National Sustainable Aviation Fuel Roadmap of Israel

An ICF Report

2024

Citation and authorship

ICF (2024) Israel Sustainable Aviation Fuel Analysis. London, UK.

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We're grateful for the support from:

- Ido Lieberman – Technion (Israel Institute of Technology)
- Prof. Gideon Grader – Technion (Israel Institute of Technology)
- Steven Gillard – Boeing
- Haggai Mazursky – Boeing

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Executive Summary

Israel's consideration of 2% Sustainable Aviation Fuel (SAF) uplift by 2027 underscores the urgent need to assess the potential for SAF production and adoption in the country. This report evaluates the feedstock availability, technologies and policy enablers to accelerate the SAF industry development in Israel.

Summary of key findings

- **Aviation is vital to Israel's economy and global connectivity.** The industry contributes approximately 5% to the national GDP, generating $16 billion annually and supporting 184,000 jobs. Air transport bridges communities, supporting the flow of people, goods, and economic development. The economic benefits permeate through extensive supply chains, employee spending, and the influx of tourists. IATA forecasts Israeli air transport activity to grow by 65% in the next 20 years, resulting in an additional 6.2 million passenger journeys and adding $26.3 billion to the national GPD.

- **Sustainable Aviation Fuel (SAF) is crucial to reduce aviation emissions.** IATA estimates SAF will be required to contribute approximately 65% of the emissions reduction needed for aviation to reach net zero by 2050[1]. SAF is produced from low-carbon feedstocks such as agricultural residues or municipal waste and can be used in existing infrastructure and aircraft engines without requiring modifications. The recently released document on SAF from the Ministry of Energy and Infrastructure has announced a gradual implementation of SAF ambitions, aligning with the legislated EU mandate (ReFuelEU) but with a delayed start, starting with a 2% mandate in 2027. However, Israel has a unique environment that must be considered and therefore a unique policy framework should be developed. In particular, the lack of biolgenic feedstocks will require Israel to use considerable volumes of power-to-liquid (PtL) SAF. PtL is produced using green hydrogen, and is a key focus of EU legislation due to its robust sustainability attributes. However, it faces cost and investment challenges. Supporting the development of national PtL capacity will contribute to Israeli decarbonization and energy security, but will require focused policy efforts. Near-term opportunities will be essential to kick-start the market, including production via co-processing, use of renewable natural gas, and imports.

- **Given the feedstock constraints, this report recommends a slightly lower target compared to the EU.** A lower but more robust target will enable production to scale using the available resources and balance economic and environmental considerations. Importantly, PtL SAF is expected to deliver greater emissions reductions than many other SAF technologies, and therefore the targets recommended in this analysis match the forecast EU emissions reduction despite the lower volumes. It was estimated that this approach would require around 1.5 million tons of SAF by 2050.

- **Achieving this target will be challenging but within reach.** It will require rapid development of the available biological feedstocks, focused commercialization of hydrogen and PtL capacity, and use of imports where appropriate. This report outlines limited biological feedstocks (such as waste and residues lipids or MSW)

[1] IATA - Sustainable Aviation Fuel (SAF)

estimating 0.04 to 0.2 million tons of SAF produced in 2030, increasing to 0.1 to 0.3 million tons produced in 2050.

- **Co-processing represents an immediate opportunity.** This approach uses feedstocks such as UCO or tallow, in existing petroleum refineries, representing an economical method for SAF production. This pathway requires limited infrastructure and investment as it uses existing infrastructure and downstream supply chains. While this analysis determines the limited availability of these feedstocks in-country the experience gained through their use builds the foundations for the whole industry. In the mid-term, other intermediates such as pyrolysis oils from waste plastics can be explored, although this will necessitate collaborative research efforts across the industry to fully understand and optimize the processes involved.
- **Landfill gas and municipal waste will be key over the next 1-2 decades.** Landfill gas is predominately methane produced during the anaerobic digestion of landfilled municipal wastes and is increasingly collected in Israel. After the cleanup of the biogas to form renewable natural gas or biomethane, it can be injected physically (through pipelines) or virtually centralized (through book-and-claim) and used in a gas-to-liquid (GtL) process to produce SAF through FT synthesis. GtL technology has been widely used in large commercial facilities worldwide and is qualified under ASTM D7566 Annex 1. Direct gasification of MSW may represent an additional source of feedstock as this technology continues to develop.
- **Policy support is crucial.** SAF-specific policies will be required to encourage the establishment of a domestic SAF industry in Israel. Implementing both demand- and supply-side policies will be critical for the development of a domestic SAF sector in Israel. Current policy frameworks in the EU, U.S. and UK provide options for developing policies that can be tailored to the unique environment and conditions in Israel.

Recommendations

ICF believes the following initiatives could accelerate the development of a SAF industry in Israel based on the findings from the analysis.

- **Establish SAF targets for 2030 and 2040:** Demand-side policies create a structural demand for SAF that offers long-term demand certainty for SAF producers and investors. Usually in the form of a mandate, this type of policy has driven biofuel development over the last two decades and can have a powerful impact on the development of SAF production to drive the decarbonization of the Israeli aviation sector. An initial target of 2% SAF use by 2027 has been proposed, but a formal target should be established to match the investment timelines for production facilities, with intermediate targets suggested for 2030 and 2040. Alignment with the 5% target for emissions reduction through SAF by 2030 established by the third conference on alternative aviation fuels (CAAF/3) is recommended. The target should recognize the different emissions reduction from different pathways, either by adjusting the contribution based on CI (similar to the UK mandate) or setting the target as an emissions reduction (as in the California LCFS).
- **Develop sustainability criteria aligned with Israel:** Aligning with CORSIA sustainability criteria and methodologies algins with international standards and allows Israel the flexibility to develop the available resources. A higher standard for minimum emissions reduction (40%-50%) is recommended (currently 10% under CORSIA) to ensure efforts focus on pathways that will be sustainable over the longer term.
- **Considerations for a hydrogen sub-target:** As PtL will be a key technology for SAF production in Israel, it is recommended that specific hydrogen targets should be explored, focusing efforts while allowing the market to retain flexibility around use for FT, methanol-to-jet, fuel cells, or other approaches.

