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Deploying Sustainable Aviation Fuels at Scale in India: A *Clean Skies for Tomorrow* Publication

INSIGHT REPORT

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Christoph Wolff
Head of Shaping the Future of Mobility, World Economic Forum

Amit Khera
Senior Partner, McKinsey & Company

The World Economic Forum's Shaping the Future of Mobility Platform aims to enable clean, safe and inclusive mobility for communities around the world. As one component of the efforts to deliver on these priorities, the platform is partnering with public, private and civil society leaders to facilitate sizeable reductions in greenhouse gas emissions, in line with the targets outlined in the Paris Agreement.

The Forum's *Clean Skies for Tomorrow* initiative is facilitating the aviation sector's energy transition across the value chain on a global scale to enable net-zero flying by mid-century. This includes a focus on scaling sustainable aviation fuels (SAF) and other clean propulsion technologies.

Advanced sustainable aviation fuels make up only a small portion of the aviation fuels available to date. They still require significant investment if they are to reach the availability and price competitiveness necessary to fulfil aviation's needs, but the required technology pathways are maturing, and new SAF production facilities are announced with increasing frequency.

Europe and North America are the front runners in SAF production for now. But for aviation's global decarbonization efforts to be inclusive and equitable, SAF production must be available and affordable in all markets, enabling all aviation customers to take advantage of its many economic and social benefits.

India is a model case study in SAF opportunity for the world. Although hit hard by the COVID-19 pandemic, the country's economy is quickly recovering and remains on average one of the world's fastest-growing economies. Its middle class will continue to expand rapidly in the coming years, fuelling the growth of India's aviation industry – itself forecast to be one of the world's top three markets by 2025.

The availability of rapid-scaling, low-cost renewable energy in India, coupled with ample amounts of SAF feedstocks (such as agricultural waste, used cooking oils and municipal solid waste), provides the country with a significant opportunity to develop its own domestic SAF production industry. With proper support, this will in turn create hundreds of thousands of jobs and increase farmers' incomes, all the while enabling a more sustainable aviation industry. In fact, the analyses presented in this report show that the initial investments to kick-start the industry will yield a ten-fold return via overall macroeconomic benefits.

The global *Clean Skies for Tomorrow* community continues to grow, and through the collaborative efforts that went into producing this report, now includes dozens of stakeholders within the Indian ecosystem alone. Together, the *Clean Skies for Tomorrow* India community has set out to achieve a goal of 100 million passengers flown on SAF at a 10% blend by 2030. The World Economic Forum acknowledges the leadership of the partners whose commitment to this project shows that this future is possible. Together, the World Economic Forum and McKinsey and Company, collaborating on *Clean Skies for Tomorrow,* present this detailed blueprint of how to achieve this goal. This report is a first step in converting the ambition of India's aviation sector into reality and a blueprint for similar initiatives in emerging economies.

Foreword

Ajay Singh
Chairman and Managing Director, SpiceJet

The Prime Minister of India, Narendra Modi, recently reminded us at the World Sustainable Development Summit 2021 that the ideals of *Bahujan hitay, Bahujan sukhay* (the well-being and happiness of the maximum number of people) cannot be achieved unless the development process is inclusive and sustainable. Aviation is a key enabler of economic development, but increasing access to aviation and its benefits cannot come at the cost of the environment. The COVID-19 pandemic has only further highlighted the importance of environmental and economic preservation, and if the environmental footprint of aviation is to be reduced as it grows, a move towards sustainable aviation fuel (SAF) is imminent.

On 27 August 2018, SpiceJet successfully used SAF on a demo flight from Dehradun to Delhi. This was a historic achievement and a bold move from the airline that successfully demonstrated the company's motive to develop cleaner skies for a better tomorrow. Since that first flight, SpiceJet has strived to make progress in developing and successfully using SAF, thus encouraging the energy transition of aviation in the country.

I am extremely grateful to the World Economic Forum for having provided a results-oriented platform, through which stakeholders worked tirelessly to develop this blueprint and shed light on the importance of SAF for a brighter and cleaner tomorrow. I am proud to serve on the prestigious *Clean Skies for Tomorrow* Steering Committee and to work together with these stakeholders to advance the development of a SAF industry in India.

India has shown a steadfast commitment to meeting the Paris Agreement targets, likely ahead of time. We would like to supplement India's efforts in the skies and SpiceJet stands committed to flying 100 million domestic passengers on SAF by 2030 – a desire I expressed at the Climate Summit on the sidelines of United Nations General Assembly in September 2019 in New York.

Clean energy is a sunrise industry that India aspires to espouse. Through the *Clean Skies for Tomorrow* community, we seek the support of the Indian government to establish a policy framework that makes SAF a commercially viable commodity. India has access to biomass from farmland and other sources at scale that today are often wasted and burnt, adding in turn to air-quality hazards. Converting this biomass to SAF instead will enable India to draw on its untapped potential and become a global leader in SAF production. Sufficient sustainable feedstocks would enable us to fully support out domestic aviation market, as well as providing surplus for export.

Adopting SAF as the primary fuel of the Indian aviation industry is an ambitious endeavour, one that does not come without its challenges. Overcoming these will require great coordination and collaboration, and I am encouraged by the leaders in the aviation and energy ecosystem, who have so far shown great willingness to build a new industry for the country. Together we can reshape the future of aviation and fulfil the *Atmanirbhar Bharat* (self-reliance) vision of our Honourable Prime Minister.

Guiding thoughts from India's *Clean Skies for Tomorrow* community

Under the Bio-Mobility™ platform, Praj develops and deploys innovative biofuel technologies to produce low-carbon transportation fuels across all modes of mobility (surface, air and water). Sustainable aviation fuel, based on the alcohol-to-jet pathway, is one of the key pillars of our Bio-Mobility™ platform. India can become a global leader in decarbonizing the aviation sector and can significantly contribute to the global bioeconomy because of the availability of surplus sustainable feedstock and conversion technologies and by implementing a supportive policy framework and funding mechanism for SAF production. It will also facilitate energy self-reliance, economic development and growth of the farming community.

Pramod Chaudhari
Executive Chairman, Praj Industries

Civil aviation today is an identified contributor to carbon emissions, with targets in place to mitigate the same by ICAO. SAF is one of the three solutions specified under the ICAO basket of measures for carbon emissions reduction. Some countries have already initiated SAF use and with the projected traffic growth for India, this initiative to bring together the various stakeholders for SAF use comes at an opportune time. Sustainability is finding increasing inclusivity in the approach of various industries. For the civil aviation industry, SAF use is one of the potential means thereof. However, challenges still need addressing at various levels, starting from the production point through to the final use; it is my expectancy that this platform would provide the required solutions for ushering in SAF use and contribute thereby to the environment.

Hardeep Singh Deol
Head, Flight Operations Technical, Tata SIA Airlines (Vistara)

PRESPL is committed to making the sustainable aviation fuel story a success in India through robust supply chain management and with a hope that proactive policy enunciation and implementation will lead to a surge in biofuels in the country. This requires effective R&D and viable business models, plus the active support of key stakeholders who are committed to synergy to bring about climate change mitigation, a reduction in carbon footprint and ushering in greater prosperity in rural India.

Rohit Dev
Chief Operating Officer, PRESPL

"The push to decarbonize the aviation sector will rely on a range of levers including advanced new technology and, vitally, a significant acceleration of sustainable aviation fuel deployment. It is an energy transition which cannot just take place in some regions: it needs to be a truly global effort and encompass all countries no matter their geographic and developmental situations. This *Clean Skies for Tomorrow* special report for India is an important step to help focus attention on the actions required from the aviation industry, governments and energy suppliers and we would like to see it replicated around the world!"

Michael Gill
Executive Director, International Air Transport Association

The development of a sustainable aviation fuel (SAF) industry offers an excellent opportunity for an economic recovery focused on jobs, growth and sustainability. The SAF industry could support local jobs and local economies through the collection of biomass and waste. It would enable investment and growth by helping to scale supply chains via micro, small and medium enterprises that can collect, pre-process, store and deliver biomass and waste to the SAF producers. Channelling biomass and waste, which is otherwise dumped or burnt, as inputs to the SAF industry would mitigate many of the challenges associated with air pollution. Further, using SAF can bolster India's reputation for innovation and climate leadership. Finally, SAF production could use green hydrogen, which would leverage India's large solar and wind energy potential. Overall, a SAF industry can demonstrate that a new social contract between the state, citizen and enterprise can indeed serve as a bulwark against negative environmental challenges and tail-end climate risks.

Arunabha Ghosh
Chief Executive Officer, CEEW

The long-term sustainability of aviation is a major focus area for Boeing. Earlier this year, we committed that our commercial airplanes will be capable and certified to fly on 100% sustainable aviation fuels by 2030. Our industry and customers are also committed to addressing climate change. Collectively, we believe sustainable aviation fuels are safe and offer the most measurable solution to significantly reduce carbon emissions from flying in the coming decades.

The World Economic Forum's timely study on scalable production and utilization of sustainable aviation fuels in India provides unique insights into not only improving the country's carbon footprint, but also socioeconomic benefits that include waste reduction, new jobs, economic growth and the development of critical technology.

Salil Gupte
President, Boeing India

Commercial-scale production of sustainable aviation fuel will help India decarbonize its aviation sector, and increasing production relies on creating a supportive regulatory framework and ongoing collaboration between government and the private sector. Shell is proud of the work we have done with the World Economic Forum because it demonstrates the impact that collaborative public-private partnership can have in support of the government's efforts to create an *Atmanirbhar* and *Swacch Bharat*.

Anna Mascolo
President, Shell Aviation

Sustainable aviation fuels provide a significant opportunity to reduce industry life-cycle emissions and are projected to be a key part of the aviation industry's response to climate change. Measures will be needed to support the development and deployment of SAF at the pace and scale required to achieve emission reduction targets. The World Economic Forum *Clean Skies for Tomorrow* initiative is a leading example of where industry participants are collaborating to accelerate pace and scale of SAF deployment.

Harish C. Mehta
Chief Executive Officer, Reliance BP Mobility

Use of Sustainable Aviation Fuel is one of the key solutions towards mitigating climate change and achieving the global aspirational goals of UNFCCC and ICAO on net-zero emission by 2050. The *Clean Skies for Tomorrow* initiative towards promoting and using SAF to its full potential is one of the important mission for Indian aviation. The report highlights various economic, environmental and social benefits of SAF, feedstock and available technologies for production, along with other findings that are crucial for the successful roll-out of SAF for Indian aviation. This report will enable government and all aviation stakeholders to take part and work towards building a successful business model and achieve the objective of becoming a net-zero emission industry by 2050. We are very happy to be a part of the coalition and hope that together we can work towards making Indian aviation truly sustainable.

M. Muthukrishnan
Airport Sector Head, EHS and Sustainability, Delhi International Airport, GMR Group

In the wake of a global mandate for emission reductions adopted by the International Civil Aviation Organization (ICAO) applicable to Indian airline operators from 2026, it is critical for the Indian aviation industry to prepare itself for the emerging challenge. A greater use of sustainable aviation fuels offers them the opportunity to meet the obligations effectively and sustainably.

TERI has worked with the World Economic Forum to assess the economic and operational issues involved in production and transition towards such a fuel regime. Its assessment of the potential of sustainable aviation fuels in the country will be vital for the industry as well as the government to shape their response in terms of policy and the use of social, fiscal and market instruments necessary for the change.

R. R. Rashmi
Distinguished Fellow, TERI

The field of biofuels stands at the confluence of several of the UN Sustainable Development Goals, from Affordable and Clean Energy to Sustainable Cities and Communities, from Good Health and Well-Being to Industry, Innovation and Infrastructure. And, above all, it addresses Climate Action. CSIR-Indian Institute of Petroleum, a constituent laboratory of the Council of Scientific and Industrial Research (CSIR), is India's first deployer of indigenous aviation biofuel technology in both civilian and military flights within the country. We see SAF as a key initiative towards our people and nation-centric thrusts to science, technology and societal pursuits. In the true spirit of the SDG Partnership for the Goals, this multistakeholder alignment augurs well for the clean skies of our planet, for India, for the aviation sector and for all who believe in and come together for a decarbonized fuel value chain.

Anjan Ray, Director
CSIR-Indian Institute of Petroleum

India can take bold steps today to produce sustainable aviation fuel (SAF) at almost current consumer prices, supporting local economies as well as India's aviation decarbonization. The technology is commercially viable but still needs investment and market confidence to scale. Power-to-liquid (PtL) is a particularly promising SAF production pathway that can take advantage of India's renewable electricity supply, and our government should ask major carbon emitters in industrial centres to capture, clean and deliver CO_2 as a clean feedstock. This report is a critical step in building India's SAF industry and we look forward to continued collaboration through the *Clean Skies for Tomorrow* community.

Manoj Upadhyay
Founder and Managing Director, ACME

Community partners

Executive summary

The *Clean Skies for Tomorrow* India community has set a 2030 goal of transporting 100 million passengers on sustainable aviation fuel (SAF) on a 10% blend.

India is working with leaders around the globe to decouple GDP growth from emissions of CO_2 and other greenhouse gases (GHGs). Making air travel more efficient could help India achieve this goal. While the aviation industry contributes less than 1% of India's total emissions today, aviation is among the fastest-growing sectors of the economy.[1] Indeed, India is on track to become the world's third-largest aviation market by 2024, up from eighth place today.[2] Aviation's share of total emissions in India may increase significantly even if power, road transport and other industries make little progress in decarbonization.

Aviation produces about 3% of total CO_2 and 12%[3] of transport emissions globally. Recent research indicates, however, that its total impact on climate warming could be two to four times larger due to additional non-CO_2 pollutants and overall radiative forcing mechanisms.[4] The aviation sector has begun to address the global challenge. In 2016, for example, the International Civil Aviation Organization (ICAO) agreed through member states on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) framework, which includes a commitment to carbon-neutral growth after 2019, through a global carbon offset programme for international aviation. In 2009, the aviation industry committed through the Air Transport Action Group (ATAG) to a reduction pathway to 50% of 2005 emissions by 2050. In 2020, ATAG reiterated that commitment and described a pathway towards achieving that goal.[5] Traditional approaches to curb aviation emissions, such as fleet renewal, efficiency improvement or intermodal integration, will not be sufficient by themselves to reach the ATAG long-term 2050 CO_2 reduction target at a national or international level. Fully zero-carbon solutions relying on renewable electricity sources, such as battery electric and green hydrogen-powered commercial aircraft, may not come to market at scale before 2030 – or, more likely, decades later.

Even electric and hydrogen next-generation solutions are unlikely to cover flights beyond 1,500 kilometres. Most observers acknowledge that sustainable aviation fuel (SAF) will be crucial in reaching net-zero emissions targets by 2050. Using technology that is available today, SAF can be synthesized from renewable feedstocks such as municipal and agricultural waste and forestry and agricultural residues. In addition, SAF can be produced as e-fuels, also called power-to-liquid fuels (PtL), from green hydrogen and CO_2 collected from industrial plants and other point sources – including direct air carbon capture (DACC) as the technology matures. Depending on the feedstock and technological production pathway, SAF can in theory be up to 100% less carbon-intensive over its life cycle when compared to conventional fuel. The technological pathways and feedstocks assessed in this report yield 60% or more GHG savings compared to fossil fuels.[6] All aircraft and airports today can handle the current maximum certified blend of 50% SAF, through seven ASTM-certified production pathways. Around the world, more than 300,000 flights have already been powered by SAF.[7] SpiceJet operated India's first domestic biofuel test flight on a 25% blend of SAF in 2018. India's Centre for Military Airworthiness and Certification (CEMILAC) piloted SAF use across the Indian Air Force's AN-32 fleet as a milestone towards expanded use in India.[8]

Through the *Clean Skies for Tomorrow* (CST) initiative, the World Economic Forum has convened an Indian SAF community of private and public institutions with the shared vision of transporting 100 million domestic passengers in India on SAF by 2030 on a 10% blend, which translates to 360,000 metric tons of SAF. India's total expected domestic need for jet fuel is estimated to be approximately 8 million tons by 2030, flying an estimated 190 million domestic passengers a year.[9]

To be an effective emissions reduction measure, SAF producers must adhere to strict sustainability criteria for feedstock and energy inputs, incorporating strong and transparent certifications throughout the feedstock supply chain. This should include crop-choice and land-use impacts for agricultural feedstocks as well as equity and income considerations for farmers, waste management workers and other stakeholders. This should also include careful consideration of waste, residue, and surplus agricultural feedstocks such that any use does not in turn incentivize production of otherwise unsustainable practices or products. Overall, the CST community takes a nuanced yet pragmatic view of viable feedstock sources in line with the UN's Sustainable Development Goals and sustainable biofuel authorities such as the Roundtable on Sustainable Biomaterials (RSB) and International Sustainability and Carbon Certification (ISCC).

India has a wealth of natural resources and bio-based feedstocks and it is already a low-cost producer of solar and wind power at global scale. The nation is well placed to become a global leader in biofuels and e-fuels and to stay ahead of the curve in global technology development.

In the short term, four SAF feedstocks and production pathways are most feasible in India:

– Hydro-processed esters and fatty acids (HEFA), mostly from used cooking oil (UCO)

– Alcohol-to-jet (AtJ) using agricultural residues and surplus sugar streams such as cane molasses and syrup

– Gasification/Fischer-Tropsch (GAS-FT), using municipal solid waste and agricultural residues

– Power-to-liquid (PtL) in particular could be feasible based on hydrogen technology and access to point sources of carbon in the chemical, steel and cement industries.

“ India is well placed to become a global leader in biofuels and e-fuels and to stay ahead of the curve in global technology development.

Additional pathways now in development do not yet have American Society for Testing and Materials (ASTM) approval, but they should be considered in near-term analyses: these include catalytic thermochemical processes such as iH2 and other advanced pyrolysis and catalytic hydrothermal liquefaction pathways, using municipal solid waste (MSW) and agricultural residues.

Feedstock availability for the pathways identified is not a constraint in meeting SAF targets, as roughly 166 million tons of various feedstocks are now available each year, including used cooking oil, municipal solid waste, sugar streams and agricultural residues. These can yield more than 22 million tons of SAF annually, according to expert analysis.[10] In this report, the focus is on ASTM approved pathways for SAF production.

Harnessing these feedstocks would require concerted efforts to build feedstock collection systems and end-to-end supply chains and infrastructure. Collecting agricultural residues will require farm-level mechanisms, for example. Collecting cooking oil and sugar streams could build on existing mechanisms with a focus on industrial users, while harnessing solid waste will require end-to-end segregation infrastructure. Fuel delivery infrastructure and airport operations will not require significant changes, as SAF is certified as a “drop-in” jet fuel today using existing infrastructure.

SAF is currently 200–500% more expensive than fossil jet fuel in India, depending on the pathway and feedstock. Producing 360,000 tons of SAF for a 10% blend by 2030 will mean bridging a cost gap of more than $335 million. This study considers three scenarios to close this gap: government funding, customer funding, and a model with costs shared jointly.

