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Sustainable Aviation Fuel

Global Opportunities in an Indian Context

WORLD FUTURE FUEL SUMMIT & EXPO
International Conference & Exhibition on Future Fuel

February 15, 2020

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40 Years

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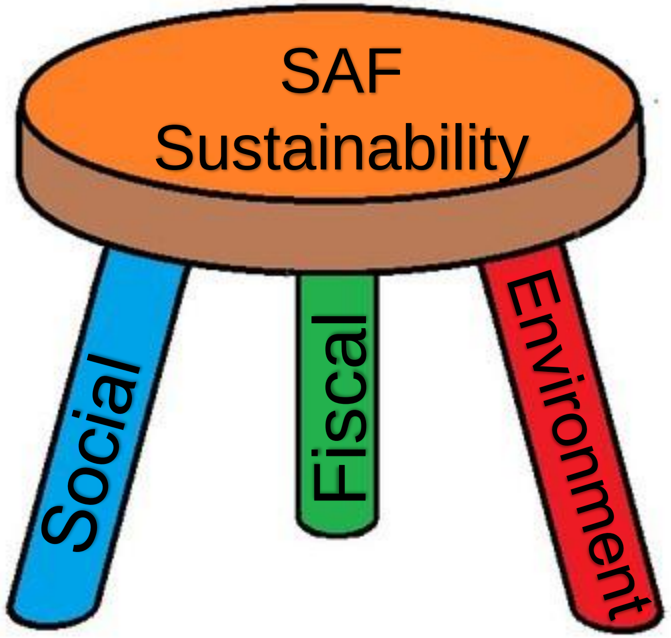
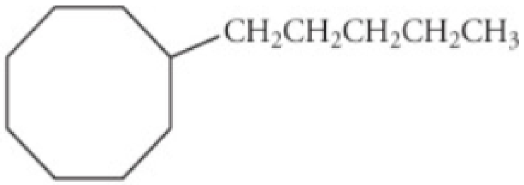
SAF in an Indian Context

- Sustainable Aviation Fuel (SAF) is of increasing interest to Governments, Investors, and Owners
- New technologies use biomass and waste resources available in India
- Recent programs to monetize environmental benefits have enabled sustainable course for SAF
  - Social – Energy Security and Jobs (particularly rural)
  - Fiscal – Monetizing environmental attributes enables fiscal performance
  - Environmental – GHG and pollutant reductions in the hardest transportation sector to decarbonize

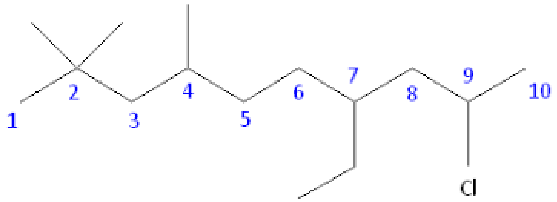


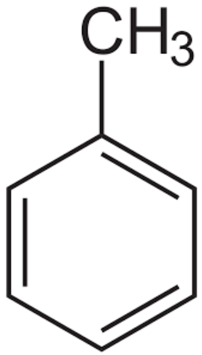
Technical Characteristics of Jet Fuel

- Kerosene based, C6 to C16 Carbon Range (Most in C12-C14)
  - Alkanes (paraffin's) and Cycloalkanes – Stable, clean burning portion of jet most of the power comes from alkane combustion
  - Aromatics – Easy burning components (8%-10% of jet) including BTX, necessary for seal and rubber component performance. Responsible for exhaust smoke and fuel odor
  - Olefins – Unstable double bonds, fuel degradation
- High in sulfur, usually in 400-800ppm range, 3,000 ppm max
  - On road Ultra Low Sulfur Diesel (ULSD) is 15 pm max
  - Creates SOx upon combustion
- Sold as Jet A, -40ºC (NA) and Jet A-1 -47ºC Europe and Asia