- **Develop a supply-side mechanism:** Supply-side policies will be essential to address some of the key challenges associated with SAF development, including the slow commercialization of technologies, the high risk associated with access to funding and investment, the high capital costs required, and the high production cost. Development of domestic SAF supply and consumption in Israel will be challenging without supply-side policies that lower the cost of SAF production, reduce the risk for SAF producers and investors, while also assisting airlines to use SAF without becoming uncompetitive. While direct incentives, as used in the U.S., are not considered feasible in Israel, there are other potential financial support mechanisms that could be explored to address these challenges. Revenue certainty mechanisms such as contracts-for-difference could make a difference in the potential financial viability of a planned facility as it will provide security for investors and lenders.
- **Catalyze and support domestic technology advancements:** Israel has focused on the development of novel and breakthrough technologies that can be licensed on a global basis. While research and development at academic institutions and for lower TRL-level technologies are well-established, there is a gap in supporting the higher TRL-levels for the construction of demonstration-scale or first-of-a-kind commercial facilities. Policy support and funding targeting this stage should be considered, and the development of a national market can serve as a springboard to accelerate technologies for global adoption.

Photo by Naya Shaw

1 Introduction and Context

This report evaluates the feedstock availability, technologies and policy enablers to accelerate the SAF industry development in Israel. The study outlines domestic support factors, such as exisiting resources, infrastructure, and industrial capabilities. Israel's announcement for the consideration of 2% SAF by 2027 underscores the urgent need to assess the potential for SAF production and adoption in the country.

1.1 Introduction

Israel's aviation sector stands as a vital pillar of the nation's economy and global connectivity. As a small country with strong international links, air travel plays a significant role in facilitating trade, tourism, and diplomatic relations. The industry's impact on Israel's economy is substantial, contributing approximately 5% to the national GDP, generating around $16 billion annually, and supporting about 184,000 jobs.[2] This economic influence extends beyond airlines and airports, permeating through extensive supply chains, employee spending, and the influx of foreign tourists.

As global air travel demand continues to rise at an estimated 4.3% per year, the aviation industry faces increased pressure to reduce its carbon footprint.[3] Recognizing this challenge, Israel has embarked on a journey towards decarbonizing its aviation sector, aligning with global climate targets while sustaining growth and economic benefits. The country's approach to this transition is multifaceted, encompassing policy development, industry collaboration, and technological innovation. Central to these efforts is the adoption of SAF, which is widely recognized as a key component in reducing aviation emissions. SAF is expected to drive a significant portion of the emissions reductions required by 2050, with IATA pointing to SAF for 65% of the necessary reductions.[4]

As a significant step forward, the Israeli Ministry of Energy and Infrastructure has published a policy document acknowledging the need to decarbonize the aviation industry.[5] This document proposes aligning with international targets, particularly those set by ICAO, which Israel is already contributing to through its participation in CORSIA. The policy document suggests a gradual implementation of SAF requirements, aligning with the legislated EU mandate (ReFuelEU) but with a delayed start, starting with a 2% mandate in 2027 and aiming for 70% by 2052. This delayed start would allow Israel time to develop the necessary standards, regulations, and infrastructure to support SAF uptake.

Israel is making notable strides in supporting the SAF industry, even when currently lacking domestic production facilities. EL AL Israel Airlines recently completed a first flight powered by a 30% SAF blend, coinciding with the delivery of its 16'th Boeing 787 Dreamliner.[6] Additionally, several universities and start-up companies in Israel are engaged in research and development (R&D), leveraging Israel's strong reputation in innovation and

[2] iata.org/en/iata-repository/publications/economic-reports/israel--value-of-aviation/
[3] https://www.icao.int/Meetings/FutureOfAviation/Pages/default.aspx
[4] https://www.iata.org/en/pressroom/2024-releases/2024-06-02-03/
[5] בתעופה משרד האנרגיה והתשתיות (SAF) בדרך לשינוי משמעותי בתעופה האווירית: משרד האנרגיה והתשתיות מוביל מהלך אסטרטגי לאימוץ דלקי תעופה ירוקים (www.gov.il)
[6] https://www.elal.com/eng/usa/press-release/sustainablea-viation-fuel

technology. With R&D expenditure at 5.4% of GDP in 2023, the academic sector is particularly well-positioned to drive progress in SAF and lead the innovation needed to decarbonize the sector.[7]

The establishment of a SAF industry in Israel presents a unique opportunity to simultaneously reduce emissions, enhance energy security, and stimulate economic growth. By investing in SAF production and related technologies, Israel can create new economic opportunities, foster innovation, reduce emissions, and maintain its competitive edge in the global aviation market.

1.2 The role of SAF in Israel

Supporting the domestic economy

Israel has a developed free-market economy driven by a thriving high-technology sector and sophisticated manufacturing industries. The country's economy is fueled by robust private consumption and investment, which account for a significant portion of economic activity. Despite challenges like regional instability and limited natural resources, Israel has achieved a high standard of living for its residents through substantial and quality industrial exports, a surging high-tech start-up sector, and internationally recognized excellence in advanced technologies. The economy has demonstrated resilience, with its GDP forecast to continue to grow at a steady rate through 2050 (CAGR 3%).

