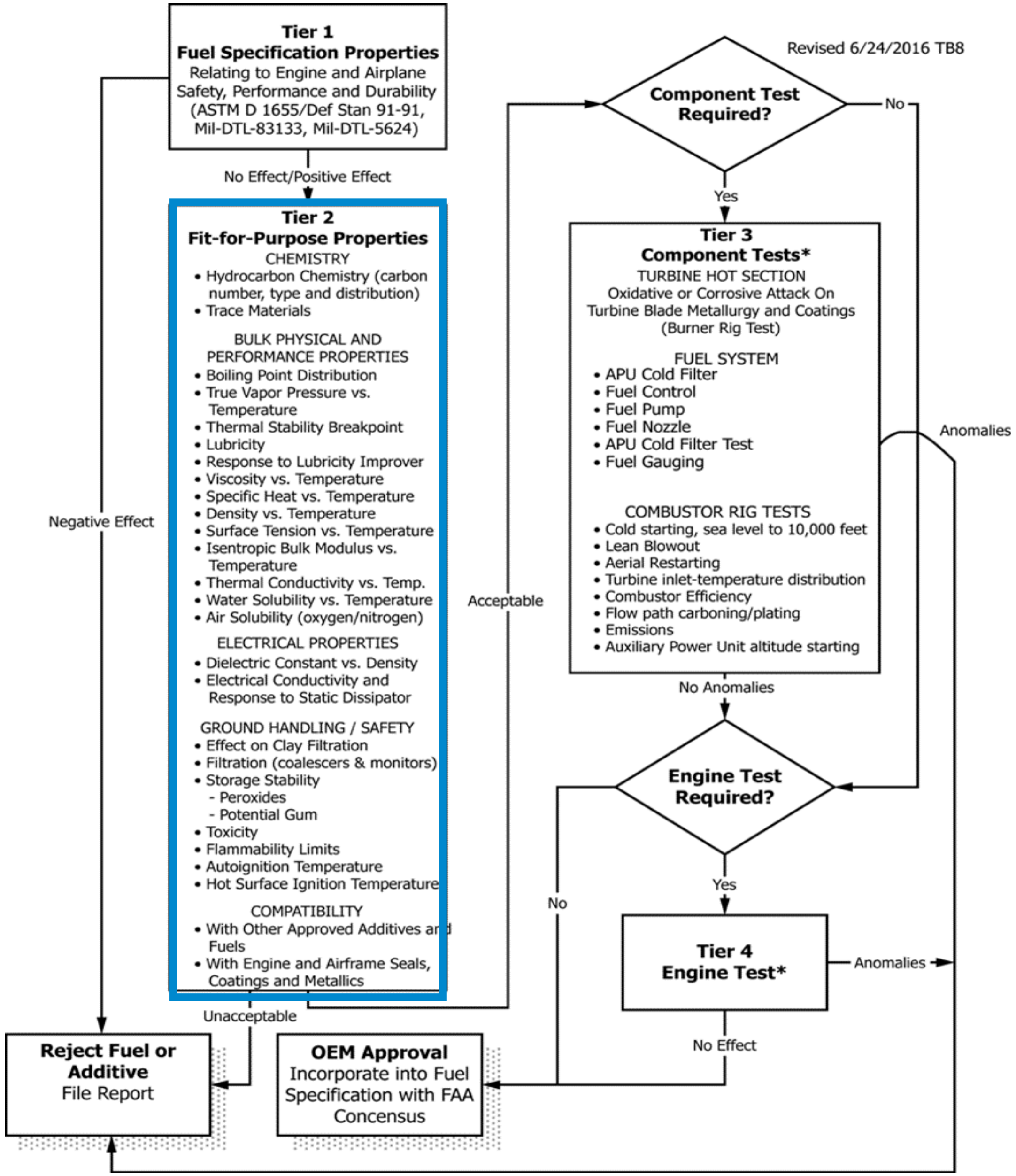


2 ASTM Qualification Process

Phase 1 Research Report in development



- Fuel Specifications Properties analysed for GBE's SAF
- Key Tier 2 parameters analysed: Hydrocarbon Composition, Trace Materials and Boiling Point Distribution
- Almost all parameters within D7566 specification limits (exceptions discussed previously)
- No trace materials present.

Next steps:

November 2020, pilot batches of GBE SAF available (> 100L)

- Three batches to demonstrate pilot production consistency
- One batch will be used to demonstrate D4054 Table 2 Fit-For-Purpose Properties
- All Tier 1 and Tier 2 tests will be performed on this pilot sample.

- Tier 1 and Tier 2 testing expected to be finalized Q2 2021. These results will complete the Phase 1 Research Report. The report will be written by SkyNRG in conjunction with Global Bioenergies and the D4054 Clearinghouse.