1-pentylcyclooctane





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Sustainable Aviation Fuel

- ASTM 1655 – Standard Specification for Aviation Fuels / IS 1571: 2001 (Seventh Revision) India
  - Renewable jet fuels have been added to specification via Annexes
- Made by assembling carbons in one of three general pathways (near term)
  - Fisher Tropsch – Synthetic Paraffinic Kerosene (FT SPK, Annex A1, A4) – C1 (Trash Feedstock)
  - Hydrotreated Renewable Jet - (HRJ, Annex A2) – C16-C18 (Used Cooking Oil & Tallow Feedstock)
  - Alcohol to Jet – (ATJ, Annex A3, Annex A5) – C2, C4 (Ethanol and Butanol Feedstock)
- SAF
  - High in C12-C14 alkanes, very low aromatics
  - Di minimis sulfur content
  - Is typically blended 50/50 for aromatics
  - Higher energy, lighter weight than conventional jet

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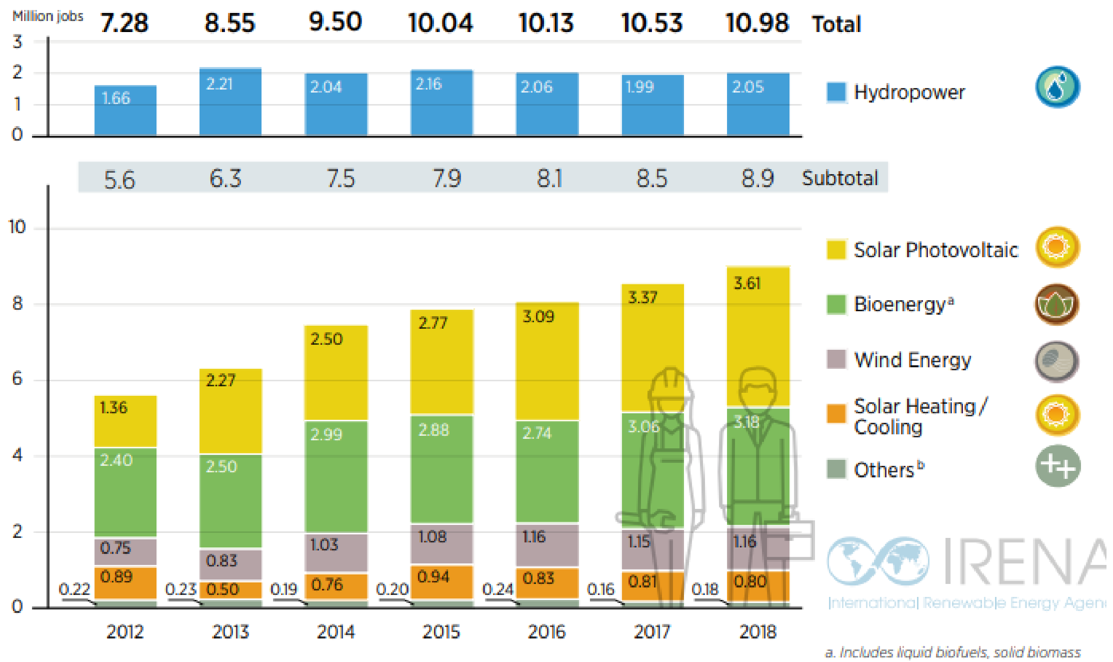
SAF Social Sustainability - Jobs

FIGURE 1: GLOBAL RENEWABLE ENERGY EMPLOYMENT BY TECHNOLOGY, 2012-2018



a. Includes liquid biofuels, solid biomass and biogas.

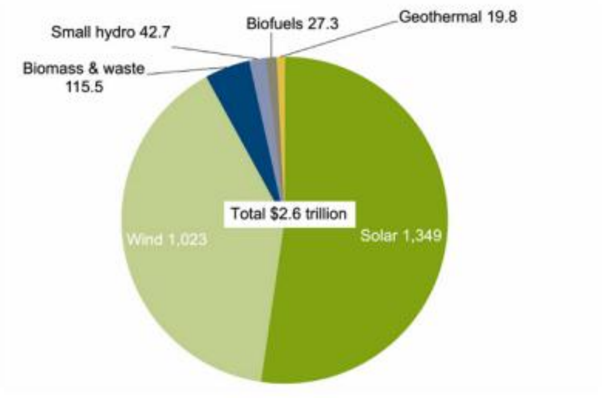
b. Other technologies include geothermal energy, concentrated solar power, heat pumps (ground-based), municipal and industrial waste, and ocean energy.