Israel's high-tech industry has been a major driver of economic growth and innovation. According to the Israel Innovation Authority, from 2018-2023, the high-tech sector was responsible for over 40% of Israel's GDP growth.[8] Israel has ranked 14'th in the Global Innovation Index in 2023 (up from 16'th in 2022), with approximately 9,000 tech companies operating in Israel, employing an estimated 396,000 employees. The sector now accounts for 20% of the country's economic output and 53% of total exports.[9]

Israel has fostered an extensive startup ecosystem and attracted significant investment from global tech giants. The country's emphasis on education, research, and entrepreneurship has fueled the rise of cutting-edge technologies across various domains, including cybersecurity, fintech, agritech, and cleantech. With a highly skilled workforce and a culture of innovation, SAF can sustain and support Israel's high-tech sector as the global SAF market continues to grow, providing significant opportunities for Israel's economic growth.

Supporting aviation decarbonization

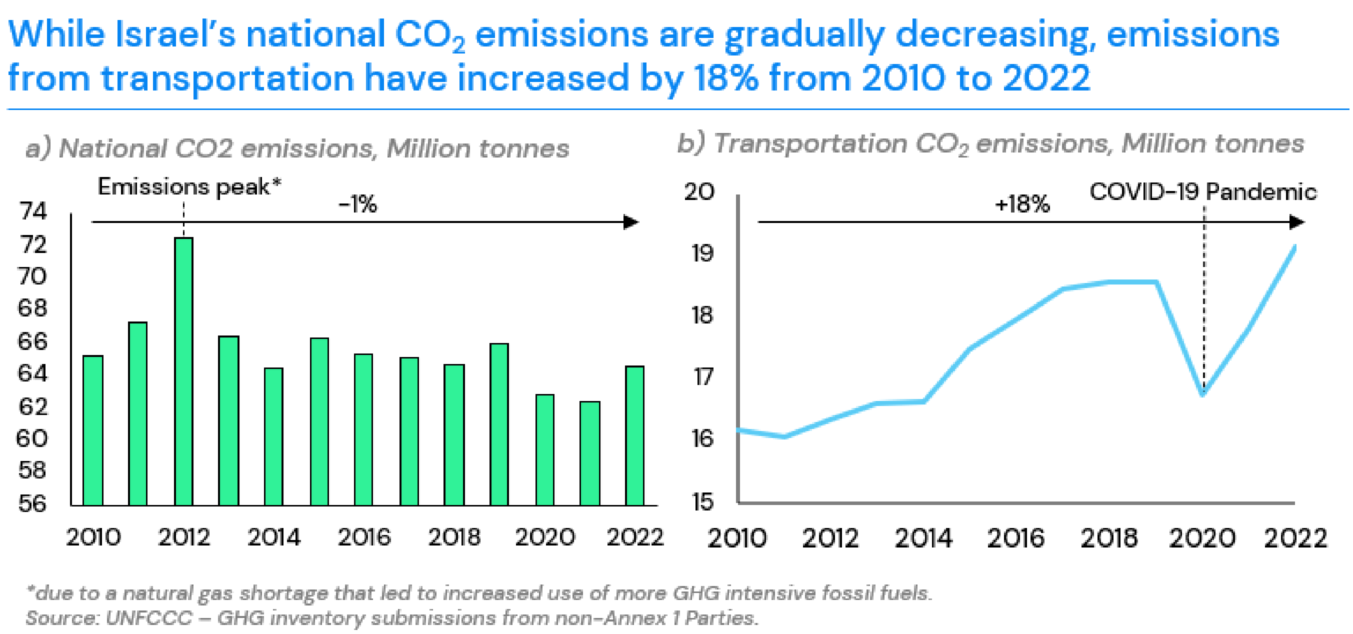
Israel has taken significant steps towards sustainability and addressing climate change in recent years. In 2021, the Israeli government approved an economy-wide emission reduction target of 27% relative to 2015 levels by 2030 and 85% relative to 2015 levels by 2050. In 2023, the Ministry of Environmental Protection for Israel presented a bill for the country to achieve carbon neutrality by 2050, however, this plan has not yet been approved. Regardless, the existing decarbonization targets will impact many industries, including aviation, and

[7] https://www.gov.uk/government/publications/uk-science-innovation-network-country-snapshot-israel/uk-science-innovation-network-country-summary-israel
[8] Reports - English Innovation Site (innovationisrael.org.il)
[9] Israel tech sector accounts for 20% of economy, Innovation Authority says | Reuters

action will need to be taken to decarbonize operations. Challenges such as rapid population growth, increasing energy consumption, and increased visitor numbers remain.

According to the UNCC[10], Israel's GHG emissions in 2022 amounted to 81 million tonnes of CO2 equivalent, with over 64 million tons associated with CO2. The transportation sector is the second largest source of emissions, accounting for 19.1 million tons, or 30% of Israel's CO2 emissions. As shown in Figure 1, while Israel's net CO2 emissions decreased by 1% between 2010 and 2022 (Figure 1a), the emissions associated with transportation have increased by 18% from 16.2 million tons to 19.1 million tons (Figure 1b).

Figure 1: Comparison of Israel's national and transportation CO_2 emissions



The global aviation sector has made significant progress in reducing emissions per passenger-kilometer, achieving a 54.3% reduction from 1990 to 2018 through more efficient aircraft and operational improvements. However, while these improve the efficiency of fuel burn, to fully decarbonize the sector, the energy source must be shifted away from fossil-origin. Three primary solutions are currently the focus of ongoing efforts: electric aircraft, hydrogen-powered aircraft, and sustainable aviation fuel (SAF).