Government support would be needed in India to begin building a SAF industry as an alternative or complement to CORSIA standards. This report shows that the macroeconomic benefits to India will greatly exceed the cost of SAF ramp-up by a factor of about 10. The full transition to SAF would happen over time, starting with a blending ratio at 5–10% and following the examples of other countries. The full transition towards a zero-carbon aviation industry over years will require close collaboration among all stakeholders, including cities, states and national regulators and legislators, as well as refinery owners, investors, fuel vendors, airlines and their commercial and private customers.

In addition to reducing carbon emissions and helping India to meet the UN’s Sustainable Development Goals, scaling up the SAF industry would provide macroeconomic benefits beyond the aviation industry. It would create tens of thousands of new green jobs, yield health benefits by reducing air pollution and improving waste management systems, provide additional income for millions of farmers who collect agricultural waste, and increase national self-reliance by promoting domestic energy security. Strict sustainability criteria is key to this success, due to the systemic impacts of crop choice and land use decision-making on local ecosystems, ground water tables, and a cost-benefit analysis of alternative land uses. But provided a holistic life-cycle environmental impact assessment is used, scaling the SAF industry in India could not only help address the threat of climate change but also approximately $2.8 billion in macroeconomic benefits to India’s annual GDP.

This report is intended to serve as a roadmap for an “Indian SAF community” that would convene all of the stakeholders required to meet the SAF challenge. It should serve as a starting point for a public-private taskforce, convened by the Indian government, to design an implementable policy framework to start decarbonizing aviation in India.

1 Introduction

Sustainable aviation fuel is the most feasible option to decarbonize air travel in India and globally for the next 15–20 years.

1.1 The global challenge

COVID-19 has affected the airline industry in unprecedented ways, shrinking capacity by about 75% in April 2020 compared to the year before.[11] Global demand will likely begin to reverse the negative trends by mid-2021, but a full return to pre-crisis demand may take several years. While the International Air Transport Association (IATA)'s industry forecasts suggest global aviation may be permanently affected by the pandemic, the growth trajectories of travel and associated emissions are likely to resume over time.[12]

With the recovery of the sector, another challenge will attract the attention of customers, regulators, airline executives and investors alike: aviation produced 915 million tons of CO_2 emissions in 2019,[13] about 3% of the global CO_2 total, along with other greenhouse gases (GHGs) that contribute to global warming.[14] Recent research also indicates that aviation's overall impact on global warming is likely two to four times larger than its 3% of emissions alone, due to additional non-CO_2 pollutants and overall radiative forcing mechanisms,[15] underscoring the need to act. Efforts to reduce those emissions began in 2009 when ATAG set a target to cut CO_2 emissions to half of 2005[16] levels by 2050. While a 50% reduction in CO_2 emissions represents a sectoral trajectory aligned with the "well below 2°C" objective of the Paris Agreement,[17] representing the recognized upper limit on global temperature increase to avoid potentially catastrophic impacts, alignment with the 1.5°C scenario requires full decarbonization by 2050.[18] International aviation climate ambition is governed by ICAO and is not yet formally part of the Paris Agreement, whereas domestic aviation emissions are covered under the Nationally Determined Contributions (NDC) of individual countries within the Paris Agreement.[19]

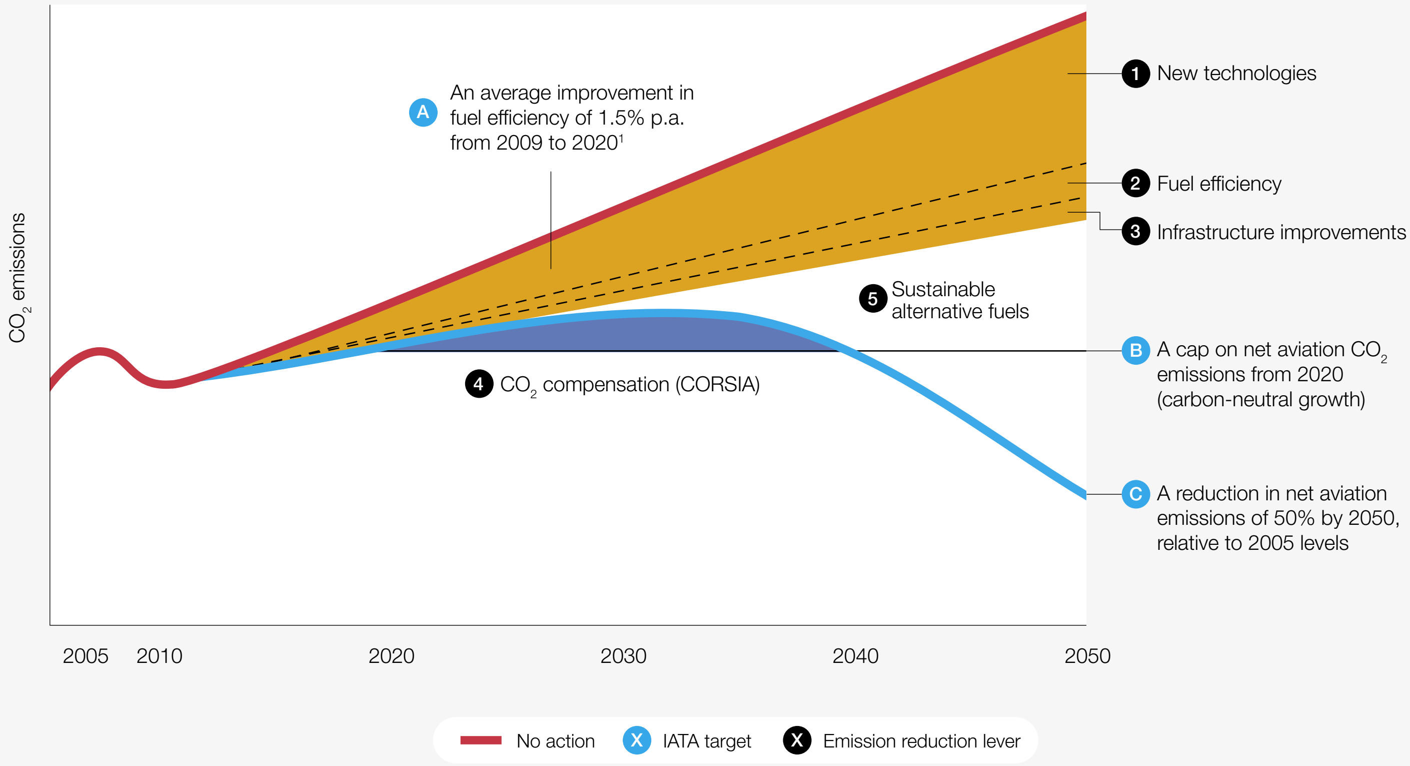
Reducing the industry's GHG output is especially important, as aviation emissions are likely to grow faster than those of other modes of transport, particularly as those modes electrify. Demand for aircraft fuel could increase by more than 50% by 2050 compared to pre-COVID levels, despite continued improvement in fuel efficiency and the steep decline in air travel during the pandemic.

The aviation industry can take several approaches to reduce CO_2 emissions. Fleet renewal, technological and operational efficiency improvements and intermodal integration, for example, directly reduce fuel consumption and therefore emissions, but the potential is limited. Fleet renewal is already underway: airlines globally invested almost $120 billion in new aircraft in 2018.[20] New models have far more efficient engines, and modern long-haul twin-engine aircraft are replacing four-engine aircraft, improving fuel efficiency per passenger by up to 20%. (Figure 1)

FIGURE 1 | **Aviation's decarbonization pathway relies on improvements in aircraft technology, operations, infrastructure, offsets and biofuels plus other radical technology such as hydrogen and electric aviation[21]**

In 2008, the aviation industry set ambitious decarbonization targets

Schematic CO_2 Emissions Reduction Roadmap (IATA)



1 ICAO puts an ambition of 2% fuel efficiency gains p.a. from 2021–2050
Source: IATA, ICAO

Airlines have agreed on carbon offsets under CORSIA, but these will not advance innovation for in-sector decarbonization. Carbon offsets need to be tightly controlled for environmental integrity and leakage risk, and the industry should uphold the pressure to innovate and scale the most suitable decarbonization options – without establishing an overreliance on offsets.

Few industry leaders expect to see scaled deployment of fully electric aircraft with more than 100 passengers in the next 10–15 years. With current battery technology, a plane would need more than 50 kilograms of battery weight to replace a kilo of kerosene. And since battery weight doesn't burn off the way fuel does, the aircraft would need to carry the full load for the entire flight, requiring additional energy, which is a particular burden for longer flights.

Smaller hydrogen-powered aircraft that use direct hydrogen combustion or hydrogen fuel cells could become feasible in the next 10–15 years, such as Airbus' ZEROe concept plane, which is expected to launch by 2035. However, scaling the technology to planes that seat 100 passengers or more will require significant advances in technology and infrastructure.[22] Liquefied hydrogen requires four times the volume of kerosene, for example, reducing space for customers or cargo. Airports would need new refuelling infrastructure, including fuel trucks that can store liquefied hydrogen. Refuelling could take longer, potentially lowering gate and aircraft use. A supply base of green hydrogen, produced from renewable energy sources, would be required to achieve decarbonization.

These challenges leave SAF as the most feasible option to decarbonize air travel, at least for the next 15–20 years in short- and medium-haul operations and likely much longer for long-haul journeys. SAF can be synthesized from a wide range of sustainable, renewable feedstocks, such as municipal waste, biomass residues, used cooking oils and in some cases surplus agricultural products. SAF can achieve significant reductions in GHG emissions with specific emissions reductions dependent on the type of technological production pathway and feedstock. For example, SAF can be more than 100% less carbon-intensive than fossil jet fuel by using direct-air carbon capture as a feedstock and

> “ Given more than 70% of aviation CO2 emissions in 2018 resulted from mid- and long-range flights, moving to SAF is vital to reducing the industry’s emissions.

production powered by renewable electricity. Bio-based feedstocks such as municipal solid waste (MSW), agricultural residue and used cooking oils (UCO) deliver significant GHG savings as well. Because their emissions reduction calculations are based on a life-cycle analysis, incorporating factors such as land-use change, emissions from collection and transportation, and local food security, regular monitoring and supply-chain transparency are essential elements of SAF production.

SAF is proven and safe: seven production pathways – combinations of feedstock and conversion processes – are ASTM-approved today.[23] More than 300,000 commercial flights have already operated on SAF since 2011.[24] Currently, sustainable aviation fuel is certified to be used in combination with today’s aircraft and engines for a level of up to 50% blending with conventional jet fuel. Early in 2021, Boeing announced its intention to deliver aircraft that can fly on 100% SAF by 2030.

Even after hydrogen-powered or electric planes become available for short-haul flights, SAF will continue to be the best option to significantly reduce CO_2 emissions for long-range flights for decades to come. Given that more than 70% of aviation CO_2 emissions in 2018 resulted from mid- and long-range flights, moving to SAF is vital to reducing the industry’s emissions.[25]

Establishing a SAF industry as a solution to mitigate CO_2 emissions follows a global trend. For example, SAF is in commercial production in California (Altair), and Finland (Neste). Some regions and countries lead the way in incentivizing SAF scale-up and are considering policies to mandate the use of these sustainable fuels. The European Commission, for example, is considering a SAF blending mandate in all member countries by 2025 as part of the “European Green Deal”. The Netherlands, Sweden, Norway, the UK, California and other governments leading on environmental responsibility are creating their own SAF policies, paving the way for other countries. Norway recently added a quota requirement for SAF of 0.5% of annual fuel use from 2020, scaling to a target of 30% by 2030.[26]

The global shift to sustainable aviation fuel is not limited to Europe and North America. Other countries including Indonesia, Japan[27] and Australia[28] have begun to implement efforts to scale SAF.

1.2 India's SAF opportunity

More than 1.5 billion people will enter the world's middle class in the next decade, including hundreds of millions of people in developing countries.[29] Air travel will subsequently follow a similar trajectory: by 2050, analysts expect global demand for jet fuel to reach 530 million tons per year, up from 330 million today, with the share of passenger miles travelled in emerging markets rising from 32% to 45%.[30]

Air travel is growing faster in India than almost anywhere else: the country is predicted to move from the world's eighth-largest user of aviation fuel in March 2019 to the third-largest by 2050.[31] Along with most other markets, India's aviation industry was hit hard during COVID-19, but at the time of this report's publication, the sector had started its recovery – at least domestically.[32]

Given the expected growth, decarbonizing the sector is therefore all the more important for India. The country has begun to reduce CO_2 in other sectors, including a commitment to generate 40% of its electric power installed capacity from non-fossil fuel sources by 2030[33] in its Nationally Determined Contributions (NDC) under the Paris Agreement.

In 2020, India achieved its voluntary target of reducing the emission intensity of its GDP by 21% over 2005 levels, and it is poised to achieve a 35% reduction well before the target year of 2030.[34] India has also set new climate and energy targets, such as to generate 450 gigawatts (GW) of renewable energy usage by 2030 – a high aspiration considering India had just 86 GW of renewable energy capacity in 2019.

Biofuels have come into focus in India, primarily with progress in ethanol and biodiesel under the National Biofuel Policy (2018) and the Ethanol Blending Programme.[35] The policy provides guidance on the use of agricultural and municipal solid waste, used cooking oil, animal tallow, sugar streams and other feedstocks. It also suggests approaches to developing supply chains, potential sources of funding, such as Viability Gap Funding (VGF) for second-generation (2G) bioethanol refineries, and lays out the roles of the respective ministries to coordinate and encourage biofuel development in India.

India's starting point for SAF is different, however, from other biofuels and other countries. Compared to European countries, for example, India is trailing in the maturity of its supply chain, demand for renewable products, and customers' willingness to pay to reduce their carbon footprints. Since fossil jet fuel is abundant and relatively inexpensive, shifting to SAF will require the support of government, industry and consumers, particularly as growth in the Indian aviation market accelerates.

India does start with some advantages, including the significant size of its market. It has abundant sustainable feedstocks and is one of the world's lowest-cost producers of renewable energy. Even with strict sustainability requirements in place, India has significant SAF feedstock potential. It could therefore be in a leadership position and build its own roadmap to scale SAF, tapping into global cross-functional expertise and the support and input of local stakeholders. The *Clean Skies for Tomorrow* initiative enables just that, bringing together the know-how and influence of private and public institutions from across the value chain to lead emissions reductions in the aviation sector.

BOX 1 The World Economic Forum's *Clean Skies for Tomorrow* coalition is advancing SAF progress in India

The World Economic Forum is the international organization for public-private cooperation. The *Clean Skies for Tomorrow* initiative epitomizes this mission, with more than 80 organizations globally and more than 20 within the CST India workstream alone. The members of the initiative are located throughout the entire value chain and incorporate public, private and civil society sectors. This report serves as a blueprint for action, informing all stakeholders in the decision-making process to scale SAF. Now, in partnership with the Indian government, the community pledges to make this 2030 vision to fly 100 million passengers on sustainable aviation fuel by 2030 a reality.

2 Economic and social benefits of SAF use

The benefits to society from SAF use include waste reduction, new green jobs, economic growth and the development of technology critical to the global economy.

Energy consumption will continue to rise in India along with population and economic growth. Since 2015, the population has increased by more than 56 million and gross domestic product has grown at an average of 6.7% annually, excluding the impact of COVID-19.[36] India can sustain this growth only if it can find ways to use its natural resources more efficiently and rely more on renewable resources. Moving to SAF will support India's efforts in meeting the UN's Sustainable Development Goals.[37] (Figure 2)

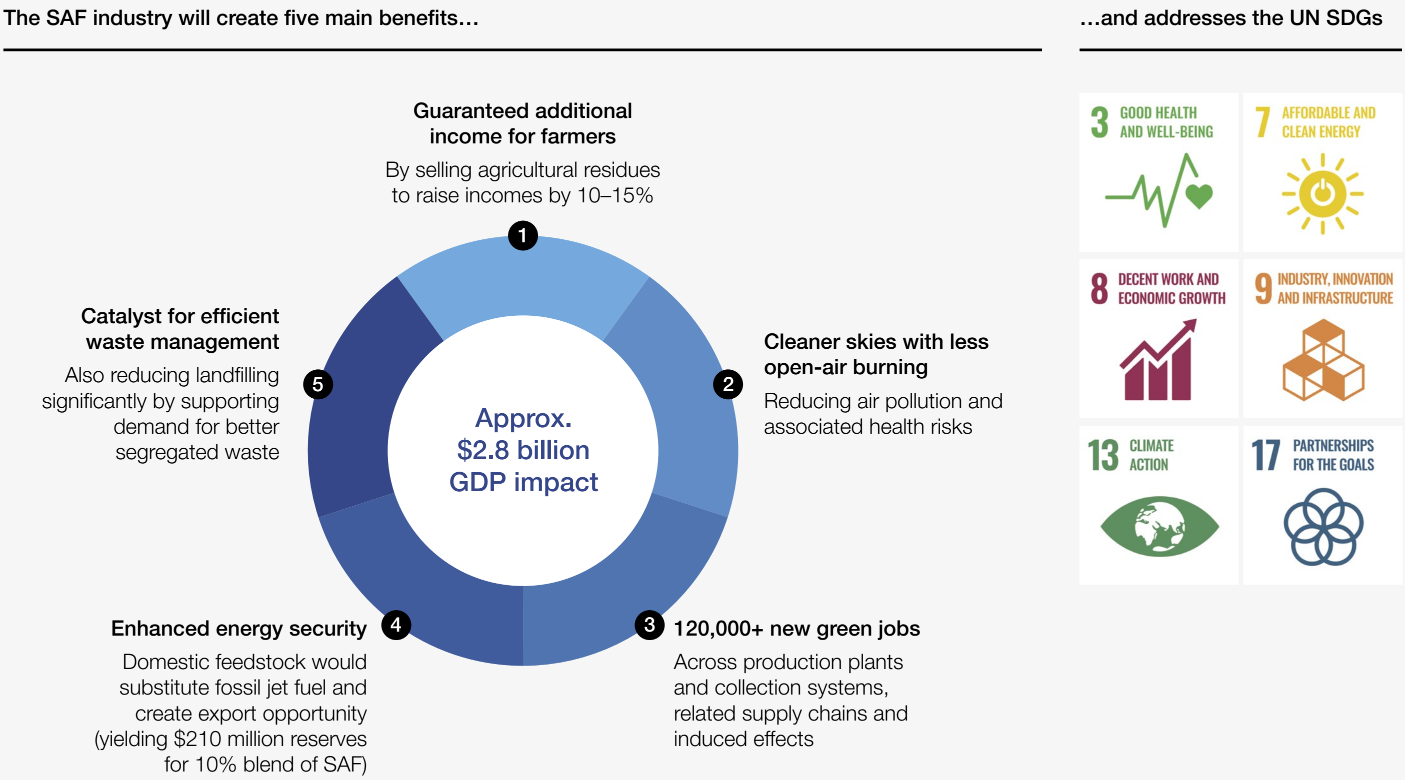
In its shift to SAF, India will build new technological capabilities and become more self-reliant. Indeed, it could become a global leader in SAF supply-chain infrastructure and production. This current 10-year period, which the UN calls a "decade of delivery", will see the development of national and international solutions that enable SAF development to decarbonize global aviation. By investing early in SAF, India can stay ahead of the technology curve for emissions reduction and meeting the growing demands of individual and corporate consumers.