Source: IRENA jobs database.

Note: Except for hydropower where a revised methodology led to revisions of job estimates, numbers shown in this figure reflect those reported in past editions of the Annual Review.

https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_RE_Jobs_2019-report.pdf

FIGURE 1. RENEWABLE ENERGY CAPACITY INVESTMENT OVER THE DECADE, 2010-2019, $BN



Includes an estimate for 2019, based partly on provisional first-half data.
Source: UN Environment, Frankfurt School-UNEP Centre, BloombergNEF

https://wedocs.unep.org/bitstream/handle/20.500.11822/29752/GTR2019.pdf

Per the UN and IRENA

- 5.2% of $2.6 trillion global RE investment has been in bioenergy
- 36% of all RE jobs are in bioenergy!

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SAF Social Sustainability – Energy Security

Spitfires in the RAF were slower than Luftwaffe's Messerschmitt's on 87 octane at outset of war, Allies developed 100 octane fuel and turbochargers which gave the spitfires a 30 mph advantage

- Domestic production of SAF makes India more secure
- Preliminary Work at USAF and USN found SAF to be better performing fuel;
  - SAF is high in alkanes, with a higher energy density and lower weight than conventional jet.
    - Between 4% - 7% increase in energy, increased the fully loaded capacity of an F-18 Hornet by 1,000kg or increased range when not fuel tank limited
  - Combustion temperatures decreased by up to 135ºF with SAF
    - "At the temperatures that military jet engine perform at, an additional 25 degrees in temperature can shorten the life of the engine by half" – USAF Consultant

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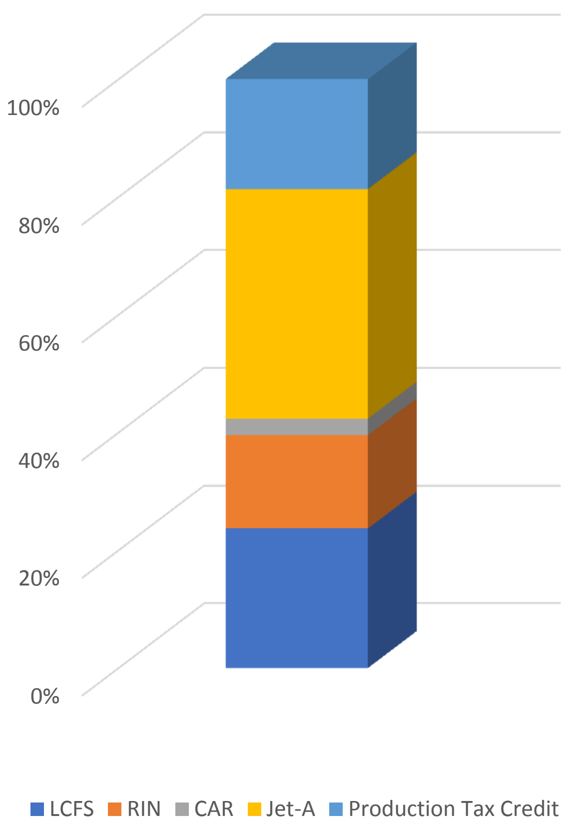
SAF Fiscal Sustainability – Value Stack

Value Stack for SAF in GHG Regulated Market (California)



Biomass Production Tax Credit $1 (US Only) – Social/Jobs Policy

Physical Fuel Value + CAR carbon tax

US Renewable Fuel Standard Value (D4 RIN) – Social/Energy Security Policy

California Low Carbon Fuel Standard Value – GHG Environmental Policy

- New GHG valuation programs add to the value stack
  - California LCFS, Oregon Clean Fuel Program, British Columbia LCFS
  - Proposed or in Study; New York, New England, Colorado, US Midwest Consortium, Canada - National Program
  - Other GHG programs; CORSIA, RED II