As battery technology improves, electric aircraft show promise for commuter and short-haul regional flights. However, these shorter routes account for only 3-4% of the aviation industry's emissions, and potentially a smaller share of Israel's emissions given the profile of air traffic favors mid-range routes.[11] Hydrogen aircraft have potential for a broader range of markets, but the extensive infrastructure changes required will limit their impact before mid-century. As a drop-in fuel compatible with existing infrastructure and aircraft, SAF is projected to play a pivotal role in the industry's efforts to achieve net-zero emissions by 2050.

[10] https://unfccc.int/documents/633031
[11] https://www.sciencedirect.com/science/article/abs/pii/S0160738319301227

Developing a domestic SAF ecosystem offers benefits that go beyond aviation. SAF production facilities generate co-products including renewable diesel and naphtha. Every technology pathway for SAF production produces a mixture of products in various proportions. For example, HEFA technology produces a substantial renewable diesel fraction (50-85%) whereas the AtJ technology can produce a predominant SAF fraction (70-90%) with either renewable diesel or naphtha as a secondary product. This presents a significant opportunity for decarbonization of the Israeli transport sector as a whole. Any policy support for expanding domestic SAF production will therefore also benefit the emissions reductions resulting from gasoline and diesel-powered vehicles. On a global level, SAF development has also been a driving force behind the commercialization of technologies that benefit all transport sectors. As drop-in fuels completely fungible with existing infrastructure, they can be blended without new supply chains or new types of vehicles, e.g. hydrogen vehicles.

Supporting energy and national security

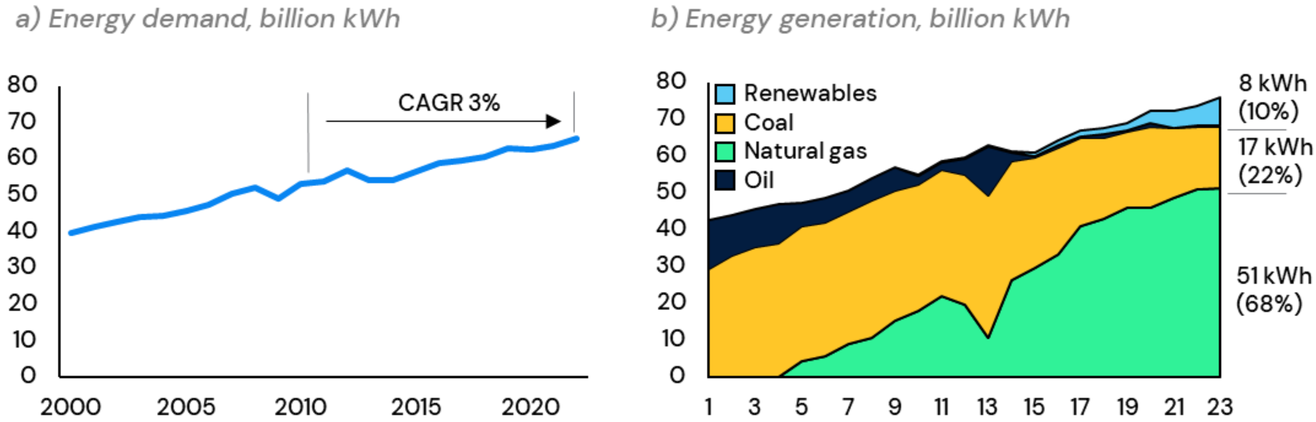
Israel is currently an electricity island, meaning that its electric grid is not connected to those of neighboring countries and hence, must be self-sufficient in meeting its energy demands. The country's energy demands have grown by an average of 3% annually between 2010-2020.[12] There have been discussions regarding the integration of Israel's power grid with other grid networks, including recent developments with the Great Sea Interconnector project, which aims to connect the power grids of Crete, Cyprus and Israel.[13]

Israel has significantly improved its energy security with the commercial discovery of natural gas in 2000. Since then, Israel has continuously developed its offshore gas resources, increasing energy production from natural gas by 120% from 2009-2019, while coal consumption has decreased by over 50%.[14] As seen in Figure 2, natural gas provided 68% of Israel's energy demand in 2022. The country aims to phase out coal by 2030, replacing old coal plants with gas-powered combined cycle units.

[12] https://www.trade.gov/country-commercial-guides/israel-energy
[13] https://www.gov.il/en/pages/news-100424-1
[14] https://gjia.georgetown.edu/2020/05/25/natural-gas-discoveries-and-israels-energy-security/

Figure 2: Comparison of Israel's energy demand and supply

Israel's gradual increase in energy demand has been met with a rapid increase in natural gas energy generation making up 68% of the supply



Source: EIA

Israel's offshore natural gas discoveries have safeguarded it from complete reliance on imported primary fuels and allowed for a cleaner energy mix. However, Israel relied almost entirely (98.9%) on imports to meet its crude oil supply demands in 2022, allotting a 36% increase in oil imports since 2000.[15] Disruptions to this network can have devastating consequences across society and the economy. Given the importance of aviation to Israel's national security, it is imperative to diversify energy sources to insulate the nation from external market shocks and actions. Therefore, establishing a domestic SAF industry would not only enhance energy security but also reduce dependence on volatile oil markets and supply chains, supporting economic resilience and national security.