As aviation emissions decline and eco-conscious air travel rises, the benefits of sustainable fuels will become increasingly clear and accelerate the growth of the SAF industry. This industry would generate a combined GDP equivalent of approximately $2.8 billion, as annual SAF production rises to 360,000 tons by 2030, based on the estimates within this report. This includes significant benefits beyond CO_2 reduction, such as green jobs, incomes for farmers, reduced pollution from better waste management as well as declines in agricultural residue and the burning of domestic waste, the sale of by-products including biochar, and enhanced self-reliance.

The move to SAF could reduce India's "social cost of carbon" (SCC): the macroeconomic damage caused by additional GHG emissions, estimated to be one of the highest in the world. SCC is defined as the net present value of climate change impacts over the next 100 years (or longer) of one additional metric ton of carbon emitted today.[38] The US government requires that SCC be included in environmental impact assessments. Canada and the UK use it in federal decision-making processes, and Mexico and other countries around the world are considering its use. Reductions in SCC represent real benefits for citizens, including increases in agricultural productivity, and reductions in healthcare costs, property damage and loss. These macroeconomical benefits were not quantified in this study and would be in addition to the approximately $2.8 billion increase in GDP.

FIGURE 2 **Moving to SAF will deliver five major societal benefits while addressing the Sustainable Development Goals (SDGs)**

Rough estimates based on ~360,000 tons of SAF in 2030



Source: United Nations; Shyamsundar et. al., 2019; expert interviews; McKinsey Global Institute

1. Additional income for farmers

On average, India's farmers have an annual income of $1,000–$1,140 and work one hectare of land. To estimate the benefits to farmers from a domestic SAF industry, this report used as a basis the calculated value of agricultural residues as biofuel feedstock. According to research published in 2019,[39] selling agriculture residue could provide farmers with an additional income of $160 per hectare, which represents an approximate income increase of 15% based on average income.

This estimated increase in income includes additional annualized fixed costs for rental or purchase of collection equipment, labour and potential fertilizer to substitute for residue nutrients returned to the land through mulching or burning. Overall, harvesting agricultural residues for SAF production instead of burning in the fields has the potential to not only generate additional income but also provide notable co-benefits, including improved local air quality.

As the SAF industry scales, annual demand for agricultural residue is expected to rise by 1.7 million tons for four plants producing 100 kilolitres of SAF per day by 2030. In total, this could provide 300,000 farmers with more than $50 million in additional income.

Gathering residues from across the country would require providing machines available for rent to farmers to reduce their upfront net investment costs after subsidies. The exact amount of additional income will depend on many factors, including crop type, season and local sociopolitical conditions, but such a business model would provide some protection against crop failures and supports the government's objective of doubling farmers' income by 2022.

FIGURE 3 **Scale-up of SAF can create a value chain with inherent incentives for farmers to encourage reduced stubble burning**

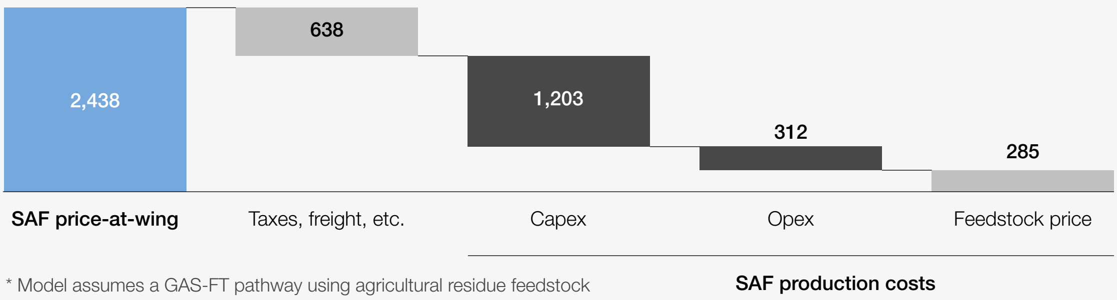
Farmers can receive additional stable income from selling agricultural residues as feedstock to SAF production

Additional income is in the order of magnitude of 15%

Significant air quality co-benefits exist, as residues are harvested instead of "stubble burning"

Cost build-up for 1 ton of SAF production $*

Rough estimates

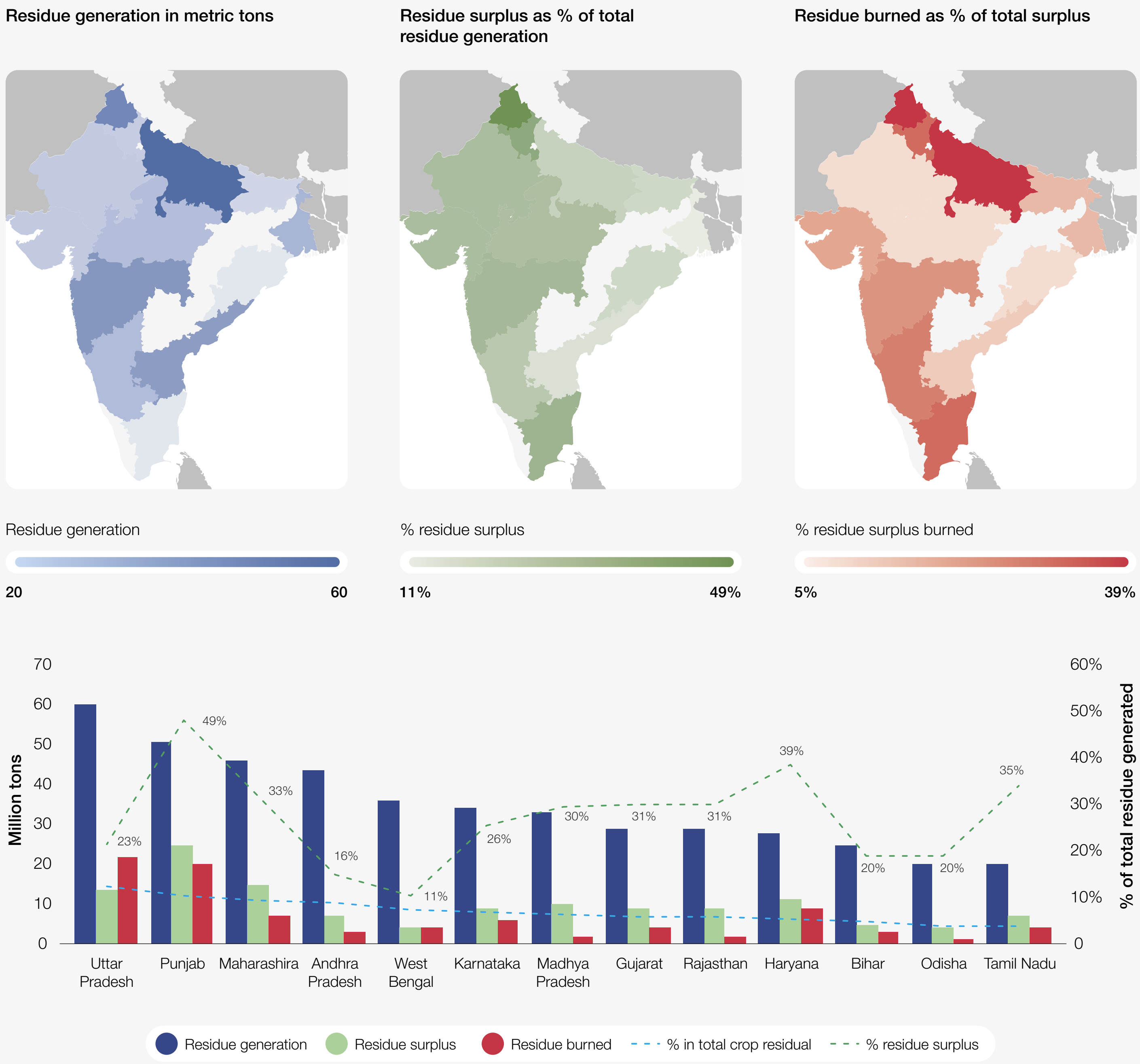


* Model assumes a GAS-FT pathway using agricultural residue feedstock

2. Cleaner skies with less open-air burning

With a robust market for agricultural residues in place, farmers will have new incentivizes to sell residues instead of burning them. Rice and wheat residues account for the highest share of agricultural residue in India (34% and 22%, respectively).[40] Alternative management practices are already well-established, such as briquetting and hay stacking.[41] This opens the door for greater acceptance and participation in an agricultural residue-to-SAF-feedstock supply chain. Decreased open-air burning would also eliminate air pollution and reduce GHG emissions by up to 78%.[42] (Figure 4)

FIGURE 4 | **Agricultural residue generation and percentage surplus burned by state**



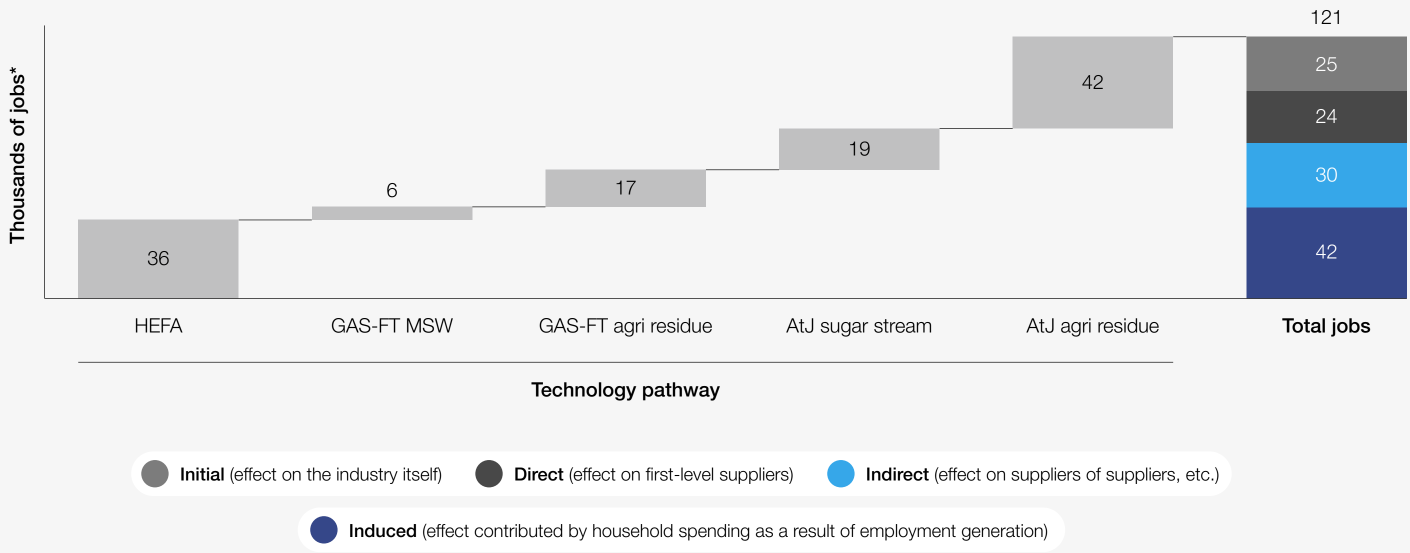
Source: Indian Council of Food and Agriculture, 2015

Roughly 90% of the emissions from open-air stubble burning are CO_2,[43] and they contribute as significantly to air pollution across the entire Indo-Gangetic Plain.[44] Air quality is the leading risk factor of acute respiratory infection in India, and experts estimate the economic costs of associated health risks at $357 million per year.[45] Educating farmers on economically viable alternatives to burning residues, and providing continued subsidies for machinery, such as 50% for *ex-situ* management tools such as rakers and balers, could boost demand for agricultural residue as feedstock for other biofuels as well.[46]

3. Green job opportunities

Achieving 360,000 tons of SAF by 2030 could generate more than 120,000 jobs (Figure 5) across the supply chain in collection, transportation and distribution, day-to-day operations, R&D and end-use distribution.

FIGURE 5 **Green jobs creation profile for 10% SAF blend by 2030**



*Numbers rounded
Source: CST expert estimates

a. **HEFA:** By 2030, four HEFA plants, each producing 100 kilolitres per day, would generate about 36,500 new jobs in all. Collecting 290,000 tons of UCO for 10% blend will generate 5,200–5,300 new jobs throughout the value chain. The collected UCO will be processed in refineries for the production of SAF, which will generate another 400–500 new jobs. Also, jobs pertaining to R&D, process operations, construction of plants etc. will further generate second-order effects in the supply chain, all of which translate into 31,500 new job opportunities.

b. **GAS-FT from municipal solid waste (MSW):** Producing 100 kilolitres of SAF through the GAS-FT process requires 30,000 tons of MSW. According to community members, Delhi alone produces 250,000 tons of MSW per day. Collection and production in one plant would create 1,000–1,100 full-time direct jobs, plus 6,000–6,500 jobs across the entire MSW supply chain, including R&D and operations.

c. **GAS-FT (agricultural residue):** Based on estimates similar to those for GAS-FT (MSW), another 30,000 tons of SAF could be produced through this route, achieving a 10% blend by 2030. Each 30,000 tons will require about 250,000 tons of agricultural residue, which should generate 2,000–2,200 jobs in collection and transportation to warehouses and refineries. Processing of agricultural residue in the plants will generate another 400–500 new jobs, generating second-order effects in the supply chain, which will translate into 17,000 new jobs and benefit more than 45,000 farmers.

d. **AtJ (sugar streams):** The technology has matured and is now producing first-generation (1G) ethanol in India. These plants can produce SAF with modest upgrades and relatively small investments. Further, this technology pathway would not add to the collection costs, since 1G plant supply chains are already established. According to experts, however, most of the jobs created in the AtJ pathway will be at the processing stage. Producing 100,000 tons of SAF on the AtJ pathway in three 100-kilolitres-per-day plants would generate more than 1,700 new jobs in production and about 18,500 in R&D and the process operations supply chain.

e. **AtJ (agricultural residue):** Based on the forecasts of CST members, 90,000 tons of SAF produced via the AtJ technical pathway with agricultural residue as a feedstock will be required each year to achieve a 10% blend in 2030. Producing that quantity would require 1.44 million tons of agricultural residue, which would generate more than 13,000 new jobs in three 100 kilolitres per day plants. Beyond feedstock collection, production in plants could create another 2,300–2,500 jobs with second-order effects in the supply chain creating 41,500 jobs in total.

Overall, producing 360,000 tons in all pathways could generate 120,000 new jobs, GDP of $2.8 billion per year, including $400 million from plant construction jobs, and $2–2.4 billion in collection, distribution and other links in the supply chain.

4. Enhanced energy security

Ranking third globally in overall energy demand,[47] India's rapidly urbanizing economy is dependent on imported oil – importing 82% of the total used in 2020. The government has established a roadmap to reduce crude oil imports by 10% by 2022,[48] through expanded renewable energy supplies and domestic biofuel production.

Producing SAF domestically would add to the total volume of jet fuel available to the Indian market, displacing equivalent volumes of production from imported oil feedstock and thereby enabling export opportunities. Subsequent jet fuel exports, estimated at a value of $210 million, support the Indian government's vision of self-reliance and the Make in India agenda.

5. Catalyst for efficient municipal solid waste management

By improving the segregation of MSW, a SAF ecosystem could catalyse efficient waste collection in India. Landfill space constraints are rising in Delhi as large dumping grounds reach saturation levels.[49] With better segregation, Delhi and other large cities could reduce the share of waste put in landfills significantly.

Better segregation can also help each metropolis generate additional annual income of $7–9 million by selling rather than landfilling waste products such as plastic, refuse-derived fuel waste, and biowaste or compost to other industries.[50] Reducing landfill can reduce environmental harm, particularly the leaching of waste into groundwater.

This is not solely a technological challenge as there are many barriers to implementation. India's landfills are commonly segregated by hand, for example, providing an essential livelihood for highly marginalized people and fuelling economic activity in the informal space. Some innovative and successful programmes include ragpickers in efforts to improve waste management systems and address associated equity and human rights issues.[51]

Realizing these and other societal benefits in SAF production will require a holistic approach that considers six key dimensions. (Figure 6)

FIGURE 6 | **Six dimensions and guiding questions as India scales SAF**

6 dimensions must be considered…

…with key guiding questions

1. What sustainable feedstock is available? Which production pathways are viable?
2. What ecosystems must we build for feedstock collection and management?
   What type of production capacity is required (greenfield, brownfield, repurposed) and feasible to meet demand, and in what locations?
   How will we need to change infrastructure and operations from production site to the wing?
3. What is the demand for SAF and by-products? How can we market and sell by-products, and to whom?
4. How large a price premium are private and corporate customers willing to pay for SAF?
5. How can we get funding to produce SAF at scale?
6. What regulatory and tax measures can support SAF scale-up?

BOX 2 | **Key takeaways**

Creating manufacturing capacity for 360,000 tons of SAF could generate a range of important benefits for Indian society. It will lead to mitigation of 0.6 CO_2 MT emissions, which aligns to the government's commitment to SDG goals for 2030, while promoting economic growth and energy self-reliance:

- 120,000+ new jobs
- Average income increase of $160 per hectare for farmers
- $7–9 million in revenue for each city, producing 9,000 tons or more of solid waste daily with improved segregation and less landfilling
- Reduced open-air burning of agricultural residues

3 Feedstocks and technology to scale SAF

Using a combination of ASTM-approved technologies and available feedstocks, India could produce up to 24 million tons of SAF annually.

