Technology Strategy for SAF (Sustainable Aviation Fuel) in NEDO

New Energy and Industrial Technology Development Organization (NEDO)
Technology Strategy Center (TSC)
Sustainable energy unit
Hiroshi ENOMOTO

Innovation for Cool Earth Forum, Tokyo
October 5, 2023
Future of SAF (sustainable aviation fuel)

In 2050
- Global SAF demand is from 294 M-m$^3$ to 425 M-m$^3$.
- In Japan, 23 M-m$^3$ is necessary.

In 2030
- In Japan, 2.0 M-m$^3$ is necessary.

In 2020
- Global SAF supply is 0.063 M-m$^3$, 0.03% of aviation fuel supply.
- SAF production cost is from 2.0 USD/L to 16.0 USD/L.
- Conventional aviation fuel cost is almost 1.0 USD/L.

Definitions
SAF = a fuel loaded in air plain.
neat SAF (nSAF) = An aviation fuel produced from non-fossil fuel.

Normally, SAF is a mixture of nSAF and conventional Jet fuel (e.g. Jet A from crude oil) with 1:1 in weight ratio. As nSAF amount is not enough, a Jet fuel mixed with few percent of nSAF is called SAF in the market.
History of the technology strategy in NEDO

- 13 technologies were selected in 2017.
- The three technologies, 1) Alcohol to Jet (ATJ), 2) Gasification + Fischer-Tropsch (G+FT), 3) Microalgae+Hydroprocess (MA+H), were selected in 2019.

NEDO TSC Foresight (2017) 21

---

**Diagram:**

1. **Saccharification** → **Saccharide** → **Fermentation** → **Alcohol** → **Alcohol fermentation to jet**
2. **Gasification** → **Synthesis gas** → **FT** → **Gasification + FT** (wood/grass)
3. **Rapid thermal decomposition** → **Bio crude** → **Hydroprocess** → **HTL hydrothermal liquefaction** (wood/grass)
4. **Entracting** → **Fats** → **Esterifying** → **Bio-diesel (FAME)**
5. **HTL** → **Crude oil** → **Reforming** → **Microalgae (oil)**
6. **Gasification** → **Synthesis gas** → **Fermentation** → **Gasification + alcohol fermentation** (wood/grass)
7. **Entracting** → **Waste gas** → **Esterifying** → **Microalgae (hydrocarbon)**
8. **HTL** → **Bio crude** → **Reforming** → **HTL (microalgae)**
9. **Gasification** → **Synthesis gas** → **Fermentation** → **Gasification + saccharides fermentation** (wood/grass)
10. **Esterifying** → **Bio-diesel (FAME)** → **Hydroprocess** → **HEFA** (hydroprocessed ester and fatty acids)
11. **Hydroprocess** → **Fats** → **Crude oil** → **Gasification + alcohol fermentation** (residue)
12. **Waste cooking oil** → **Gasification** → **Synthesis gas** → **Gasification + alcohol fermentation** (residue)
13. **MSW, Waste gas** → **Gasification** → **Synthesis gas** → **Gasification + alcohol fermentation** (residue)
14. **Waste cooking oil** → **Gasification** → **Synthesis gas** → **Gasification + alcohol fermentation** (residue)
15. **Waste cooking oil** → **Gasification** → **Synthesis gas** → **Gasification + alcohol fermentation** (residue)
For “carbon neutral” production and enough supply, the followings are approximated to find the dominant cost.

- The production rate \([m^3\text{-nSAF/plant/year}]\) is varied from 1,000 (1k) to 1,000,000 (1M).
- Any utility (electricity and steam) in the plant is from the raw material.
- Number of labor is calculated with Japanese standard.

The index are as follows.
1. CAPEX of 30 years plant lifetime
2. OPEX (labor): Japanese standard in 2023
3. OPEX (utility)
4. Raw material cost

Pros in general
ATJ   Alcohol (ethanol) has the conventional market.
      Alcohol from cellulose (future technology) won’t compete against food demand.
G+FT  Conventional plant technology is enough.
      Any place could be used for the plant.
MA+H  Higher growth rate could be achieved.
      “Reasonable” CO2 usage is possible.
In large scale, raw material cost is dominant. This means that alcohol should be from cellulose (or waste).

In small scale, labor OPEX is dominant. This means that "full-automatic" plant could be adapt in local usage.
In large scale, raw material cost and CAPEX are dominant. This means that the plant should be placed at the raw material production area and that low price gasifier is necessary.

In small scale, labor OPEX is dominant. This means that “full-automatic” plant could be adapt in local usage.
Microalgae+hydroprocess, (MA+H)

- 10 times of wood growth rate could be achieved.
- Gene recombination is not necessary.
- “Effective” CO2 supply technology is necessary for ultimate usage of photosynthesis.

Effective land use evaluated with the growth rate

- Wood in Japan: 5 ton-dry/ha/year
- Wood in tropical region: 30 ton-dry/ha/year
- Sugarcane in Brazil: 80 ton-dry/ha/year
- Microalgae in tropical region: 100 ton-dry/ha/year (target of NEDO project)

Theoretical maximum of photosynthesis efficiency is 0.124.
Higher heating value (HHV) of microalgae is 22 MJ-HHV/kg-dry.
Solar energy for photosynthesis around equator is 60 TJ/ha/year.

From these approximations, the maximum energy by photosynthesis is $60 \times 0.124 = 7.44$ TJ/ha/year.
The maximum microalgae growth rate is $7440/22 = 338$ ton-dry/ha/year.

For 400 M-m³-νSAF, almost 8 M-ha (only 0.2% of Moon surface area) is necessary with the ideal microalgae.
How much area can we use for biomass?

- The forest around Pacific ocean (Asia and Oceania) can supply 30% of global nSAF demand from wood.
- Microalgae in NEDO project can supply 100% of global nSAF demand from these forest.

1.0% of production forest in Asia = 1.1 M-ha = 5.5 M-m³-nSAF = 2%
50% of unknown forest in Asia = 12.5 M-ha = 62.5 M-m³-nSAF = 20%
50% of unknown forest in Oceania = 19.5 M-ha = 97.5 M-m³-nSAF = 30%

10 ton-dry/ha/year (wood) is approximated.
0.5 m³-nSAF/ton-dry = 5 m³-nSAF/ha/year

The three technologies as follows are evaluated.
1. Alcohol to Jet (ATJ) will be a solution with low price alcohol.
2. Gasification and Fischer-Tropsch (G+FT) could be constructed with small capacity in any place.
3. Microalgae and hydroprocess with carbon neutral CO2 (MA+H) has the largest growth rate.

In case of 1.0 M-m$^3$/year production rate, as the ratio of raw material cost is large, the plant should be places at the raw material production area.

Hydrogen and water are also important raw materials in any case. The carbon intensity of them should be evaluated.

As the plant or the place for the place should be designed to make the carbon intensity [kg-CO2/kg-nSAF] minimum, the supply chain design is important.