- Total Value = $5.36 / gallon
  = INR 100 / liter

- $4.36 / gallon (INR 81 / liter) available to Indian Producers shipping to California

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SAF Fiscal Sustainability – GHG Regulated Market (California)

- LCFS credits stack on top of RIN and physical fuel value
- SAF – February 2020
  - LCFS = $1.27 ($208 @ CI of 39)
  - RIN = $0.85 (D4 $0.50)
  - CAR = $0.15
  - CA Jet-A = $2.09 per gal
  - **Total = $4.36 / gal w/o producer credit ($1)**
- Waste to Fuel Producers can even more credit value
  - Negative CI (methane capture) projects

CAR = Cap-At-The-Rack is a premium paid for conventional diesel under the California Cap and Trade program, LCFS and RIN value is NOT passed through to rack under this arrangement

Potential LCFS Credit Value (2020)

Fuel	Assumed CI Value (g/MJ)	LCFS Credit Price ($/MT CO_2e)				Units
		50	100	150	200	
Corn Ethanol	71	0.07	0.14	0.22	0.29	$/gal
Cellulosic Ethanol	30	0.24	0.48	0.72	0.96	$/gal
Biodiesel	30	0.37	0.74	1.11	1.48	$/gal
Renewable Diesel	30	0.38	0.76	1.14	1.52	$/gal
Hydrogen	88	0.80	1.60	2.40	3.20	$/kg
Landfill NG	40	2.10	4.20	6.30	8.40	$/mmBTU
Dairy NG	-276	18.92	37.84	56.76	75.67	$/mmBTU
Electricity	105	0.04	0.07	0.11	0.14	$/kW-hr

Source: California Air Resources Board

LCFS imposes $0.15 of cost per gallon of fuel sold in California ($3.47/gallon retail cost)

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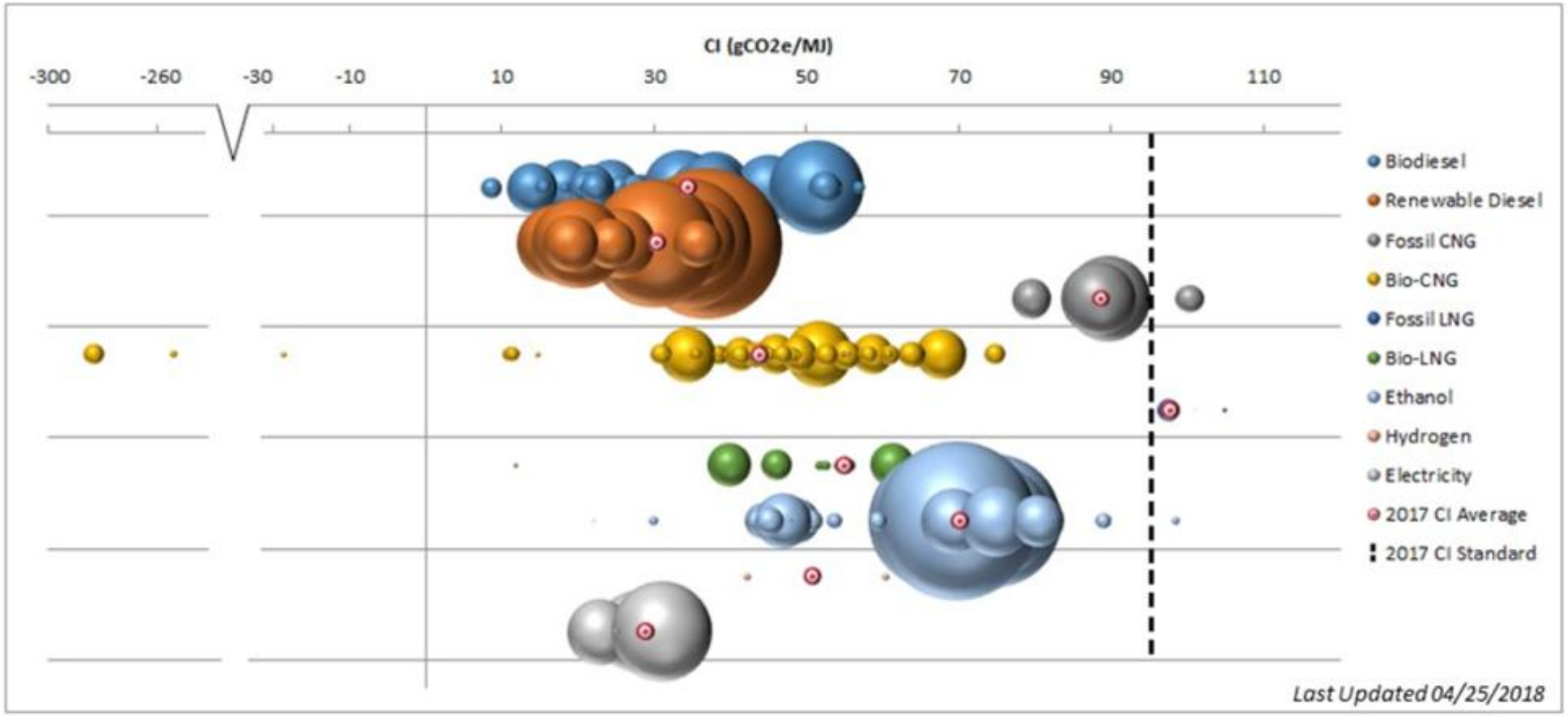
SAF Environmental Sustainability – GHG's