India can reach its target of serving 100 million passengers with a 10% SAF blend by 2030 using a mix of technologies and sustainable feedstocks as approved by the American Society of Testing and Materials (ASTM):

1. Hydro-processed esters and fatty acids (HEFA) made from lipid feedstocks

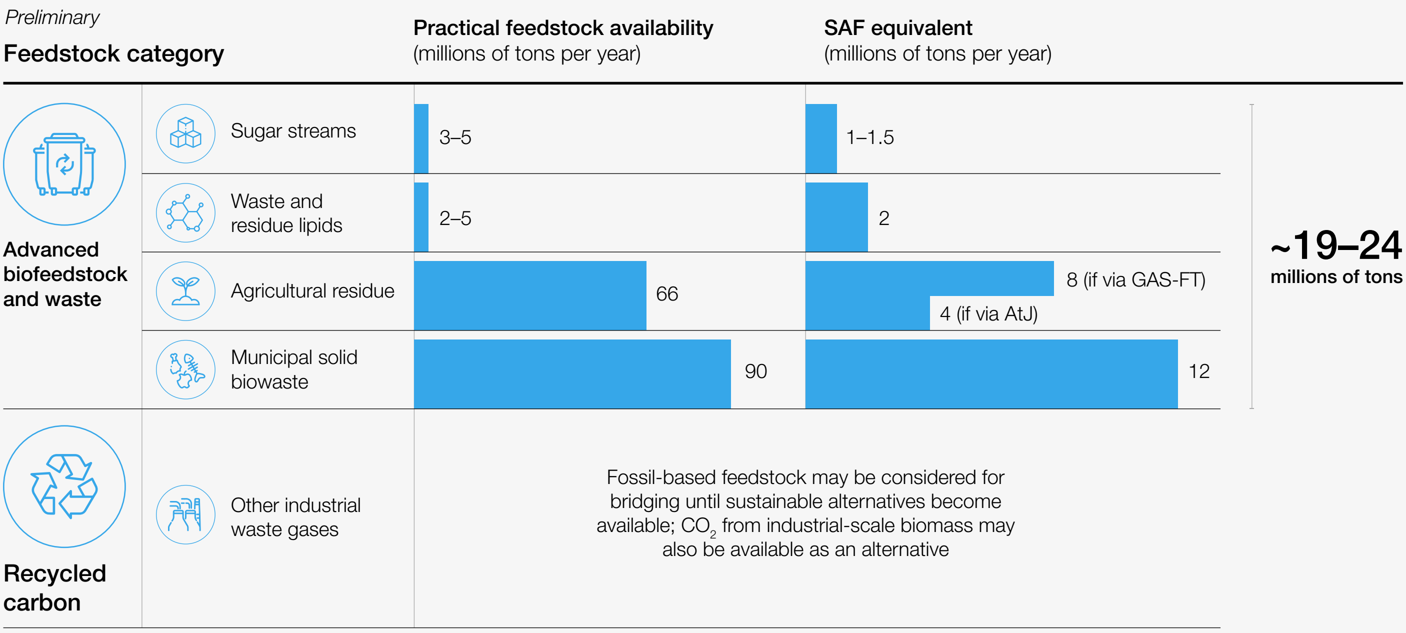
2. Gasification/Fischer-Tropsch (GAS-FT) made from municipal solid bio and plastic waste or agricultural or forest residues

3. Alcohol-to-jet (AtJ) made from agricultural or forest residues and surplus sugar streams such as cane molasses or syrup

4. Power-to-liquid (PtL) produced with hydrogen technology and carbon from industrial processes or other point sources

Using a combination of these approved technologies and feedstocks, India could produce up to approximately 24 million tons of SAF annually (Figure 7), far exceeding the target production of 360,000 tons. Organizations such as the Technology Information, Forecasting and Assessment Council believe output could be even higher.[52]

FIGURE 7 **Five main categories of feedstock could yield far more SAF than will be required in 2030**



Source: ACRE McKinsey solution based on e.g. GLADA, Bai et al., 2008, Gibbs et al., FAO, Mapspam, FAO 2015 FRA, ESA CCI Land Cover, FAOstat, USDA, World Bank, Greenea, Ecofys, Fischer Solve, Statistik der Verarbeitung Tierischer Nebenprodukte 2016, WRI, press search

These estimates are relatively conservative. Other promising SAF production technologies are not considered; for example, because they have yet to be certified by the ASTM, including pyrolysis (catalytic depolymerization) and catalytic thermochemical processes such as IH2 made from plastic municipal waste (which itself uses mainly plastic as a feedstock and therefore provides limited CO_2 reduction opportunity anyway), and hydro-pyrolysis and hydrothermal liquefaction processes from biomass and MSW.

All edible feedstocks are excluded, since they cannot be used for fuel by law in India except in special cases, such as the use of surplus sugarcane or spoiled grains for ethanol production. (The government is now considering a proposal[53] to use surplus rice for bioethanol production.[54]) Also excluded are any crop residue offtake support that encourages unsustainable practices such as rice cultivation in North India, where it might damage underground water tables.

This report is focused on a consideration of five feedstock categories for scaling SAF production in India (Figure 8):

– Lipid feedstocks, such as animal fats, used cooking oil (UCO) and tall oil

– Agricultural residues, such as straw of grain crops and processing residues such as husks and chaff

– Sugar streams derived from surplus availability

– Municipal solid biowaste (MSW)

– Electrolysis of water to extract hydrogen as fuel.

BOX 3 | **Sustainability considerations**

Strict sustainability filters, supply-chain transparency and holistic life-cycle assessments are necessary to ensure SAF delivers appropriate CO_2 emissions when compared to conventional fossil jet fuel. This report's appendix details the sustainability criteria applied to this analysis, including direct and indirect land-use change, potential impacts on biodiversity, water security and systemic shifts. Also implemented in this report's analysis is a pragmatic approach to using feedstocks currently available in significant quantities of surplus or waste as a bridging input until additional supply-chain capabilities are established, such as industrial waste gases to support scaled GAS-FT production. All other fossil-based feedstocks are excluded. This strict yet pragmatic approach is necessary to quickly advance the SAF production scale required to address the immense challenge of climate change and requires both further study in advance of any firm investments and continued monitoring once implemented. (See Appendix for additional information.)

Meeting the 2030 SAF goal will require advances in three categories of enabling infrastructure: collection systems for feedstock; production systems using the four pathways; and delivery infrastructure – although airport operations require no change at all. Because ASTM-approved SAF is virtually identical to its fossil-fuel counterpart, it has "drop-in" status and requires no additional infrastructure investment.

To accelerate progress, the industry will need to adapt best practices to set up collection systems, plan the required production capacity, and close any gaps in the current delivery systems.

1. Hydroprocessed esters and fatty acids (HEFA) based on lipid feedstock

Five subcategories of lipid feedstocks typically serve globally as HEFA feedstock: used cooking oil (UCO), animal fats, palm oil mill effluent (POME), palm fatty acid distillate (PFAD) and other oils (e.g. tall oil, technical corn oil and fish oil). As palm oil refining volumes grow in India, more PFAD will likely be available, although sustainability concerns may limit its applicability. Tall oil is not widely available, and technical corn oil is unlikely to be a significant component of the feedstock slate in India, as corn may not be used to produce biofuels.

India is one the world's largest consumers of edible oil at 22–27 million tons annually, indicating that UCO has significant potential as a feedstock,[55] even though it is commonly reused. Practical UCO collection is possible only from large industrial users.

While India is one of the largest exporters of meat products, demand for animal fats and tallow is high in both the organized and informal sectors. Much of the nation's annual production of about 360,000 tons of tallow, for example, goes into competing uses such as soaps, oleochemicals and exports. A large volume of animal fats is lost into the informal system or adulteration.[56]

India has significant theoretical availability of HEFA feedstocks in an estimated 2–5 million tons of UCO, but accessibility is limited by collection issues and other factors. (Figure 8)

FIGURE 8 | **HEFA feedstock availability**

Largest infrastructure hubs – not exhaustive

2–5 **Million tons potentially available HEFA feedstock (mainly used cooking oil) across India per year**

2 **Million tons potential SAF output (4.5 million tons total output) in proximity to logistic hubs, compared to 1 million tons required to meet 2030 ambition**

To exhaust potential, plants should be located in proximity to logistic hubs **(e.g. ports or Delhi-Mumbai corridor)** to facilitate national feedstock supply scheme

Degraded land serves as an opportunity to increase HEFA feedstock potential as well as tree-borne oil

Major cities | Major ports | Highway hubs | Largest highways

Source: BDAI, ICCT (2018), US Environmental Protection Agency, FAOstat, IRENA, E4TECH (2020), BEIS (2017), ICCT (2016), Wan Nur Aifa Wan Azahar et al., OECD, EC 142/2011, Greenea, USDA, Ecofys, Fischer Solve, FAOstat, VDP, press search

To make the most of the HEFA pathway, India will need to expand its UCO collection system, as up to 40% is disposed of illegally today.[57] Building this collection system presents challenges, since UCO producers range from households and small food stands to food factories and petrochemical companies. The collection system today, geared to collect UCO from industrial producers in and near large cities, is a starting point. UCO pricing will directly depend on the pricing of fresh cooking oil. Reasonable prices for UCO will give large food business operators incentives to participate in collection systems. Soap and petrochemical producers will remain as key competitors, and some UCOs will be reused in the food industry.

Best practices in existing efforts include harnessing digital tools for traceability, such as those used in online food platforms. The Food Safety and Standards Authority of India (FSSAI) and the Biodiesel Association of India (BDAI) run a “Repurpose Used Cooking Oil” web portal to trace and collect UCO-based biodiesel to supply public-sector oil marketing companies (OMCs) under a national programme.[58] These mechanisms, already running in eight states and union territories, can be expanded to a national UCO system, providing traceability across collection, production and supply. Digital tools are used to estimate the UCO outputs of different sources and to prioritize collection areas.

Given the decentralization of UCO producers, national, local, public and private participation will be required. The FSSAI needs to enforce notifications for UCO discharge and require large companies to commit to safe disposal. Local authorities, especially local Food & Drug Administrations in Mumbai, Delhi and other metropolitan areas, can help identify large industrial producers and collaborate with the largest private collectors of HEFA feedstock, such as Munzer, Zomato, Blue Energy, Arises and Banyan, to set up a collection and production scheme along with national authorities, including the Ministry of Petroleum and Natural Gas (MoPNG). These partners should be selected early, as it will take time to build a workable system.

This digital and partner collection infrastructure will need to be supported by stakeholder education and training. For example, collectors must educate consumers on the proper disposal of UCO, as already initiated by FSSAI with its “Triple E” strategy. As collecting UCO from industrial users in large cities will be more efficient than in small cities, HEFA production sites should also be near major hubs, such as ports and logistics corridors, to ease SAF distribution to customers. It is estimated that all available feedstock can yield a total annual SAF output of up to 2 million tons at the standard SAF pathway yield rate of 46%.[59] (Figure 8)

2(a). Gasification/Fischer-Tropsch based on municipal solid bio and plastic waste

Municipal solid waste can be used to produce SAF via the Gasification/Fischer-Tropsch chemical synthesis process. While only a few large plants have been built so far outside of India, the technology is scaling up rapidly and can be licensed for use.

Expert analysis suggests that approximately 200 municipal solid waste plants of 100 kilolitres per day could be viable close to large cities in India. A complete and unified waste-processing system will need to be built, including collection, segregation, sorting and transport, ideally with the coordination of central and local authorities.

While the Ministry of Housing and Urban Affairs has published MSW guidelines, state governments and municipalities are responsible for setting up collection systems. Partnerships with local municipal authorities are key to the sustainability and cohesiveness of MSW systems. As India moves to revenue-sharing to involve private MSW providers such as Eco Green[60] and Rollz India Waste Management[61] in Gurgaon, it will need to define a future-looking, sustainable MSW business model.

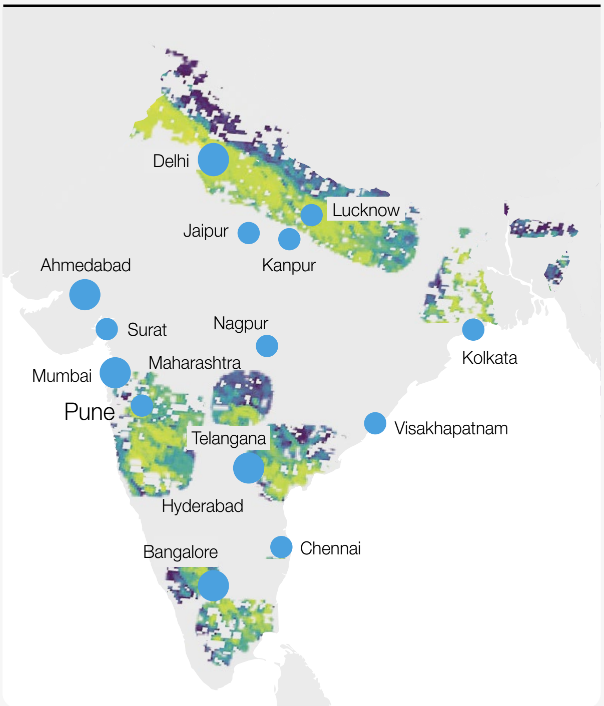
End-to-end segregation infrastructure is required across the MSW value chain to isolate the most useful feedstock components, such as biowaste and plastic, and impurities such as metal and stones need to be removed. While segregation improved at source under the *Swachh Bharat Abhiyan* campaign (with Bhopal[62] as a leading model), infrastructure such as segregated transportation is required to segregate waste types, maximize reuse and minimize the volumes ultimately delivered to landfills.[63] Producers could use plastic and mixed waste until a sorting and segregation system is in place; segregated transportation is considered best practice to limit mixed waste at landfills. A detailed study is also required to prioritize MSW locations, given the generally low calorific value of waste in India. Combined, agricultural residues and MSW could supply up to 12 million tons of SAF.[64] (Figure 9)

Many fuel producers are using MSW feedstocks today, including compressed biogas producers, coal plants and bioethanol refineries. Established biofuel projects demonstrate that India recognizes the importance of alternative feedstocks. About 500 letters of intent have been released for compressed biogas production plants under the Sustainable Alternative Towards Affordable Transportation SATAT scheme (see below).

The SAF output from Gasification/Fischer-Tropsch production plants is based on a number of economic assumptions, but to be economically viable, plants require a certain amount of practically available feedstock within a 70-kilometre radius, with an estimated 90 million tons of MSW available from large cities by 2030.

FIGURE 9 | **Geographical concentration of municipal solid waste and agricultural residues**

Rough estimates



Agriculture residues (t/100km²)

- 2
- 50
- 150
- 250
- 600
- 1,000
- 2,000
- 4,000
- 8,200
- 65,000

MSW availability*
Mt of SAF output

- 0.1–0.3
- >0.3

Significant potential for SAF production

200 GAS-FT plants using MSW feedstock closely located to seven large cities

200 Plants based on agricultural residues in six major hotspots (average of AtJ-Gas-FT)

12 Million tons SAF output[1]

Sustainable energy sector in total will benefit–

– Aviation and road fuel are synergistic, not competitive: SAF and road diesel can be produced together, based on the same feedstock

– Surplus of feedstock available; scaling effective collection systems will benefit the economics of all bio-based energy production

– Current SAF vision requires a fraction of total feedstock

1 Assuming average of 77% yield for AtJ and 55% for Gasification + FT and total output of 100 KLPD

*Analysis is sourced from expert input and McKinsey's ACRE solution. Other sources indicate a higher range from 150 million tons (India's Press Information Bureau) to 387 million tons (World Bank)

Source: McKinsey ACRE solution

2(b). Gasification/Fischer-Tropsch based on agricultural residue

Fuel producers currently use agricultural residue for feedstocks in bioethanol refineries. Under the SATAT scheme for compressed biogas, production plants represent the demand for 35,000–40,000 tons annual agricultural residue, sugarcane bagasse and MSW.[65] Coal plants run by NTPC[66] use 10% agricultural residue, requiring 70–75 million tons of annual feedstock. Twelve 2G bioethanol refineries to be completed in 2023–2024 are expected to use 2.5 million tons of feedstock each year.[67]

Available agricultural residue in India would yield 7.9 million tons of SAF through this pathway, taking into account alternative uses such as animal fodder and uses in other industries. The collection of surplus agricultural residue is scattered over India (Figure 10) and poses challenges in terms of collection and transportation to refineries – although developing a robust supply chain of feedstock to refineries would lead to increased jobs and income.

Agricultural residue can be used to produce SAF via Gasification/Fischer-Tropsch. This technology still presents engineering challenges, as only a few large plants have been built so far, but the technologies are maturing rapidly and can be licensed for use.[68]

It will be important to develop agricultural residue collection infrastructure in India, with supply chains accounting for high transportation costs (especially for bulky field residues), seasonality of crop production and the huge numbers of farmers requiring coordination. Storage infrastructure is also vital to limit deterioration in the quality of the feedstock, while adhering to safety standards, given the high flammability of agricultural residue. Operating models for feedstock collection need to incorporate location considerations as well; for example, feedstock collection in South India typically lasts much longer than in North India, due to the limited harvesting season in the north and its single crop production. Developing an agricultural residue collection supply chain can start with defining a business model for collection, involving local stakeholders and determining the role of local entrepreneurs (as PRESPL[69] has demonstrated) or of a central coordinating authority. Developing an adequate feedstock collection system must dovetail with policies for residue management, such as the National Policy for Management of Crop Residues, to both involve and incentivize farmers to sell any residue, while also raising awareness about alternate economical practices to residue burning.[70]

Given their limited quantity in India, forestry residues were not considered further in this analysis. Additional feedstock can be extracted from tree-borne oils and cover crops that require four to five years to grow.

3(a). Alcohol-to-jet based on agricultural residue

Agricultural residue feedstocks can also be used to produce SAF via the alcohol-to-jet technical pathway. This technology is in the early stages, similar to GAS-FT, but it is developing quickly. The supply chain and the production challenges and opportunities will be similar to those discussed in the previous section. The net surplus of 66 million tons of agricultural residue in India would yield 4 million tons of SAF through this pathway. Under current analysis, the GAS-FT pathway is 50% more efficient than the AtJ pathway using agricultural feedstock, but still needs significant technical development to produce SAF at scale.

3(b). Alcohol-to-jet sugar streams (cane molasses, cane syrup)

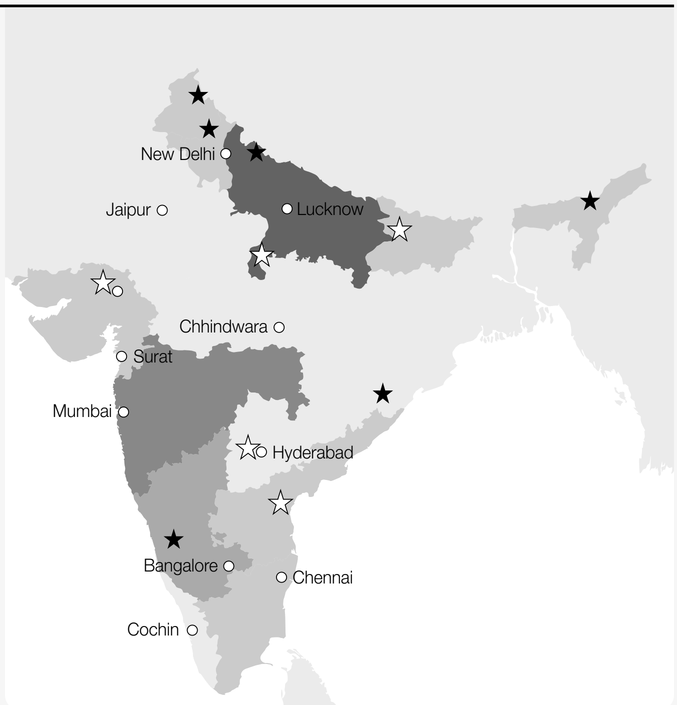
When it comes to sugar streams feedstock, India produces an average of 3–5 million tons of surplus sugar annually.[71] Sugar yields are growing due to new crop varieties. Instead of producing excess sugar, the existing sugar mills with total surplus capacity of 5 million tons per year can be used to produce isobutanol (IBA), an intermediate product that serves as an input for SAF. The IBA produced in sugar mills can then be converted into SAF at a conventional petroleum refinery. There is potential to produce 1–1.5 million tons of SAF per year, using the surplus cane syrup equivalent to 3–5 million tons sugar/year.