[15] https://www.iea.org/countries/israel/oil

Photo by Samuel Markovich

2 Global SAF Outlook

2.1 SAF technology developments

SAF is defined as a low-carbon alternative to conventional fossil-derived aviation fuel that can be blended with conventional jet fuel without requiring engine modifications. As of 2024, there are multiple approved pathways for SAF production, each with specific blending limits. The American Society for Testing and Materials (ASTM) D7566 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons outlines these approved pathways and their respective blending limitations. Once SAF is blended and certified to meet all requirements of ASTM D7566, it is operationally equivalent to conventional jet fuel under ASTM D1655. The below figure provides an overview of the approved conversion pathways and their respective feedstocks.

Figure 3: ASTM-approved SAF pathways

There are 11 ASTM approved pathways for SAF production

Pathway	Feedstock	Max. Blending Limit
FT	Coal, natural gas, biomass (i.e. MSW, agricultural wastes)	50%
HEFA	Vegetable oils, animal fats, used cooking oils (UCO)	50%
SIP	Biomass used for sugar production	10%
FT-SKA	Coal, natural gas, biomass (i.e. MSW, agricultural wastes)	50%
ATJ-SPK	Ethanol, isobutanol and isobutene from biomass	50%
CHJ	Vegetable oils, animal fats, UCO	50%
HC-HEFA-SPK	Algae	10%
ATJ-SKA	C2-C5 alcohols from biomass	
Co-processed HEFA	Hydroprocessed esters/fatty acids from biomass	24%
Co-processed FT	Fischer-Tropsch hydrocarbons processed with petroleum	5%
Co-processing of esters and fatty acids	Vegetable oils, animal fats, used cooking oils from biomass processed with petroleum	5%

Source: [Conversion processes (icao.int)]

The maximum allowed blending ratio for SAF with conventional jet fuel varies from 10% to 50% depending on the production pathway. This limit is expected to increase over time, and aircraft have already flown on 100% SAF in test flights using a mixture of SPK and renewable aromatics, demonstrating its feasibility. ASTM

International has established a task force to explore allowing the blending of different SAFs to enable 100% SAF. Additionally, Boeing and other aircraft manufacturers have committed to producing aircraft capable of operating on 100% SAF, ensuring the blend limit will not be a bottleneck to SAF uptake.

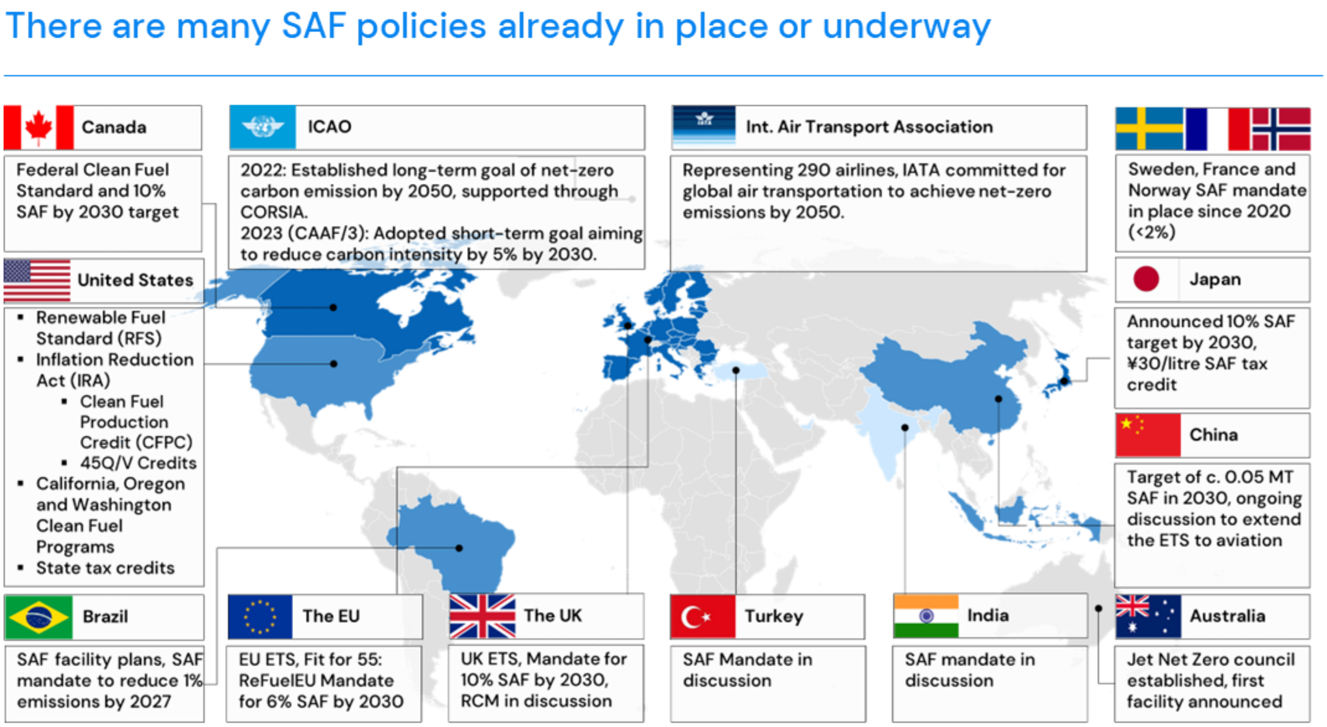
As the most affordable and mature technology, the HEFA pathway is currently used to produce almost all commercially available SAF. Other pathways are in various stages of development, with commercial-scale facilities under construction that will utilize the FT-SPK and AtJ technologies, among others. The HEFA pathway is likely to be increasingly constrained by the availability of feedstock. Expanding the global SAF industry will require the commercialization of additional pathways to widen the feedstock pool that can be accessed. In addition to the approved pathways, several other conversion processes are under evaluation, including Methanol-to-Jet and pyrolysis of non-recyclable plastics[16], both of which provide significant opportunities in Israel.