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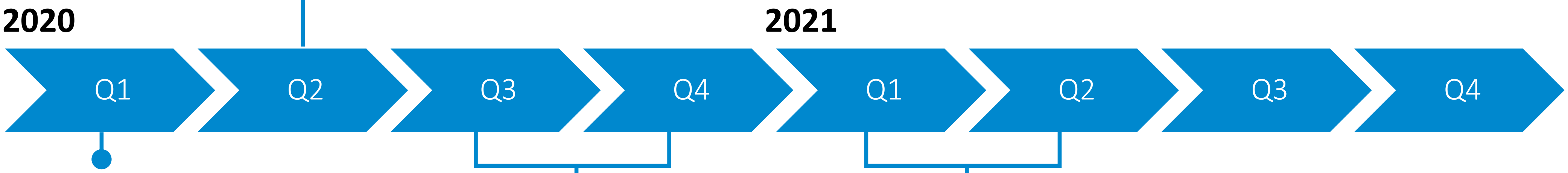
Timeline: OEM review of Phase 1 Research Report expected end Q2 2021



2020 Q1

- Chemical analysis of laboratory SAF batches
- ASTM Work Item registered (WK71952)

2020 Q2

- Testing laboratory SAF batches to confirm similarity with Gevo's ATJ-SPK
- Commissioning of REWOFUEL conversion pilot facility in Lyon, France
- Set up ASTM Collaboration Area

2020 Q3–Q4

- Access to large volumes of SAF produced in pilot facility
- Tier 1 testing of pilot batches in 3-fold
- Tier 1 testing of 50% blend pilot batch with conventional Jet A1
- Tier 2 (FFP) testing of neat and blended batches from pilot facility (1-fold)

2021 Q1–Q2

- Continuation FFP testing of neat and blend batches
- Aim to submit Research Report for OEM review

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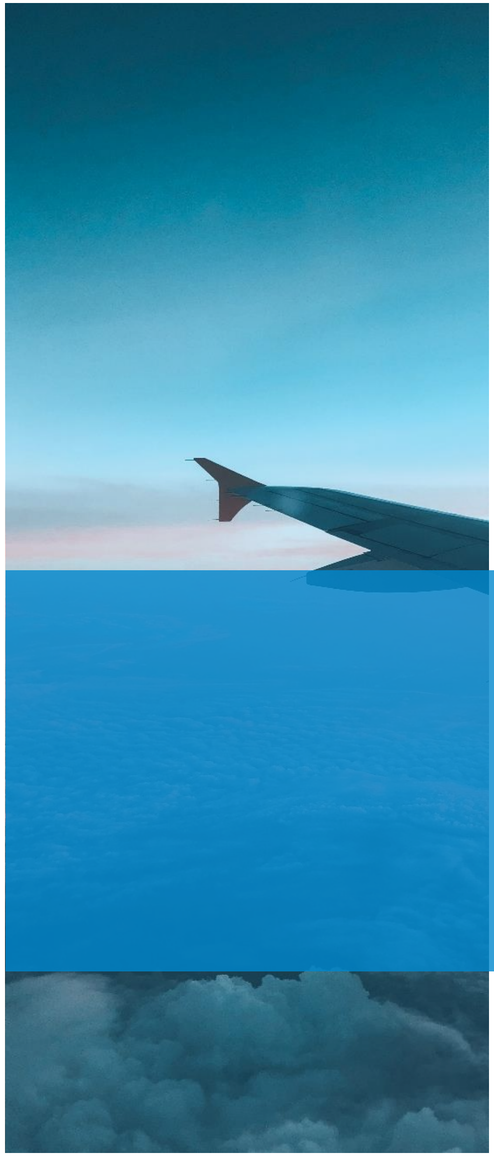

3 Experience and Tips for seeking ASTM approval

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So far, very positive experience in the ASTM approval process

Experience

- There is a tremendous amount of knowledge and experience available at ASTM outside of publications
- Bi-annual ASTM meetings (and other fuel quality conferences) in person allow for more detailed and informal discussions with OEMs, other candidate fuel producers and ASTM committee members. Much more challenging via virtual meetings.
- Guidance by FAA and Clearing House essential and very helpful
- Chemical analysis results are not always straightforward, consistent or realistic.
- Delays are unavoidable

Tips

- Make sure to invest in personal contact with FAA, Clearing House and OEMs to fully understand the approval process
- Start engagement with stakeholders timely
- Take the opportunities to present at ASTM and OEM meetings to communicate progress and obtain feedback.
- Make sure task force members are aware of any challenges timely.
- Try to schedule frequent discussions with members of your task force now that there are no more easy discussion opportunities during conferences.
- Keep a strict sample administration and record all changes. Chemical analysis will reveal any small change.

Questions?

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