By adding a bolt-on module for IBA alcohol recovery, existing 1G bioethanol plants can be retrofitted at a marginal capital investment of 15–20% relative to the greenfield capex of a corresponding-scale new SAF refinery. Similarly, 2G bioethanol plants can be explored as well, where biomass to ethanol plants (12 refineries) under execution by OMCs can be converted for the production of IBA. Figure 10 shows the potential locations of these plants. IBA produced can be aggregated and further processed into SAF at a central refinery location.

FIGURE 10 **Existing and planned 2G bioethanol plants**

Sugar mill output and under-construction and planned 2G bioethanol plants

- Two 2G ethanol plants announced under the National Policy of Biofuels and PM-JIVAN Yojana
- AtJ pathway (sugar to SAF via biobutanol) mature, scalable, >80% GHG savings
- Isobutanol bolt-on module can be added to existing ethanol plants:
  - 1G plants based on sugar streams
  - 2G plants based on rice/wheat straw, bagasse and corn cob



Minor growing areas | Major growing areas

★ Under-construction 2G ethanol plants ☆ Proposed 2G plants

Source: Praj Industries

4. Power-to-liquid based on hydrogen technology and carbon gathered at point sources

The power-to-liquid (PtL) pathway converts renewable energy to liquid fuels and chemicals via hydrogen and carbon captured from point sources such as chemical, steel or cement plants or, in the future, from direct air carbon capture (DACC).[72]

Until recently, the costs of producing SAF with PtL synthesis were assumed to be three to five times those of conventional jet fuel, but the levelized cost of energy has fallen dramatically in recent years and is expected to decrease further. India has become one of the most competitive markets anywhere for solar energy, generating electricity at costs as low as $23/MWh per kilowatt hour solar and $32–$34/MWh for wind on and offshore.

Green hydrogen produced through electrolysers using renewable power is the basis for producing green SAF via Fischer-Tropsch (FT) synthesis. The FT process combines green hydrogen with carbon dioxide from point sources (ultimately from direct air capture) to first produce a syngas mixture (carbon monoxide and hydrogen), and then transform the syngas catalytically into aviation fuel alongside other carbo-hydrant liquids. The ratio of fuels produced can be changed using different catalyst compositions and/or altered process conditions.

ACME, with its first pilot project in Rajasthan, is demonstrating the production of green hydrogen and green ammonia. The plant, with a capacity of 1,825 megatons of product per annum (MTPA), is under construction and should be operational by Q2 2021.

The capex for electrolysers and production plants for chemical conversion in India can be reduced by using long-term loans at reduced or subsidized interest rates. Access to capital in international markets at lower rates of around 4–5% rather than 8–10% from indigenous lending institutions will reduce capex significantly; at the same time, India has access to low-cost equipment. Point carbon can be procured at zero or even negative cost within India, as CO_2 producers such as cement, steel or chemical plants need to otherwise pay to sequester the CO_2 produced. With low energy cost, zero cost of carbon, access to low-cost equipment

at lower-cost international finance, the PtL technical pathway could over the coming years become competitive and yield a price-at-wing well below $1,000/ton in the course of this decade. Given that it has a lower technical readiness level (TRL), this option should be investigated in more depth in the next phase of the initiative.

Another option in the short term could be power-to-hydrogen (PtH), where hydrogen comprises 5–10% of a typical refinery's energy inputs. PtH can convert this hydrogen required by refineries into green hydrogen, while maintaining the refinery's infrastructure and processes. This is obviously only a short-term intermediate step to full conversion to SAF from the PtL pathway. Green hydrogen can also be used as input to the HEFA and AtJ pathways.

The technology route provides additional options to diversify the pool of industrial-scale use cases and products from renewable energy, made in India. It can also help India make good on its commitment to increase its share of renewable energy from 175 GW in 2019 to 450 GW by 2030, as announced by Prime Minister Modi during the UN Action Summit in September 2019.

India's push towards hydrogen is gaining speed, as some of the country's top energy companies such as Indian Oil, Reliance Industries and Adani Group highlight the urgency of moving towards the carbon-free-fuel.[73] As part of India's efforts to strengthen and modernize itself in terms of power and energy efficiency, the government is collaborating with the US to launch a public-private Hydrogen Task Force to help scale up technologies to produce hydrogen from renewable energy and fossil fuel sources and bring down the cost of deployment for enhanced energy security and resiliency.[74]

BOX 4

Key takeaways

– India can produce more than enough SAF to serve 100 million passengers by 2030.
– A mix of four main feedstocks and three technology pathways seems to be the best option to produce the target amount of 360,000 tons a year for now: UCO for the HEFA pathway, and both agricultural residues and MSW for Gasification/Fischer-Tropsch and alcohol-to-jet pathways.
– Pyrolysis and hydrothermal liquefaction can be explored as solutions based on feedstock determinations and how the technologies develop.
– Concerted efforts by national and local as well as public and private organizations will be required to build feedstock collection and SAF production systems.
– Collecting UCO for HEFA will need to build upon existing best practices, involving FSSAI, local authorities and private players. HEFA could yield a total annual SAF output of up to 2 million tons from nine plants.
– The existing infrastructure of sugar mills and ethanol plants can be employed to produce isobutanol (IBA), an intermediate product for producing SAF. AtJ based on sugar streams could yield an annual SAF output of 1.5 million tons.
– Using municipal solid waste as a feedstock will require end-to-end segregation infrastructure. Combined, agricultural residues and MSW could supply 11 million tons of SAF per year.

4 Scaling SAF deployment in India

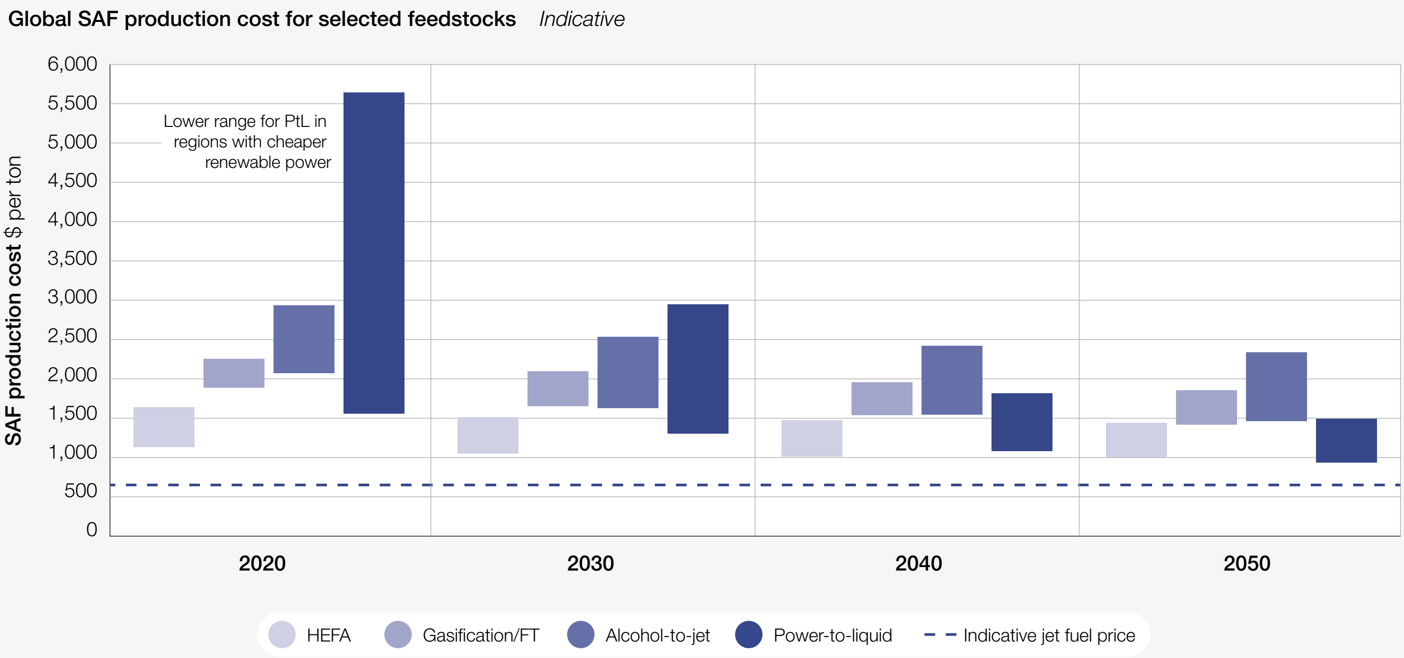
Although SAF is significantly more expensive than fossil-derived jet fuel today, costs should fall significantly in the coming decades as technologies mature and the industry reaches economies of scale.

4.1 SAF economics

As noted, SAF is significantly more expensive than fossil-derived jet fuel today. Costs should fall significantly as the relevant technologies mature, the industry scales up to harness economies of scale and participants advance the learning curves on feedstock supply chains and production. That said, market prices for SAF will likely remain higher than for fossil jet fuel until 2050.[75]

The analysis by the *Clean Skies for Tomorrow* initiative outlines in previous reports specific cost-reduction curves by pathway.[76] Figure 11 demonstrates the overall trend, with PtL notably decreasing significantly by 2030 in global markets, eventually reaching and potentially surpassing cost competitiveness with HEFA-produced SAF. In India, the combination of low-cost solar power and equipment prices may create competitive advantages for hydrogen-based PtL in comparison with other geographies, so this decline may actually come much sooner.

FIGURE 11 **SAF's global cost curves show a significant decrease over time, with PtL reaching competitive parity with HEFA in a matter of decades**



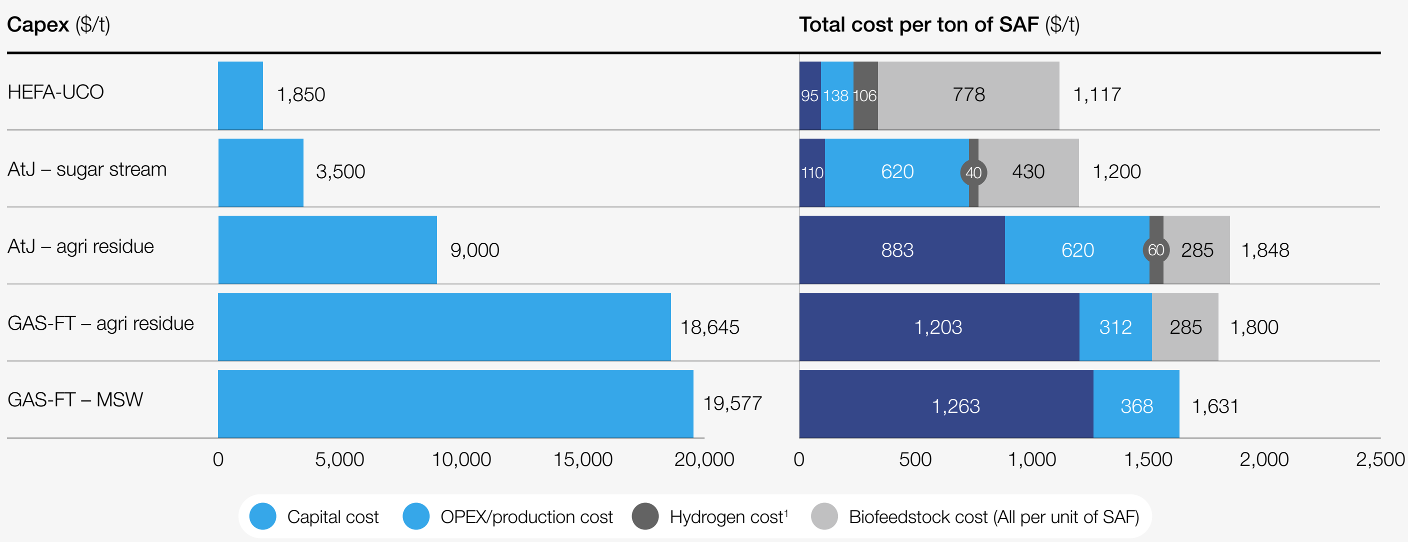
Source: World Economic Forum (2020), Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation

A SAF production system that meets the 360,000 tons required for the 2030 goal could be met by a combination of 12 plants producing 100 kilolitres per day, each leveraging a variety of technical pathways via HEFA, GAS-FT and AtJ. Power-to-liquid plants are not yet considered as capex requirements require further validation in the next phase of work.

The total capex required is approximately $2.5 billion in initial investments in the available technical pathways, incorporated into the total cost per ton of SAF as shown in Figure 12. Capex requirements by pathway vary depending on local context, but are roughly $1,850 per ton of production capacity for HEFA, $3,500 for AtJ (sugar stream, an extension of 1G ethanol plants), $9,000 for AtJ (agricultural residue), $18,645 for GAS-FT (agricultural residue) and $19,577 for GAS-FT (MSW).

Due to variations in local conditions, in the cost of feedstock and the technologies used by different technology providers, the cost of SAF production per ton is expected to vary from $1,100–$1,500 for HEFA, $1,200–$1,600 for AtJ (sugar streams) and $1,800–$2,200 for AtJ (agricultural residues) in India. Estimates for GAS-FT (MSW and agricultural residues) are similar at $1,600–$2,500, although due to lower technological readiness, the ranges of expected total cost are higher.

FIGURE 12 | **India-specific capital expenditure vs. total cost per ton of SAF, by pathway***



[1]Breakdown not available for GAS-FT as direct input

Source: McKinsey analysis and expert input

Note: *Capex includes only extension of existing 2G ethanol plants and not greenfield

The HEFA pathway has both the lowest capex and production cost, making it the preferred technology in the near term, although it has a limited feedstock availability. Capex for the AtJ pathway is relatively low, but it has high production costs. GAS-FT (MSW) has the potential to become one of the cheapest options in the near future. Feedstock is freely available and capex costs will decline over time. GAS-FT has significant potential to gain economies of scale if employed commercially.

PtL production pathways are not included in this report given the nascent stage of the technology, but it is a highly promising technology with significant opportunity in emissions reductions and cost competitiveness over time. Costs still vary significantly given technical readiness at scale.

4.2 Monetizing SAF by-products

As demand increases in terms of both road and aviation applications, there is significant potential for side products to create new opportunities in the biofuel ecosystem in India.

Depending on the SAF production pathway, 25–70% of the output will be non-jet fuel products such as road fuel and light-ends (by-products produced in the refining process), including LPG and naphtha. The Indian government aims to reach 5% share of biodiesel in road fuel by 2030, up from 0.14% in 2019.[77] This will require scaling up production capacity to at least 5 million tons per year. Because SAF production also yields significant levels of by-product, it yields a range of sustainable fuels that also help to decarbonize other transport sectors such as road transport, as detailed below.

Even as the share of electric vehicles (EVs) in India rises from 10% in 2018 to an expected 44% by 2030, absolute sales of internal combustion vehicles will continue to increase.[78] More biofuels will therefore be required in the road sector to limit the increase of road transport's carbon footprint. SAF production to achieve the 2030 goal will yield an additional 360,000 tons of alternative biofuels. This would create a win-win situation for the aviation and road sectors.

1. **Hydrotreated renewable diesel (HRD):** This road fuel, produced as a by-product of the HEFA pathway, can be blended in most diesel engines. Hydrotreated renewable diesel road fuel has several advantages over other types of road biofuels,[79] including lower NOx emissions

and better storage stability, even if production costs are more expensive.[80] Alternatively, as sustainable road fuel is traded globally at a premium, the road fuel from SAF production in India could be exported at prices that include a fair share of production costs.

2. **LPG and naphtha:** Light-ends such as LPG and naphtha can be commercialized, especially for environmentally conscious customers willing to pay a premium for renewables and for those who need to meet carbon-reduction regulations. While there is no premium on renewable side products today, that could change: naphtha could earn a premium in petrochemicals, especially through exports to meet international demand. Such premiums greatly affect net SAF production costs. Demand for naphtha is growing, with 11 plants in operation today and five more proposed in the next five years.[81]

3. **Iso-octane and ethanol:** The AtJ pathway with sugar streams as feedstock yields iso-octane (premium gasoline) as a co-product, which can provide additional revenue for the producer. Meanwhile, the AtJ pathway with agricultural residue as feedstock yields ethanol as a co-product, which has an established market in India. Both co-products will help SAF de-risk its own production.

4.3 SAF demand recognition

SAF will likely cost more than fossil jet fuel for decades. The key question for initial deployment is how SAF can be integrated into the market, given its necessity for environmental purposes but high comparative cost. In a survey of roughly 5,300 fliers in 13 markets around the world, most respondents (74%) believe public policies to reduce airline carbon emissions are necessary, even if this were to increase the price of flying. Further, 55% of Indian customers believe most of these costs should be borne by private customers, corporate customers or government subsidies.[82]

In a simplified example, if the cost premium of SAF is allocated based on the number of passengers and without any other measures to allocate cost, this could mean that all domestic passengers in 2030 would pay an approximate additional $1.80 for an average flight on a 10% SAF blend (Figure 13). The Indian aviation market is notedly price-sensitive. Fierce price competition has forced out players such Jet Airways and kept prices low; domestic airline revenues and cost per available seat kilometre are lower than those in other markets. This suggests that corporate and private customers are unlikely to pay a significant premium for SAF.

As Indian customers become more environmentally conscious, early selective Indian corporate adopters of green-friendly policies may begin to encourage uptake.

The *Clean Skies for Tomorrow* initiative is seeing a strong and global demand signal from major international corporations – nearly all of which have a large presence in India – for more sustainable aviation.