2.2 Global SAF targets and policies

SAF policy is the primary catalyst for the development and growth of the SAF market, addressing the significant cost disparity between SAF and conventional aviation fuel production. This diverse regulatory landscape underscores the critical role of government intervention in driving SAF adoption, fostering innovation in advanced technologies, and creating a stable investment environment for the SAF industry, ultimately shaping the transition towards sustainable aviation across different regions, including Israel. As outlined in Figure 4, the current regulatory environment resembles a patchwork, with diverse approaches taken across regions and within countries, reflecting the complexity and substantial efforts behind decarbonizing aviation.

16 https://www.icao.int/environmental-protection/GFAAF/Pages/Conversion-processes.aspx

Figure 4: Global SAF policies



Source: ICF Analysis

International aviation targets

Efforts to reduce carbon emissions in the international aviation industry have been driven by the International Civil Aviation Organization (ICAO), primarily through the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

- **ICAO**: In October 2022, the member states of ICAO adopted a collective long-term global aspirational goal (LTAG) of achieving net-zero carbon emissions from international aviation by 2050.[17] This ambitious target signifies a shared commitment to significantly reduce and ultimately eliminate carbon emissions from the aviation sector to mitigate climate change impacts. To support the realization of this goal, member states also endorsed the new ICAO Assistance, Capacity-building, and Training for Sustainable Aviation Fuels (ACT-SAF) program. This program aims to facilitate the development and adoption of sustainable aviation fuels, contributing to the broader efforts to decarbonize the aviation industry and achieve the net-zero emissions objective by 2050.

- **CORSIA**: CORSIA is another ICAO initiative, designed to achieve carbon-neutral growth in the global aviation sector from 2021 to 2035 - with a baseline reference point set at 85% of the 2019 emission level. CORSIA is a widely adopted mechanism for international aviation to align with the goals of the Paris Agreement and mitigate climate change. Airlines operating between participating countries are required to report emissions

[17] Long term global aspirational goal (LTAG) for international aviation (icao.int)

data and purchase and cancel 'emissions units' to offset the increase in international CO_2 emissions between signatory countries covered by the scheme. Sustainable Aviation Fuels (SAFs) that meet CORSIA specifications, including a minimum greenhouse gas saving threshold of 10% against a fossil fuel baseline, can be used by airlines to reduce their CORSIA offsetting obligations. Reporting the use of SAFs and claiming associated emissions reductions will be governed by CORSIA's Standards and Recommended Practices (SARPs) and the accompanying Environmental Technical Manual (ETM). Furthermore, to be eligible for use within the program, SAFs must demonstrate sustainability through a CORSIA Approved Sustainability Certification Scheme , such as the International Sustainability and Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB). Israel is a signatory to CORSIA, obligating the national airlines to comply with this policy.

Policy examples

Many countries are introducing SAF policies, with the U.S., EU, and the UK currently leading. These policies have typically been built by adjusting existing policies to decarbonize the road industry, although pressure from corporates and the wider public has lead to the introduction of new policies to decarbonize aviation specifically.

- **U.S. SAF policies:** The U.S. is leading the SAF industry with both the highest level of ambition and the greatest policy support. The cross-government SAF Grand Challenge aims for 3 billion gallons SAF (c. 15%) by 2030, and full replacement of fossil fuels with SAF by 2050. The Inflation Reduction Act (IRA) combined with existing federal policy (Renewable Fuel Standard) and state-level policies put this within reach.

  The RFS is the backbone of the U.S. SAF and biofuel industry. This policy is a mandate on fuel suppliers to include a specified volume of biofuels into the fuel supply, mainly focusing on road transportation. The RFS is designed with nested obligation categories, known as RINs. Each category has different feedstock and emission criteria, meaning that while the obligation is predominantly met by corn-derived ethanol, smaller volumes of more advanced renewable fuels are also mandated. Although fossil jet fuel is not an obligated category, SAF blended into the U.S. fuel pool generates compliance credits. Imported fuels are also eligible for blending and compliance with the RFS.

  On August 2022, the U.S. government announced the Inflation Reduction Act (IRA), which introduced specific incentives for SAF. The IRA provides a two-phased approach to incentivize SAF. Starting from 1 Jan 2023, the SAF blenders tax credit (BTC) provides $1.25/gal baseline incentive for SAF achieving a minimum of 50% emissions reduction, plus a $0.01 incentive will be provided for each +1% emissions reduction, up to 100%. This means that SAF demonstrating a 100% reduction will be eligible for the maximum incentive of $1.75 per gallon. In 2025 (to 2027), the SAF BTC will transition to the Clean Fuel Production Credit (CFPC), also known as Section 45Z. The CFPC sets a baseline emissions factor for SAF at 50 $KgCO_2$/MMBTU (approximately 50% reduction), scaling to $1.75/gallon for SAF with a 100% emission reduction. Additionally, the IRA included two tax credits, the clean hydrogen production tax credit (45V) and the carbon capture and storage credit (45Q).