- Each individual production facility assigned its own Carbon Intensity based on feedstock, process, and transport to market

- SAF has lower GHG emission rate than Jet
  - Jet = 89 gCO2e/MJ
  - SAF (HRJ) = 39 gCO2e/MJ

SAF from this HRJ reference facility has 56% lower GHG's than Jet A1

2017 Volume-weighted Average Carbon Intensity by Fuel Type



Source: California Air Resources Board

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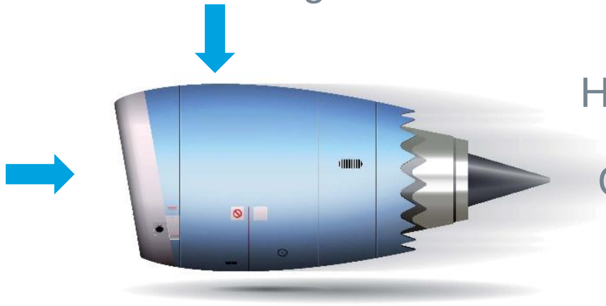
SAF Environmental Sustainability – Soot & SO_x

- NASA - Alternative-Fuel Effects on Contrails and Cruise Emissions (ACCESS) Study
  - 50% SAF (HRJ) Blend – Reduced soot particle number and mass emissions by 50% on ground and cruise

- Fuel components to pollutants
  - Aromatics make soot
  - Sulfur makes SO_x

- SAF 50% blend reduces sulfur and aromatics in fuel by half



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Why India?

- To be successful with SAF, Countries need
  - Biomass – Alcohols and oils near term, cellulosic in future
  - Labor – Farmers, Operators, Logistics, Waste Collection
  - Waste – Used cooking oils, fats & tallows, dry trash
  - Refining / Biofuel Infrastructure to build on – World class Indian companies
  - Supportive Policy – National Policy on Biofuels 2018
- India has most all the elements in place….

Using 10 pc biofuel for first time, IAF"s AN-32 aircraft conducts flight ops at Leh
January 31, 2020

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In Conclusion…

- New policies to monetize GHG reductions are making SAF truly sustainable (Social, Fiscal, and Environmental)
- SAF technologies are available from Global and Indian companies
- India has all the elements necessary to produce SAF for global consumption, and domestic consumption with GHG policy updates
- Market studies, technical diligence, feasibility studies, whatever your need; ICF is here to help!

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Lets Get Started…

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