FIGURE 13 **Passenger premiums vary from $1.80 to $9.00 for a typical domestic flight, depending on the blend, ranging from 10–50%**

Rough estimates

6.8 million tons jet fuel demand[1] | **220 billion** revenue passenger km[1] | **150** PAX/flight[2] | **1,148 km** per flight[3]

Domestic demand assumptions for 2030	Total surplus cost[5] (billions)		Surplus cost[5] (distributed to all domestic pax[6])		Surplus cost[5] (per 100 million SAF pax)	
	INR bn	$ bn	INR	$	INR	$
10% blending[4]	~23.5	~0.34	126	1.8	231	3.3
25% blending[4]	~58	~0.8	315	4.5	578	8.25
50% blending[4]	~117	~1.7	630	9	1,155	16.5

1 From SAF demand estimate model, **2** 80% set load factor on Boeing 747, **3** Length of Mumbai-Delhi route, **4** Average price at wing at $1,980 per ton of SAF (no producer margin included) and $1,003 for fossil jet fuel, **5** 70 INR/$, rounded numbers, **6** Total of 190 million passengers

Source: Press search; expert interviews; McKinsey analysis; GEP SAF production cost model

> As Indian customers become more environmentally conscious, early selective India corporate adopters of green-friendly policies may begin to encourage uptake.

Major Indian corporates with significant business travel and known environmental responsibility objectives, such as those listed on GREENEX India, might have at last three main reasons to pay a premium for SAF as promoters of a sustainable aviation industry in the mid to long term:

- **Emissions reporting:** As more businesses adopt net-zero emissions targets driven by corporate leadership or investor demands, purchases of carbon credit options and offsetting replacements will continue to rise. There may even be an opportunity to link such carbon credits to the already operational PAT (Perform, Achieve, Trade) market mechanism for energy footprint reduction in India. Scaling SAF opportunities now will provide India with greater optionality and flexibility for its international obligations.

- **Social responsibility:** SAF is a good way to lead in social and environmental responsibility and enhance self-reliance for India and the world. Such corporate social responsibility funding could also be directed towards farmer support programmes to generate feedstock at affordable prices for scalable SAF production.

- **Leadership and branding:** Investments in low-carbon innovation and environmentally responsible brands have high marketing value in many industries, as consumers, investors and communities increasingly look for corporations to demonstrate environmental responsibility, particularly in the contexts of rural investment, tribal uplift and farmer empowerment in India.

By 2030, the total fuel demand for domestic aviation in India is expected to reach 8 million tons annually. The 2030 goal for the CST India community of 360,000 tons of SAF would meet just under 5% of total fuel demand. Key airline players in India have already started estimating their SAF demand. SpiceJet, for its part, expects to require 232,000 tons of SAF at 10% blend per year.

The price sensitivity of Indian air passengers will require policy intervention to ensure SAF's viability versus conventional jet fuel and maintain a level playing field across Indian operators.

The Indian Air Force has already committed to 10% blend for expanding the use of biofuels.[83] The SAF industry for aviation could be included in an existing framework that establishes minimum take-off agreements available in other biofuel programmes such as the road sector. This would create synergies between producers of biofuels for the road and aviation sectors and build a level playing field of incentives for participation of state-run oil marketing companies (OMCs) such as Indian Oil, Bharat Petroleum and Hindustan Petroleum.

4.4 Delivery infrastructure and operations

Because SAF is a drop-in fuel, delivery infrastructure will require only minimal adjustments to achieve SAF compatibility and airport operations will require no changes at all. Oil producers can work with OMCs to blend SAF with fossil jet fuel in the proper ratios. Blending SAF with Jet A1 kerosene by OMCs may require only limited operational adjustments at refineries.

Other options would require additional infrastructure: blending on the delivery route to the airport, for example, would require an additional blending facility, while blending close to the airport would require additional tanks and supply routes. Current regulations hinder blending on the airport grounds – as all fuel needs to enter airport facilities as ASTM-certified[84] – but it could be done nearby.

4.5 Certification

Certification in India is provided by two regulatory institutional bodies: the Centre for Military Airworthiness and Certification (CEMILAC) and the Directorate General of Civil Aviation (DGCA).

CEMILAC, a regulatory body under the Defence Research and Development Organization, certifies the airworthiness of military aircraft, helicopters, aero-engines and other airborne stores. CEMILAC has given full clearance to the Indian Air Force to operate all flights using bio-jet by CSIR-IIP, Dehradun, including its fleet of more than 100 AN-32 turboprop transport aircraft. The Indian Institute of Petroleum (IIP), a government-owned, Dehradun-based Council of Scientific and Industrial Research (CSIR) laboratory, is the first institute in India to produce high-quality bio-jet fuel from jatropha curcas oil. This fuel meets all specifications as per ASTM D 1655 and ASTM D7566 for Jet A-1 fuel (ATF). The Indian Air Force is now focusing on 10% blending due to availability feedstock; so far, the blending test has been successfully conducted at the 50% level.

The Directorate General of Civil Aviation (DGCA) certifies civil aircraft. The International Civil Aviation

Organization (ICAO), which has its own technical advisory board for certification on the basis of sustainability and technical criteria, certifies SAF blends approved by ASTM. Under CORSIA, any SAF or CORSIA-eligible fuel (CEF) needs to meet the sustainability criteria set by ICAO. SAF (CEF) producers have to be approved under the Sustainability Certification Scheme of ICAO. Once approved as CORSIA-eligible, use of SAF can be counted towards CORSIA. The DGCA can guide SAF producers through the entire process of ICAO. However, the DGCA currently does not have a domestic certification process for sustainable aviation fuel or other drop-in-fuels. If a SAF producer requires certification on fuel for a test flight, the fuel will have to be met by the Bureau of Indian Standard IS 17081:2019 Aviation Turbine Fuel (Kerosene Type, Jet A-1). Subsequently, the producer will also require approvals from the Director General of Civil Aviation.

BOX 5

Key takeaways

- SAF by-products have economic value and could create new opportunities in the biofuel ecosystem in India.

- Repurposing existing plants will require further investment; existing supply chains can be leveraged. Because SAF is a drop-in fuel, delivery infrastructure will require only minimal adjustments to achieve SAF compatibility and airport operations will require no changes at all.

- A variety of certification criteria exist that producers and users of fuel can access and learn more about through the Centre for Military Airworthiness and Certification (CEMILAC) and the Directorate General of Civil Aviation (DGCA).

5

Accelerating SAF deployment

India has a proven track record in promoting the development of nascent technologies and can leverage its experience to firmly establish a domestic SAF industry.

The development of a robust and sustainably sound SAF industry in India will require a basket of innovative financial and policy measures to adequately de-risk and incentivize the necessary investment in SAF production facilities and corresponding supply-chain infrastructure, and account for the price premium of SAF in the near to medium term.

5.1 Incentivizing investment

India has a proven track record in promoting the development of nascent industries such as solar energy and in using innovative measures such as green bonds and the National Policy on Biofuels 2018. It can leverage these and other tools to firmly establish a domestic SAF industry.

Risk-mitigation measures might include government guarantees or offtake agreements from major Indian corporations with significant business travel and known environmental responsibility objectives. Additionally, public-private partnerships may reduce risk and provide a more attractive business case for the investment in SAF infrastructure. Loan guarantees or multilateral lending from development finance institutions that are focused on facilitating achievement of the Sustainable Development Goals, and that already have a presence in India, such as FMO and Proparco,[85] may provide further opportunities for those looking to finance SAF infrastructure. Foreign direct investment could also be employed in the context of joint ventures and technology transfer agreements, considering the likes of funders such as the Asian Development Bank and World Bank.

Although India's corporate bond market is relatively undeveloped, the energy transition will offer significant opportunity for growth – including through traditional investor engagement as well as more innovative structures such as green bonds, which are specially designed to finance environmental projects.

Green bonds have had particular success in India; it is already the world's second-largest market for green bonds, with transactions worth more than $10 billion in the first half of 2019.[86] This mirrors global trends – investors expect sustainable investments in alternate feedstock development alone to increase from $1 billion in 2020 to $5–10 billion by 2030. Government agencies such as the National Bank for Agriculture and Rural Development (NABARD) (for collection projects), public-sector banks (PSBs), such as the State Bank of India (SBI) and Small Industries Development Bank of India (SIDBI), can play important roles in disseminating information and promoting sustainable finance in green bond issuance, as demonstrated by the Indian Renewable Energy Development Agency and Indian Railway Finance Corporation.

Furthermore, the trend towards environmental, social and governance (ESG) or sustainable investing may see an increasing role for private equity firms that include ESG as an investment philosophy.[87] With financial institutions looking to establish more environmentally responsible portfolios, investment along SAF production supply chains can result in a win-win scenario. Similarly, environmental management or public health programmes could provide investments on expected emission reductions.

5.2 Policy interventions

In order to accelerate investment and commitment to building a SAF industry in India, there are both existing India-specific policy tools as well as emerging tools conceptualized and adopted in other geographies, which may prove useful for policy-makers to consider in the near term.

The National Policy on Biofuels as a key mechanism

A policy framework is vital to making SAF a viable option for airlines and OMCs. One option is extending the National Policy on Biofuels 2018 for bioethanol and other alternative fuels. Under the National Biofuel Policy, the government has identified blending targets of 20% for ethanol and 5% for diesel for road transport by 2030. To support the National Biofuel Policy, the government has introduced a range of schemes to enhance agricultural productivity, farm mechanization and sustainable practices for economic growth in the rural sector (Figure 14).

Given the significance of SAF in the energy transition of aviation, a blending target of 10% for SAF by 2030, as this report suggests, could potentially be incorporated into this national policy. The existing policy already includes clear and transparent environmental integrity criteria for biofuels; this would avoid the unintended consequence of SAF production, which results in a conflict between energy security and food security. The policy also offers minimum prices for seeds and for the purchase of the biofuels, introduces financial incentives and promotes R&D for the production and commercialization of the fuels. All of this could be adapted and expanded in order to provide the same policy measures for SAF.

Under the conditions of the National Policy on Biofuels, states such as Uttar Pradesh,[88] Chhattisgarh[89] and Karnataka,[90] among others, have set up biofuel boards to invest in building biomass collection systems, a model that can be extended or replicated for SAF. Such boards can enable state government land support for infrastructure, fiscal incentives under the National Biofuel Policy that are feedstock-, technology- and fuel-agnostic, or price supports for SAF or related feedstocks.

As biofuel penetration increases in India, it may also be useful and necessary for the government to set up an independent regulator to monitor and manage feedstock pricing, mandates and blending targets depending on the policy regime in place.

FIGURE 14 **The CST community has identified several policy levers useful for enabling increased SAF production**

SAF production costs **200–500%** more than fossil jet fuel

$335 million in cost difference between SAF and fossil jet to bridge, to enable SAF scale-up and realize a GDP impact of about **$2.8 billion**

Several unlocks to scale SAF

Provide government stimulus for supply:
- SAF of nil to max of 5% GST in line with other biofuels

Scale demand through various measures:
- Redistribute existing air ticket charges that accrue to government (e.g. passenger service) to airlines flying on SAF
- Introduce offtake agreements led by the oil marketing companies
- Introduce a blending mandate for SAF under the National Biofuel Policy, potentially offset by a domestic passenger charge of nominal charge per passenger and flight

Enable de-risking investment in the first wave of SAF scale-up:
- Provide investment support or appropriate viability gap funding required[1] for production plants

Illustrative mix of levers

1 INR 70:$1 exchange rate

Source: Team analysis, expert interviews

Emerging policy tools for SAF scale-up

SAF production pathways beyond HEFA, such as AtJ and Gasification/Fischer-Tropsch, are not yet deployed at scale in India, although they are scaling up quickly internationally to the extent that the technology could soon be licensed to India. SAF is at an earlier point of cost degression compared to biodiesel. To create a level playing field for the use of biofuels in the aviation sector, policy support for SAF could include a mix of the tools that may reach beyond what currently exists in the National Policy on Biofuels. This could occur in the National Policy or, for example, under the imperative of India's strategic fuel security or other macroeconomic considerations detailed previously.

Based on the experience in other countries, a combination of the following types of policies could support SAF scale-up:

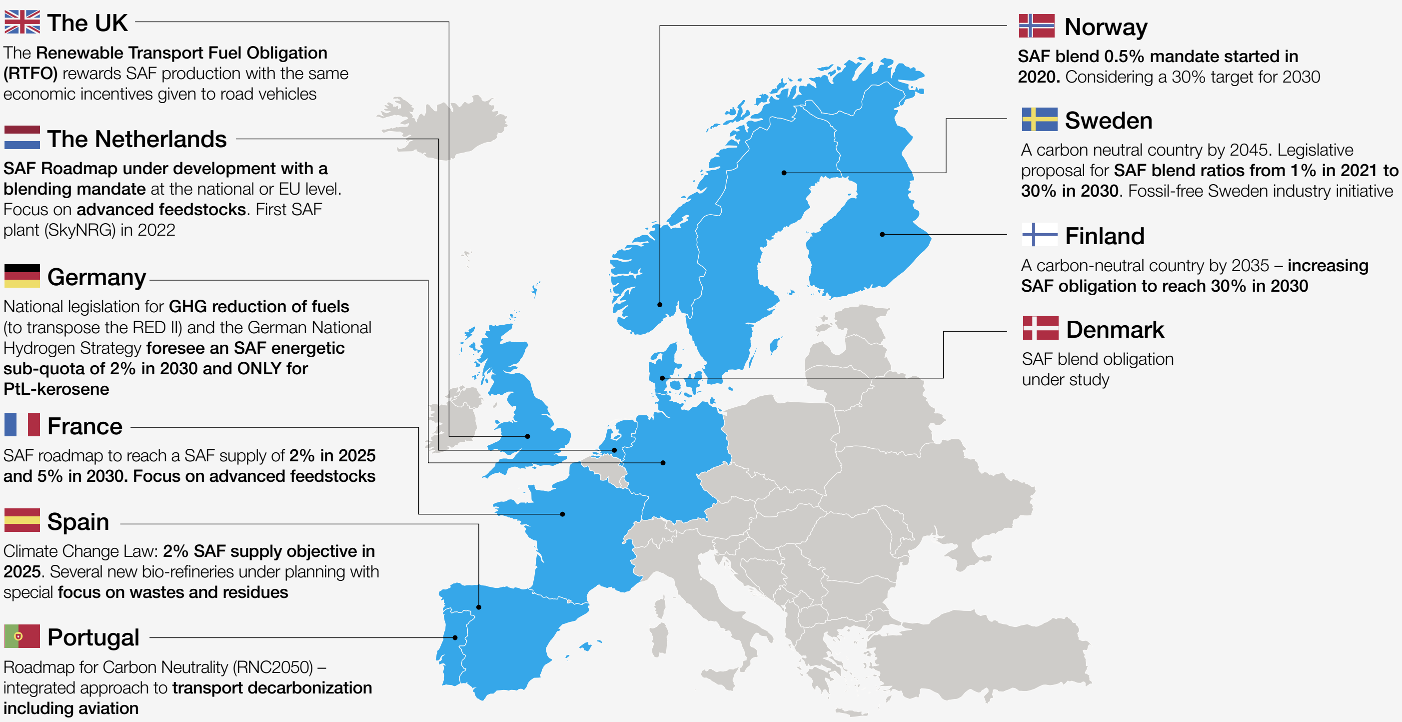
– *Mandates* have been introduced in India for road fuel, with targets of 20% ethanol blending for petrol and 5% for blending with diesel by 2030.[91] Similarly, large power consumers in India have renewable energy purchase obligations, which can be adapted for aviation fuel. Developing suitable blend rates for the Indian context, including a dynamic ramp-up scheme towards net-zero in 2050, will be vital for SAF development.

Some ambitious regions and countries already offer incentives for SAF and some, mostly in Europe, are considering mandating the use of sustainable aviation fuels. The European Commission is considering mandating a SAF blending mandate in all member countries by 2025 as part of the "European Green Deal". The Netherlands, Sweden, Norway, the UK, California and other governments leading on environmental responsibility are creating their own SAF policies, paving the way for other countries. Norway recently added a quota requirement for SAF – 0.5% of annual fuel from 2020, with a target of 30% by 2030.[92] (Figure 15)

Indonesia was the first country in the world to announce a SAF mandate in 2015 with a 2% SAF blend requested by the Ministry of Energy Direction, but this rule has yet to be implemented and does not yet include sustainability safeguards. Japan[93] and Australia (under the Australian Initiative for Sustainable Aviation Fuels)[94] have also begun important efforts to encourage the nascent industry but have not yet introduced blending percentage requirements.

FIGURE 15 **Countries throughout Europe are considering SAF blending mandates by 2030**

Some decisions pending



Source: SENASA

– *Taxes and subsidies* **–** to support inclusive air travel and economic development, the Indian government introduced in 2016 the UDAN-RCS scheme to provide subsidized air travel and enhance regional connectivity to Tier 2 and Tier 3 regions. As part of the programme, air fares are capped at INR 2,500 for a one-hour flight, with the government providing financial support for airlines to cover any resulting operating expenditure shortfall through VGF. The government has also offered a three-year exclusive partnership to airline routes that fall within the Regional Connectivity Scheme (RGS). Besides these, it will also offer concessions on other services and tax relief on aviation fuel at underserved and unserved airports.

  An additional example is the PM-JIVAN Yojana introduced in 2018.[95] The scheme encourages greenfield refineries by subsidizing capex (20% or INR 150 Cr, whichever is lower) per plant. Incentives such as tax reductions via GST adjustments are also offered to facilitate low-cost air travel. If SAF were to be included under India's biofuel classification, this GST reduction lever could be extended to SAF flights as well. Other levers such as reducing passenger taxes on SAF flights can also be explored. Biomass-based SAF projects could be afforded "nil GST" status and standard GST for the balance of the process until final sales could be shifted to 5–12%.

  Categorizing the SAF industry as a priority sector could qualify it for an array of benefits and schemes currently enjoyed by other related industries such as agricultural production. The ministries of Skills Development and Entrepreneurship, Agriculture and Farmers' Welfare, and Tribal Affairs, and institutes such as NABARD are already providing concessional soft loans, for example. Extending comparable schemes to SAF stakeholders could spur the growth of the supply chain.

– *Producer incentives and risk diversification* through extending current biofuel policies, such as the National Biofuel Policy 2018 to incorporate SAF under the umbrella of biofuels and develop a roadmap for a 10% blending mandate for SAF by 2030, can help facilitate industry growth. In addition, the VGF scheme, similar to the one expended for 2G ethanol biorefineries under Pradhan Mantri (JIVAN) Yojana, could be extended for SAF production facilities. Further, the transition in India to incentivize the industry through fiscal incentives such as tax credits, advance depreciation, subsidies for utilities and infrastructure etc. will make SAF plants commercially viable and will aid risk diversification for biofuel producers.

– *Cap and trade mechanisms* such as EU ETS and reductions in free-of-charge certificates, incentivize companies to cut emissions in cost-effective ways, and are cost-neutral for the government. This may be a long-term solution for India, given the lack of sectoral emissions cap or proposed environmental or sector-specific regulations.

5.3 Scaling SAF production: three scenarios

Airlines, airports, corporate and private customers and the government need to consider how to best share and close the cost gap.

SAF production costs are likely to remain significantly higher than those of fossil jet fuel for decades, with declines dependent on the maturity of technological pathways and efficiencies of production scale. Airlines, airports, corporate and private customers and the government need to consider how to best share and close the cost gap.