  State policies complement those on the U.S. federal level. These include the Low Carbon Fuel (LCF) programs like those in California, Oregon, and Washington, which are mandates to reduce the Carbon Intensity (CI) of the fuel pool. SAF is eligible to earn credits, but is not a mandated fuel category, so these policies also act as incentives for SAF producers, funded by customers using other fuels (e.g. road fuels in California are c. $0.1/gal more expensive due to the policy). To date, there are three key additional, separate state incentives available in Illinois, Minnesota and Washington state:

- **Washington bill SB 5447 promoting the alternative jet fuel industry in Washington:** This bill provides incentives available for purchases of SAF for flights departing Washington State. It is equal to $1 for each gallon of alternative jet fuel that has at least 50% less CO_2e than conventional jet fuel and increases by $0.02 for each additional 1% reduction in CO_2e emissions beyond 50%. A SAF tax incentive to manufacture and purchase SAF was also implemented to incentivize fuel producers to build SAF production facilities in Washington by creating a business and operations tax rate of 0.275% for the manufacture and sale of sustainable aviation fuels. The tax incentive will go into effect July 1, 2024, but only after a facility capable of producing at least 20 million gallons of alternative jet fuel is operating in Washington. It will be applicable for 10 years.

- **Illinois Sustainable Aviation Fuel Purchase Credit:** This credit is available for every gallon of SAF sold to or used by an air carrier in Illinois. Airlines can claim a credit of $1.50/gallon of SAF that achieves a 50% reduction in GHG emissions and is only available to airlines operating in Illinois. The incentive is effective for ten years, from June 1, 2023, through June 1, 2033. By 2028, all fuel must be derived from domestic biomass resources.

- **Minnesota Sustainable Aviation Fuel Tax Credit:** The refundable tax credit provides $1.50 per gallon of sustainable aviation fuel produced or blended in Minnesota and sold for use in planes departing Minnesota airports. It further provides a sales tax exemption for construction materials and supplies to support the construction of facilities that produce or blend SAF. The tax credit expires on January 1, 2035.

The U.S. also offers a series of grant/loan guarantee programs, which can be leveraged for developing SAF technologies. The IRA included a $244 million dedicated SAF grant funding through a new U.S. Department of Transportation program. The DOE and other agencies also offer loan guarantees and grant programs, although these can be challenging to access.

SAF in the U.S. can claim multiple incentives, known as 'stacking'. For example, a fuel producer could access as much as $7/gal by selling the physical fuel, claiming the federal RFS and BTC, and selling into California to access the LCFS. This value stack makes the U.S. the most economic region to purchase SAF and has resulted in airlines focusing efforts on geography. It has also attracted considerable investment and resources to develop SAF facilities in America, with ICF estimating that almost two-thirds of all announced SAF capacity is located in the United States.

- **EU SAF policies:** In July 2021, the European Commission announced the Fit for 55 package which included a set of proposals to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared with 1990 levels. The package included a recast of the Renewable Energy Directive (RED II), to ensure the EU delivers on their new target by ensuring at least 32% of its energy consumption comes from renewable energy sources by 2030. This also includes a target of a minimum 40% share in final energy consumption by 2030, accompanied by sectoral targets. It also included ReFuelEU Aviation, which introduced a set of policies to decarbonize aviation. The ReFuelEU proposal includes a SAF mandate to support the scaling up of the SAF industry, which will go into effect on January 1, 2025. This mandate creates an obligation on fuel suppliers to supply an increasing share of SAF at EU airports. To reduce the competitive disadvantage for European airlines due to the higher fuel costs, airlines can reduce their EU Emissions Trading Scheme allowance purchasing obligations through SAF use. Fuel suppliers in the EU that fail to comply with the ReFuelEU Aviation mandate would have to pay a non-compliance penalty equal to double the price difference between conventional fuel and the applicable SAF type. Any revenues generated by fines will be used by EU member states to support R&D in the field of SAF or for other mechanisms to bridge the difference in price with conventional fuel,. The fuel supplier will still have to supply the SAF volume the following year. This mandate will scale up the SAF requirement until 2050 and includes a sub-mandate for Power-to-Liquid ("synthetic") SAF:

Table 1: ReFuelEU SAF mandate

Year	Total SAF Mandate	PtL Sub-Mandate
2025	2%	0%
2030	6%	1.2% (increasing to 2% in 2032)
2035	20%	5%
2040	34%	10%
2045	42%	15%
2050	70%	35%

In December 2022, the EU reached an agreement on the EU ETS Aviation reform which paves the way for a faster phase-out of free airline emissions allowances and introduces a system to monitor, report, and verify (MRV) non- CO_2 emissions as well as a "SAF allowances" pricing scheme. As a result of this reform, free emissions allowances for airlines covered by the EU ETS will be phased out by 2026 (a year earlier than originally planned), which is expected to increase operational costs of airlines substantially. Emission allowances will be phased out gradually starting from 25% reduction in 2024, continuing with 50% reduction in 2025 and finalizing with a complete phase out by 2026.

The EU is also considering a scheme to support airlines cover the price premium for SAF by allocating an additional fund of 20 million ETS credits. Over the longer term, this may have a meaningful impact in reducing the cost implications of the SAF mandate to airlines and ultimately passengers.

- **UK SAF policies:** The UK government has committed to scaling the use of SAF to achieve its "2050 Jet Zero target", announced in July 2022. As part of this strategy, by 2025 the UK has committed to have at least five UK SAF plants under construction and a SAF mandate in place, with a target of 10% SAF by 2030 (equivalent to 1.2 million tonnes).

  The UK government has allocated £180 million in funding for the SAF industry by 2025, which is incremental to the Advanced Biofuels Demonstration Competition (ABDC, 2014, £25m), Future Fuels for Flight and Freight Competition (F4C, 2017, £22m) and Green Fuels Green Skies Competition (GFGS, 2021, £15m) funds that supported the development and commercialization of SAF pathways.