Working backwards from a landed SAF price-at-wing premium versus fossil jet fuel can help identify opportunities for policy interventions and efficiency investments. India followed a similar approach for biodiesel produced from UCO, setting a landed price guarantee at INR 51 per litre by OMCs, allowing producers to model production and feedstock costs.[96]

The first step is to identify the production costs of SAF and fossil jet fuel. This report has modelled the production costs of the main SAF pathways by incorporating various inputs, including the cost of feedstock and utilities, capital expenditures, yields and output product slate; it also assumes cost allocation between the by-products. To achieve the goal of 100 million passengers on a 10% SAF blend by 2030, 360,000 tons of SAF will be needed. Associated additional costs over fully fossil jet fuel use is expected to reach $335 million. This cost gap needs to be bridged to make SAF a viable option for airlines.

The three scenarios outlined below offer different routes to cover the costs: full ownership of costs by government, full ownership of costs by customers, or a shared arrangement. Regardless of whether government funding or consumer demand drives SAF production, the resulting socioeconomic benefits are estimated to be 10-fold. However, coordinated government investment will be far faster and more effective than relying solely on consumer demand.

Scenario A: Government provides funds to close the cost gap

The government could enact a range of measures such as tax breaks on aviation fuel, lowering SAF's GST bracket, subsidizing investment in SAF production through Viability Gap Funding or VGF, and/or minimum price support for feedstocks or fuel. Across measures, the PM-JIVAN Yojana, introduced by the Ministry of Petroleum and Natural Gas, is a flagship programme to provide financial support for 2G bioethanol projects using lignocellulosic biomass and the other renewable feedstocks. Under this scheme, the maximum financial support per project has been capped at INR 150 Cr ($21.4 million).[97] This could be extended to develop SAF plants through the support for drop-in fuels.

India's annual outlay of $500–$800 million in sugar subsidies is expected to end by 2023 when World Trade Organization (WTO) regulations on sugar exports take effect, or earlier pending ongoing discussion over India's subsidies in the WTO dispute settlement mechanism. Although this is expected to affect exports as well as domestic prices, the current levels of sugar production, the current levels of sugar surplus, and the continued domestic support for the industry suggest little change to the status quo in the short term, as the livelihoods of millions of farmers are affected.

As a result, potential use of surplus production for conversion to SAF via the AtJ pathway is expected to remain both cost-effective and a pragmatically sustainable solution – at least until more sustainable feedstock supply chains are established and additional SAF conversion plants come online.

In the next phase of work, the environmental integrity of using surplus sugar strains should be reviewed more in depth. With a shift towards different feedstocks, the government could also consider reallocating the current sugar subsidies to VGF for commercialization of SAF (while still requiring strict adherence to environmental standards). This move alone would be more than sufficient to close the entire cost-gap.

For the PtL pathway, access to international financing for plant capex – as the end product is considered an internationally tradeable oil product – is an indirect financial support to lower capex.

Scenario B: Government budget-neutral option where increased passenger ticket prices close the cost gap

As detailed earlier, an additional cost of $1.80 on all domestic flights at a 10% blend spread over the total 190 million domestic passengers projected in 2030 could be incurred, with the associated revenues reallocated to airlines depending on their share of SAF flights. This solution would be cost-neutral for the government, but a policy or mandate would be needed to introduce a blanket passenger charge to prevent price competition between airlines on the basis of SAF deployment. Such a passenger duty would be successful only if it will not lead to substantial intermodal substitution.

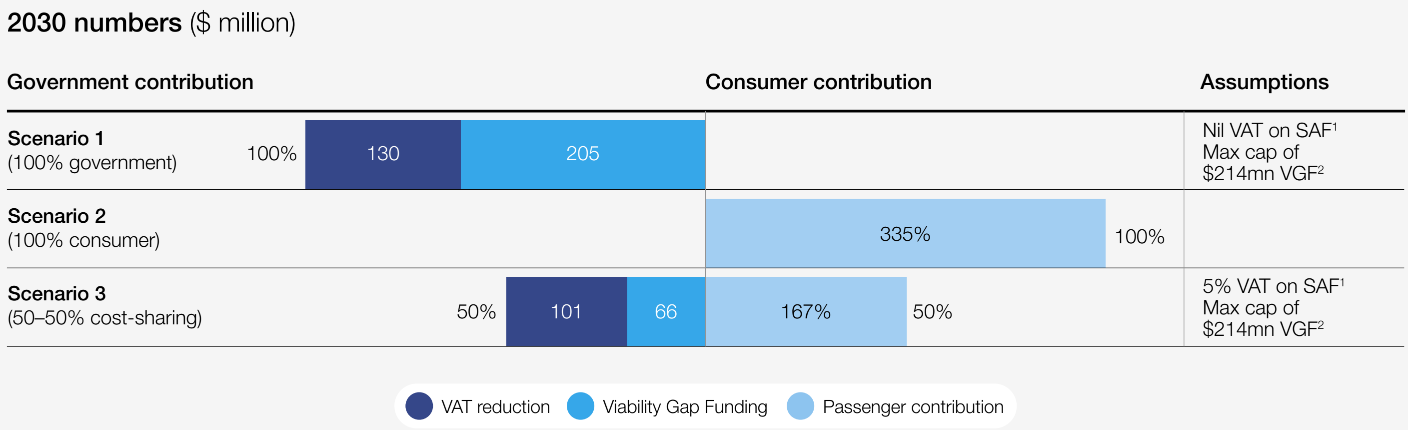
The passenger charge would grow in line with SAF production and blending rates and decrease over time as unit costs for SAF decrease. The passenger SAF charge can be a flat or differential rate, linked to distance, ticket cost, or the most common routes (and therefore the most polluting, akin to a "polluter pays" model), depending on costs and how global best practices evolve.

Scenario C: Government subsidizes a share of the expected societal benefits, with passengers closing the cost gap

In a 50-50 cost-sharing model between government and end consumers, the government could use various levers, such as a GST subsidy, distribution of passenger fees or airport subsidy, and the passengers would cover the rest. Cost-sharing by the government will likely be required until a global solution is in place, such as a policy that places a price on CO_2 emissions and thus incentivizes SAF, which many observers expect in the next 10 years.

FIGURE 16

Hybrid cost-sharing options can bridge the expected gap between the cost of producing fossil and sustainable jet fuels



1 From current VAT at 23%, **2** For each plant, taken as minimum of 20% capex for plant or INR 150 Cr ($0.024 billion)

Source: CST analysis

BOX 6

Key takeaways

Meeting the 100 million SAF passenger target at 10% blend by 2030 will require investments of approximately $335 million, where risk-mitigation measures will be critical to give investors confidence.

A combination of measures and entities will likely be needed to raise investment, including multilateral lending with development or environment finance institutions, green bond issuance by key public entities such as PSBs, state biofuel boards and PPPs.

6

Achieving the 2030 target

Transforming this report into reality and achieving the 2030 vision will require demonstrable leadership from both India's private industry and its policy-makers.

Setting clear SAF production targets and operational and regulatory milestones can give stakeholders a clear pathway to achieving the 2030 goals. Policy changes can incentivize long-term investment and short-term implementation. To achieve the 2030 objective, policies should aim to develop feedstock supply chains and raise investments to begin building the first few plants immediately, with additional scale in the following years.

Scaling SAF production will not occur overnight, and this report has outlined technological pathways, feedstock availability, financing mechanisms and policy options that can advance the objective. The intention is not to proscribe specific actions but to present options – informed by significant contextual research and industry expert opinions – to facilitate aviation's energy transition in India.

6.1 Stakeholder leadership

Transforming these concepts into reality will require demonstrable leadership from both private industry and policy-makers.

Industry is pioneering the effort: Companies included in the CST India community are committed to scaling sustainable aviation fuel in the country. Given the industry's nascency, a unique opportunity exists to capitalize on first-mover advantages and establish not only a robust Indian SAF market, but also to demonstrate global leadership in sustainable aviation.

Consistent with CST's end-to-end value-chain approach, this can include transitioning existing ethanol plants to SAF production or building new direct-to-SAF facilities, such as those planned by Praj Industries. It can also include actions from ambitious airlines such as SpiceJet, which have committed to the 2030 target and are already making proof-of-concept test flights. Indian airports such as GMR have pledged to support these efforts where possible, including incentivizing SAF use for airlines and passengers alike.

Collectively, public declarations of interest followed by direct investments in pilot projects and new plants will demonstrate industry adoption of this technology and establish clear market demand for increased production, in turn driving wider adoption and investment.

Government leadership to overcome inertia: The Indian Air Force's leadership on SAF use[98] not only supports proof of concept but provides an initial level of confidence for increased SAF production with secured customer contracts. The intention to expand this programme further underscores the air force's commitment to scaling the use of SAF as a standard form of aviation fuel.

Public policies will be crucial for accelerating the SAF ecosystem. Near-term policy nudges might include government-specific financing mechanisms such as GST adjustments, VGF schemes and air ticket fee redistributions. In the longer term, policies such as expanding existing biofuel blending mandates to include aviation fuel, or government commitments to invest directly in the additional research and development required to accelerate next-generation technologies, such as power-to-liquid SAF pathways, will significantly accelerate the effort.

6.2 Next steps

A combination of the technological pathways, along with supporting policies, new technologies, and the sustained effort of existing and new champions, can move this initiative forward. CST champions are willing to work jointly with government leaders so that India can build a domestic SAF industry with a 10-fold socioeconomic return on investment, simultaneously positioning itself as a leader in both global SAF production and the global effort to decarbonize aviation.

Three action pathways could feasibly catalyse action in the near term, each of which is implementable individually or in addition to one another:

1. Producers build on India's National Biofuels Policy and VGF schemes to incentivize biofuel research and development and to provide market certainties as well as government funding. Together, this could establish a funding envelope for underwriting the production of new SAF facilities by converting 1G and 2G ethanol plants for SAF production. The Indian Air Force could provide offtake certainty to guarantee the purchase of initial volumes for its continuing test flights, immediately overcoming initial inertia.

2. A second approach would be to build on India's national mission to build a world-class

solar power market through government identification of SAF production as a priority sector, with incentives to increase lending speed and volume, coupled with Central Financial Assistance. India's exceptionally low cost-per-unit of renewable electricity, coupled with advances in industrial carbon capture and on-site production localities, can help establish the nation as a global leader in PtL SAF development and production.

3. A third option, drawing on existing policy levers without establishing new policy schemes or funding programmes, would be to drive market shifts, such as redistribution of ticket charges to subsidize SAF premiums, and placing SAF within the regulated GST scheme, while allowing fossil jet to remain outside and at greater sensitivity to global market shifts.

Regardless of the choices made, the first steps in establishing a SAF industry in India will require the building of a first cohort of facilities and prioritizing technological pathways and plant locations. To provide a hypothetical yet actionable plan, the Clean Skies of Tomorrow community has identified milestones and actions needed between 2020 and 2025 to lay the groundwork to achieve the 2030 goal, as SAF production requires a significant lead time. The actions required to achieve 360,000 tons of SAF by 2030 are outlined above, and Figure 17 details a specific year-by-year action plan.

FIGURE 17 **Operational and regulatory milestones 2020–2025 that will help maintain accountability to the 2030 vision**

Milestones through to 2025

	2020	2021	2022	2023	2024	2025
Operational	Prioritize pathways and locations Forge commitments from key players Engage financial institutions	Break ground on HEFA/AtJ[1] (sugar stream and agri) demo plant Scale-up of UCO and design supply chain for AtJ with agri residue	Construct 1st HEFA plant Break ground by extending 1G ethanol plant for AtJ with sugar streams and construction of first AtJ agri residue	Construct second HEFA plant at beginning of year and scale up to third HEFA plant by end of year	Build second AtJ plant with agri residue and extend second 1G ethanol plant for AtJ with sugar stream	Extend third ethanol plant for AtJ with sugar stream and third AtJ with agri residue Design supply chain for GAS-FT MSW Break ground on GAS-FT[2]
Regulatory	Receive commitment from government on establishing a CST India taskforce headed by Secretary MoPNG[3]	Share World Economic Forum report with government	Draft and finalize policy	Consider establishment of independent biofuels regulator	-	-

1 Assumes three years to construct, **2** Assumes five years to construct, **3** Ministry of Petroleum and Natural Gas (MoPNG)

The CST India community suggests that HEFA and AtJ plants should be the first SAF plants established, relying on sugar stream, agricultural residue and UCO feedstocks. These would rely on VGF funding of 20% and would represent the likely choice for first plants, as a result of feedstock availability, technological maturity and overall economic viability. Meanwhile, the PtL route should be explored further as this holds significant return on investment potential, both economically and in terms of overall GHG emission reductions.

TABLE 1 Estimated plants, SAF production and feedstock requirements by 2030

Technology pathways	Feedstock type	Proposed number of plants	Annual SAF production (million tons) total across plants	Annual feedstock requirement (million tons) per plant
HEFA	UCO	4	0.12	0.072
GAS-FT	MSW	1	0.03	0.250
	Agricultural residue	1	0.03	0.250
AtJ	Sugar stream	3	0.09	0.341
	Agricultural residue	3	0.09	0.481
Total		12	0.36	

Source: CST analysis

While these plants are under development, the next steps – preferably launched simultaneously – could be taken, with existing first-generation ethanol plants being modified to enable them to also produce isobutanol (IBA) as an intermediate conversion to SAF and IBA to SAF production via AtJ at new plants. The new second-generation ethanol plants (six of which are already expected to begin construction in 2022) should be built from the outset to also produce IBA as an intermediate conversion point. Furthermore, the technology basket should be diversified beyond HEFA, as HEFA feedstocks such as UCO and animal fat feedstock are limited. Technological readiness and economies of scale for GAS-FT and ATJ technical pathways are accelerating, and MSW and agricultural residues as feedstock have huge potential in India overall. Following this route, volumes would increase step by step towards 360,000 tons.

Figure 18 and Table 1 (above) detail an estimated ramp-up curve and associated production volumes, feedstock quantities and plant types. The PtL pathway was not included in this initial analysis, but it is worthy of additional analysis as it has significant innovation and market potential for India. At a global scale, the PtL pathway is expected to become the dominant technical SAF pathway after 2030, and India has the opportunity to capture a strong position in this promising market by leveraging its low-cost solar energy position.

FIGURE 18 | **Establishing a SAF production ramp-up plan supports delivery of the 2030 vision**

Ramp-up curve is based on the following assumptions:

India's 2030 domestic aviation market is expected to require 8 million tons of jet fuel

AtJ bolt-on conversions, having an established supply chain and proven technology, will come online at scale first via three plants in 2024

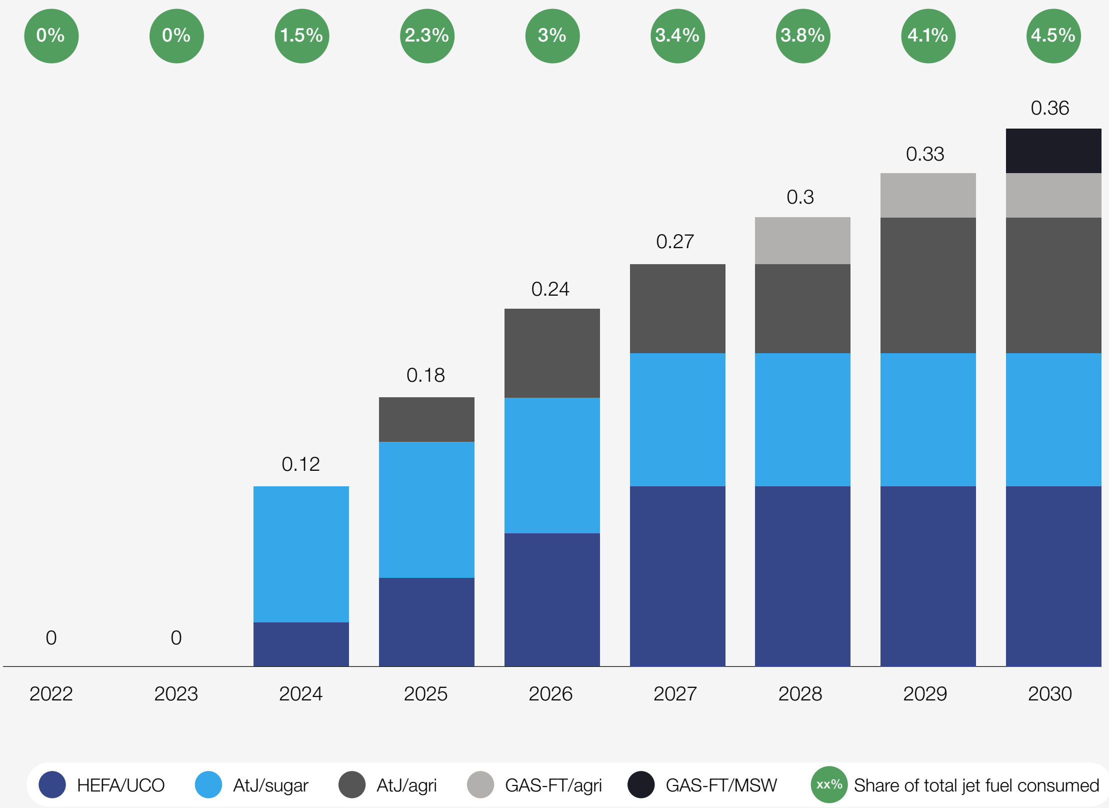
HEFA is a proven technology, but it requires establishing a supply chain, necessitating a tiered deployment with four sequential plants from 2024–2027

Gasification-FT will scale last, coming online in 2028 (agricultural residues) and 2030 (MSW[1])

Power-to-liquid additional upside, not yet included

1 Municipal solid waste

Production capacity ramp-up until 2030 (million tons)



To be clear, this report is agnostic and intended to showcase options rather than be prescriptive. It is up to Indian industry and policy-makers to choose which pathways or combinations are the most appropriate for specific actions. But the most successful approaches in other markets are generally those that rely on a blended approach, using a basket of measures to both distribute risk and costs, maintain a level industry playing field and maximize benefits among stakeholders.

Conclusion

To achieve its 2030 vision, the CST India community stands ready to work in partnership with the Indian government to translate this goal into reality.

India's aviation sector is among the fastest-growing in the world, mirroring the nation's economic and population growth; by 2030, over a billion people are expected to join India's middle class. While the aviation industry has achieved notable success in reducing carbon emission intensity and offsetting emissions, sustainable aviation fuels are the only near-term method by which to reduce carbon emissions beyond traditional efficiency measures and at a speed consistent with reaching science-based targets for the industry.

This report was produced in collaboration with and based on input from a growing *Clean Skies for Tomorrow* community in India. The community has not only identified the need to use more sustainable aviation fuel, but has also detailed the economic, social and environmental benefits to India from its use in domestic aviation – and the tremendous global leadership potential for India in developing a domestic SAF industry. The community has also outlined the technological pathways and estimated feedstock availability and has identified the financial and policy levers that can incentivize and support investment in the necessary infrastructure.

Several viable choices exist for the next steps, for both industry and government partners. Most importantly, action is required immediately due to significant lead times and in order for India to establish itself as a global leader. To achieve its 2030 vision, the CST India community stands ready to work in partnership with the Indian government to translate this goal into reality.

Although this report has provided significant foundational analysis, scaling India's SAF industry is complex and continued research and analysis is required. Considerable work remains; in particular, resolving questions about potentially competing demand for available feedstock between sectors and refining sustainability filters to a more granular level, especially for crop-based feedstock and including consideration of displacement effects.

Also required is additional consideration of the improvement and, where necessary, establishment of supply chains and collection systems for various feedstocks required, from UCO to agricultural residue and MSW. Producing India's SAF from PtL via green hydrogen requires advancing the technology's technical readiness level in order to build India's leadership position as well as continued development of the supporting infrastructure, such as low-cost solar power and point source CO_2 as a feedstock.

In addition, further macroeconomic assessments of cost-sharing options for implementing a SAF ramp-up and detailed job creation benefits in feedstock collection will support informed project planning – and national and subnational biofuel policies will need revision and adaptation to sufficiently incorporate SAF.

The next steps will address these questions, but require the establishment of specific consultative multistakeholder processes on crucial policy asks, with the CST India community working in partnership with a government task force to select the best pathways forward, using this report as a non-prescriptive guide. While reaping the extensive economic and social benefits of scaling SAF, India can become a technical hub of expertise, staying at the forefront of green efforts. As the SAF journey begins, all stakeholders must act now in order to make the 2030 vision a reality and to set the stage for cleaner skies in India.

Appendix

The World Economic Forum's *Clean Skies for Tomorrow* initiative in India

The World Economic Forum's *Clean Skies for Tomorrow* (CST) initiative[99] is a purpose-built platform for leaders throughout the aviation value chain to facilitate the transition to net-zero flying by mid-century. Through the project's dedicated resources and collaboration, more solutions can be delivered faster. The community is already working hard to scale up SAF production for industry-wide adoption by 2030. CST draws on the convening power and expertise of the World Economic Forum with that of McKinsey & Company, the Rocky Mountain Institute, the Energy Transitions Commission, and the initiative's advisory partners, including ACI, ATAG, IATA and ICAO. Dedicated to decarbonizing aviation, it is accelerating global SAF development through innovative demand, financial and policy mechanisms. This platform rallies collective action among stakeholders across the aviation ecosystem. (Figure 19)

Established in 2019 with eight Founding Champions, CST has grown to include more than 80 corporations, international organizations, industry associations, think tanks, NGOs and academic institutions around the world. The initiative includes regular workshops, dialogues, analytical reports and strategic guidance to engage actors throughout the aviation value chain and related industries, including the mobility, energy, chemical, agriculture, climate and financial sectors.

The project is structured strategically to focus on key impact areas, including demand-signal stimulation, public policy alignment and transition finance, each informed by an analytical foundation. Despite technological improvements, aviation-based GHG emissions are likely to rise substantially through to the mid-century. And with the rising urgency of climate change, the industry faces significant social, regulatory and financial headwinds. CST was established to help solve these challenges, working within existing structures where possible and enabling innovative solutions where necessary.

While alternative energy sources such as hydrogen and electric-based propulsion have incredible long-term potential, they have significant technical limitations in the near term that will necessitate other decarbonization routes. To meet decarbonization goals, efforts need to begin today, but technologies like hydrogen-based fuels and battery-electric flying will require years of development. Because new aircraft have long lifespans and will likely operate through to at least 2040, SAF is the most achievable and most effective pathway to reduce aviation's life-cycle emissions in the immediate future, and it should remain a key component of industry sustainability for decades to come.

SAF also offers a significant opportunity to rebuild the aviation industry as it can satisfy quickly rising consumer demands for sustainable flying and meet new regulatory requirements. This is why SAF remains a main pillar of CST's mandate and community focus. A global public-private partnership such as CST increases the likelihood of rapid SAF scale-up because if offers a supportive regulatory framework, active marketplace and mechanisms to finance the transition. These enablers are being addressed in parallel impact areas.

FIGURE 19 ***Clean Skies for Tomorrow* is pursuing five impact areas to help scale the production of sustainable aviation fuels**

	Groundwork to create a fact base		Enablers for scale-up		
	1 Assess SAF feasibility and sustainability	**2 Democratize global SAF supply**	**3 Align on industry-backed policy proposals**	**4 Create a scalable SAF marketplace**	**5 Develop a blueprint for financing**
Context	The industry needs a broadly accepted fact base, but some SAF studies convey partially conflicting messages and leave key questions unanswered	States with access to substantial sustainable biomass or low-cost power can benefit from a global energy transition	Global scale will require policy interventions to trigger learning curve effects and economies of scale that could benefit the rest of the industry	US corporate flyers seem willing to pay a premium for SAF, translating into a 10% SAF blend that will require a scalable SAF marketplace	Funding must be mobilized for R&D and SAF supply-chain scale-up, and investments must be aligned to shifting investor portfolios

Focus of this document

CST is fundamentally a global initiative; the project's full breadth and community are outlined in a previous report.[100] Core to the project, however, are deep-dive efforts in key markets such as India. Aviation is an inherently global industry and climate change is an inherently global challenge. But different markets present different challenges, and to match efforts for SAF production and scale-up and supportive public policies to the local context, CST is creating detailed market analyses for vital aviation markets, such as this one for India.

The World Economic Forum's Shaping the Future of Mobility initiatives, including CST, work to build a world with clean, safe, inclusive mobility – here the aim is to make the aviation sector in particular more sustainable for existing customers as well as expanding the benefits of air travel for new customers. It is therefore essential that SAF be scaled globally and not limited to Europe and the United States. This deep-dive report for India will be the first of several that focus not just on sustainability but also on equity.

Over the past 12 months, CST India has brought together a community subset to inform and learn from the global effort. Here too, members of the community bring expertise across the entire SAF value chain; they are showcased below.

Report methodology

This report was developed through literature research and consultations with experts across the CST community and incorporating insights on suitable production pathways, technical maturities, potential challenges, cost indications and scaling effects that will lower the costs of SAF production over time. With such a diverse range of inputs, triangulation methods were employed to determine "best fit" consensus, with data ranges and outliers marked as necessary. Unless otherwise cited, the information and analysis presented are original findings from this report.

McKinsey & Company's insights and solution products were used as complementary information sources. The firm's Agricultural Commodity Research Engine (ACRE) tool, for example, which provides data on global biomass density based on geospatial data with a granularity of 10x10 kilometres, helped estimate SAF feedstock availability. Data and insights from the McKinsey Global Energy Perspective (GEP) serve as the basis for energy consumption forecasts across transportation sectors, typical product outputs from production pathways, and the cost of input factors such as hydrogen, further guiding the analysis on industry trends and fuel-use forecasts. In producing this report, the CST India community also worked in collaboration with McKinsey & Company experts to run unique calculations and analysis.

Above all else, this report relied on robust and predetermined sustainability metrics to evaluate the feasibility and usability of SAF production pathways and feedstocks, building on work from previous *Clean Skies for Tomorrow* publications.[101] Other decarbonization options such as new technology, carbon removal and improved intermodal traffic integration should play a central role in reducing CO_2 and are considered as complementary to SAF. These findings are presented using a structured process. Four ASTM-approved SAF production pathways were selected for further assessment based on expected CO_2 reductions, maximum blending ratios with conventional jet fuel, the maturity of the technology and commercial readiness. For this subset of production pathways, feedstock were prioritized based on careful sustainability criteria and requirements for at least 60% GHG savings.

Only those net surplus feedstocks that meet sustainability criteria and deliver reductions in life-cycle CO_2 emissions compared to conventional jet fuel were considered. Three filters were applied: sustainability criteria, excluding land with low soil organic carbon, high erosion or biodiversity, wetlands and peatlands, and crops that are unsustainable in their current growing regions; environmental considerations, including how much biomass stays on the ground to maintain the carbon cycle; and competing demand for uses other than energy production. In short, feedstock from important biodiversity areas, peatlands and wetlands, intact forest landscape, protected areas, water-intense crops in arid regions, and locations where erosion is high were excluded.

FIGURE 20 | Practical availability assessment based on sustainability and competing demand

Sustainability

Availability is assessed against sustainability criteria

- **Soil health:** Amount of feedstock included ensures good physical, chemical and biological conditions of soil
- **Carbon stock:** Land with high-carbon stock (e.g. primary forests, wetlands, peatlands) not used[1]
- **Conservation:** Protected land (for biodiversity, conservation value, ecosystem services) not used

Recycled carbon considered as bridging feedstock until more sustainable alternatives become available

- LCA GHG emission reduction potential clearly exists compared to fossil jet fuel (excluding reusable plastic waste)
- However, from a broader sustainability perspective, existing feedstock use case should not encourage the continued production of carbon waste in the long run

Competing demand

Feedstock used outside the energy sector is not considered available

- Biomass used for animal feed or animal bedding not taken into account
- Biomass used for production of, e.g. chemicals or pulp and paper, not considered

Within the energy sector, division of practically available feedstock not further assessed

- Usage preference for aviation sector versus road (incl. intermediary products like ethanol) and electricity/heat highly dependent on sustainability driven regulation, availability of alternatives and willingness to pay
- Synergetic effects, e.g. from building up feedstock collection systems, exist

Logistics and viability

Current collection rates and accessibility depend on specific feedstock and local circumstances

- Feedstock have varying degrees of fragmentation and specific challenges, in some cases requiring significant logistics for collections
- Current existence of local supply chains not taken into account for practical availability
- Remoteness or geographical conditions (e.g. slope) not factored into availability numbers

Economic viability can only be analysed locally

- Some feedstock can be transported and sold globally
- Others do not transport well and thus may provide an economically viable option only if concentration is high enough close to potential production site

1 Including land with high carbon stock converted after 1 Jan 2018; RED II also defines high and low indirect land use change (ILUC)

Source: ICAO 2017; Staples et al., 2017

Figure 20 describes the *Clean Skies for Tomorrow* overarching sustainability criteria and scope and Figure 22 contains a more detailed breakdown by feedstock of suitable crops. Of note, this report includes supportive consideration of SAF produced from sugar-cane-derived ethanol via AtJ that does not on its own satisfy the normal sustainability criteria outlined. However, the report takes a pragmatic approach as a result of India's unique market conditions and the on-the-ground realities of the agricultural sector. India's subsidy support for the sugar industry is significant and results in sizeable volumes of surplus sugar production annually. Additionally, current ethanol production plants can be converted with relative ease and low cost for SAF production.

Doing so creates an opportunity to kick-start SAF production years before other pathways are constructed at scale and feedstock supply chains can be established. Because the required feedstock (340,000 tons annually) relies on a significant proportion of the overall sugar crop surplus (500,000 tons annually),[102] considerations of land use change and system lock-in should continue to be evaluated against the context of anticipated surplus production.

As outlined in this report, in the next phase of work, the overall assessment of feedstocks such as surplus sugar stream, PFAD and palm-based UCO should be reviewed holistically before plant investments are undertaken. To ensure sustainability criteria are met and to support market confidence, full value-chain sustainability verifications and transparency should be implemented wherever possible. Feedstock classifications should also be backed by strong certifications (including on a case-by-case basis where necessary) to ensure that a growing SAF industry does not in turn incentivize production of otherwise unsustainable feedstock.

SAF production costs were built from the bottom up, starting with pathways using different feedstocks, production locations and technologies, depending on factors including crop type, season, local socioeconomic and political conditions and income for farmers, based on expert input from CST community members. Biofeedstock and CO_2 reduction costs are based on CST expert inputs and historic market prices and are assumed to be constant for the timeline considered. Capital expenditure estimates and production cost estimates are based on media reports, academic literature and market-specific expert inputs, inclusive of costs of labour, equipment and transportation. The total capital investment of approximately $2.5 billion required is incorporated into the SAF cost structure (as detailed in Figure 12), distributed over a 15-year time period and assuming a weighted average cost of capital of 8.5% and a 91% operating capacity factor. Cost reductions enabled through scale-up and learning curve effects are based on CST expert assumptions.

The CST India community's vision is to transport 100 million domestic passengers by 2030 on a SAF blend of 10%. Estimating this expected SAF volume relied on a three-step process. First, McKinsey & Company estimates India's domestic annual revenue passenger kilometres (RPKs) to reach 218 billion by 2030. (Due to impacts from the COVID-19 pandemic, initial pre-COVID 2030 estimates of 245 billion are expected to be reached only by 2032.) Second, estimated fuel use requirements for this post-COVID 2030 passenger volume are expected to reach 8 million tons annually by 2030. Third, using a model considering an average India domestic flight between Delhi and Mumbai (~1400 kilometres), the requisite fuel use for 100 million passengers flown on a 10% SAF blend equates to a need of 360,000 tons of SAF.

FIGURE 21 **Structured approach to identify sustainable feedstock**[103]

All feedstock must fulfil sustainability criteria

Feedstock type	Feedstock category			Feedstock[6]	Substantial GHG savings potential[7]	No fundamental sustainability concerns[8]
1st gen/ crop-based	Edible oil crops			Palm	✗	✗
				Soybean	✗	✗
				Other (incl. sunflower, rapeseed/canola)	✗	✗
	Edible sugars			Sugar cane	◯	✗
				Maize	✗	✗
				Other	✗	✗
Advanced and waste	Waste and residue lipids[2]			Used cooking oil (industrial or private sources)	✓	✓
				Animal waste fat (tallow)	✓	◯
				Other (incl. tall oil, technical corn oil, fish oil, POME, PFAD)	✓	◯
	Purposely grown energy plants	Oil trees on degraded land		Jatropha, pongamia	✓	◯
		Rotational cover crops	Oil cover crops	Camelina, carinata, pennycress	✓	◯
			Cellulosic cover crops	Miscanthus, switchgrass, reed cannarygrass	✓	◯
	Agricultural residues			Rice straw	✓	✓
				Sugar cane bagasse	✓	✓
				Other (incl. corn stover, cereal residues)	✓	✓
	Forestry residues[3]				✓	✓
	Wood-processing waste[4]				✓	✓
	Municipal solid waste[5]				✓	✓
Recycled carbon	Reusable plastic waste				✗	✓
	Industrial waste gas	CO_2 from point source capture (CCS)			✓	✓
		Other (e.g. flue gas from steel production)			✓	✓
Non-biomass based[1]	CO_2 from direct air capture (DAC)				✓	✓

| Focus of analysis ✓ Satisfied ◯ Potentially satisfied[9] ✗ Not satisfied

1 Adjustment of RED II category "Renewable fuel of non-biological origin"; **2** Some not included in RED II definition of advanced (e.g., used cooking oil, animal waste fat), while others are (e.g. tall oil, POME); **3** Leftovers from logging operations, including leaves, lops, tops, damaged or unwanted stem wood; **4** By-products and co-products of industrial wood-processing operations, including sawmill slabs, saw dust, woodchip; **5** May contain up to 20% non-reusable plastics; typically inefficient to separate organics and plastic; **6** Algae not assessed due to limited feasibility; **7** In line with RSB: >60% based on LCA,; **8** Mainly related to food security and land use change; **9** Depending on local circumstances

Source: World Economic Forum (2020), Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation

Expected construction timelines for respective technological pathways were assessed according to benchmarked expert stakeholder analysis. Estimated greenfield construction assessments conclude that HEFA and AtJ plants require three years of construction lead time before production and GAS-FT requires three to five years of construction lead time before production. AtJ brownfield conversions are expected to require two years of lead time. Based on market-specific context, all plants regardless of technological pathway or feedstock were assumed to produce 100 kilolitres per day, or 0.03 million tons per year, in line with existing 2G ethanol plants operating in India today. The respective technology coefficient of feedstock to output and output to SAF is based on inputs from expert CST members.

Specific societal and macroeconomic benefits were determined via a structured process leveraging multiple inputs. By working backwards from the estimated SAF feedstock production ratio required by a technology pathway, requisite volumes of feedstock were estimated on a per-plant basis. Average jet fuel prices were taken from publicly available data provided by India's Ministry of Petroleum and Natural Gas. Estimated SAF prices were taken from previously published work via the CST initiative. While not part of the main quantitative model, CO_2 savings were estimated using the United Nations Framework Convention on Climate Change (UNFCCC) coefficient for jet fuel.

Each SAF technology pathway creates multiple by-products with commercial value. Their independent value was estimated using the average market prices as indicated by India's Ministry of Petroleum and Natural Gas. Cost estimates of overall economic benefits resulting from SAF production do not include the estimated value from by-products; the specific cost figures were proportionally adapted using the share of by-products in the SAF end product. Any additional value from by-products is thus effectively outside the scope of this report.

To estimate the impact on farmer jobs and additional income, industry multipliers for job creation, productivity per technology pathway, and average levels of agricultural productivity and per-worker and per-famer estimates were used as provided by McKinsey & Company and as verified by CST community stakeholders for the appropriate market context. Using assessments for agricultural-based feedstocks as an example, calculations are based on the assumption that farmers will receive on average INR 1 per kilogram of biomass production and that each hectare of land can produce 5.5 tons of biomass per annum. Economic impact calculations include considerations such as increased labour for residue collection over stubble burning as well as potential increased costs for fertilizer to displace nutrients otherwise obtained by burning or mulching in the field.

This report relies heavily on the input of the *Clean Skies for Tomorrow* India community as well as its broader international coalition. This is especially the case with Chapters 5 and 6 in detailing the policy and market mechanisms considered as supportive levers in growing India's SAF industry. Lessons learned were taken from similar efforts in markets around the world but rely on frameworks and policy schemes that India has leveraged successfully in other sectors.

Throughout, this report uses the standard terms "initial", "direct", "indirect" and "induced" economic effects. In layman's terms, these are defined as follows:

– Initial economic effects are defined as the immediate impact of collection and transportation of agricultural residue from farm or collection of UCO to production plant, the R&D involved to mature the technology, and the actual plant production operations.

– Direct effects are defined as the next-round economic impact of suppliers, such as for agricultural residue collection equipment; for example, rakers and balers.

– Indirect effects would subsequently be the impact from Tier 2 suppliers, such as producers of aluminium, steel and other materials for the rakers and balers.

– If a farmer's income increases due to the sale of agricultural residue, any enhanced household spending (such as on home stoves, clothes or a bicycle) by the farmer is classified as an induced economic effect.

Financial figures throughout the report are in US dollars except where noted. The report uses metric tonnes (tons) as the unit of measure. For conversion purposes, the following numbers can be accepted: 161 metric tonne = 331 US gallons, 1 US gallon = 3.78541 litres, and 1 barrel = 42 US gallons.

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