In April 2024, the UK government released the results of its second SAF Mandate Consultation, detailing the final design and implementation schedule of a SAF mandate. The mandate will start in 2025 and will establish targets through 2040. The policy aims to scale up SAF uptake by gradually increasing the supply requirement, similar to the EU SAF mandate, as outlined in the table below.

Table 2: UK SAF mandate

Year	Total SAF Mandate	PtL Sub-Mandate
2025	2%	0%
2030	10%	0.1%
2035	15%	0.5%
2040	22%	3.5%

The UK SAF mandate will contain provisions which may represent key variations from the ReFuelEU mandate:

- **Sustainability criteria**: SAF must achieve at least 40% greenhouse gas (GHG) savings relative to fossil jet fuel, a figure which will increase over time.
- **Feedstocks**: The feedstock constraints are similar to the ReFuelEU, with waste/residue feedstocks allowed but food/feed crops and energy crops excluded.
- **HEFA cap**: HEFA contributes to the standard obligation, but can only be used up to a capped percentage. From 2027 onwards HEFA cap is set at 92% before being lowered to 71% in 2030 and then to 33% in 2040.
- **Buy-out price:** The UK has proposed a fixed buy-out price in situations where the fuel supplier is unable to comply (compared to the EU proposal of a buy-out price as a multiplier of the premium). For SAF and PtL obligations the price has been set at £4.70 and £5.00 per litre, respectively. Unlike the EU, the fuel supplier's obligation is not transferred to the following year (i.e. the buy-out fulfills the obligation)
- **Carbon intensity (CI) mechanism**: The UK mandate includes a mechanism to scale the certificates value based on the SAF CI factor, strongly incentivizing the use of SAF with a greater emissions reduction.

The UK has announced a plan to create a Revenue Stability Mechanism for the SAF industry. This aims to overcome the volatility inherent to pricing under a mandate by creating a stable price (or potential price floor) for SAF. This has long been the ambition of the industry, and the scheme announcement represents a recognition by the government that the current policies are likely insufficient to attract the necessary investment. However, this scheme faces several challenges, including that it is intended to be implemented in 2026 (one year after the mandate starts), and that it will be funded by the aviation sector.

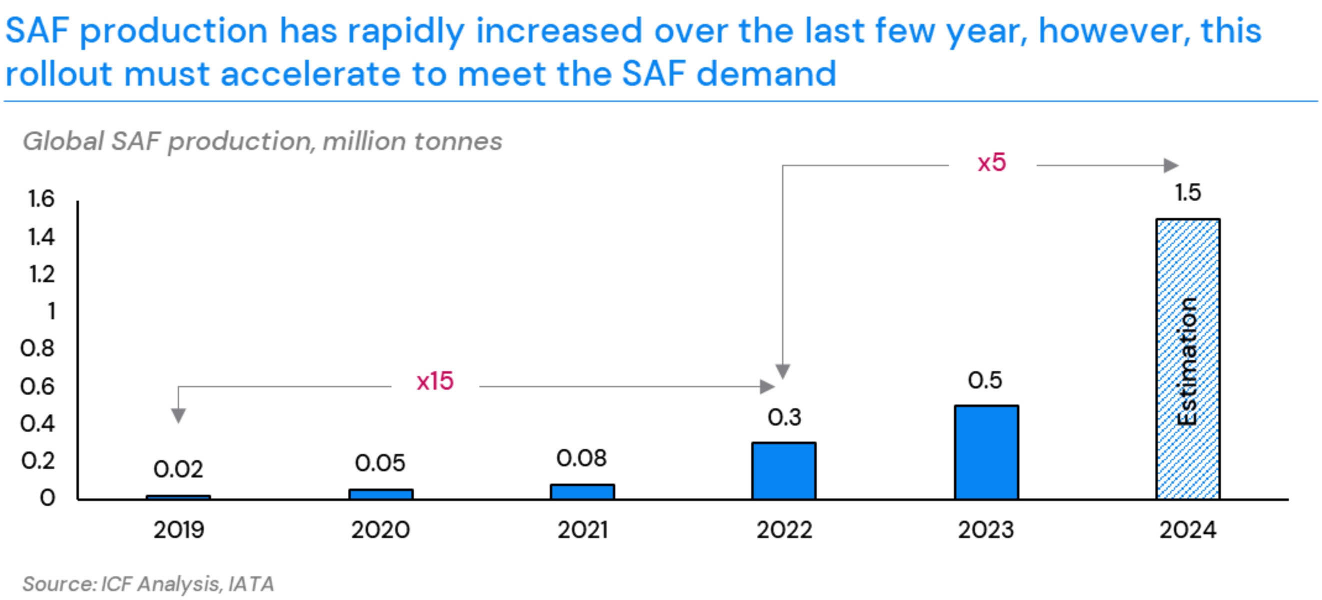
Today, the SAF industry is focused in Europe and North America. However, there is a growing number of governments which have committed to fostering SAF and establishing production capabilities, including

Singapore, Japan, Canada, Australia, the UAE, Türkiye – as well as other countries at earlier policy-design stages. Each jurisdiction is developing policies and approaches to fit its local economic, ecological, and industrial contexts.

2.3 SAF market outlook

The production of SAF is rapidly scaling up across the world. In 2023, over 0.5 million tons of SAF were produced globally[10], accounting for approximately 0.2% of the global jet fuel consumption.[11] As outlined in Figure 5, this marks a doubling of SAF production compared to 2022 and a 25-fold increase compared to 2019 levels. However, projections indicate that the quantity of SAF produced will triple to 1.5 million tons in 2024[12], with the growth driven by demand stemming from regulation.

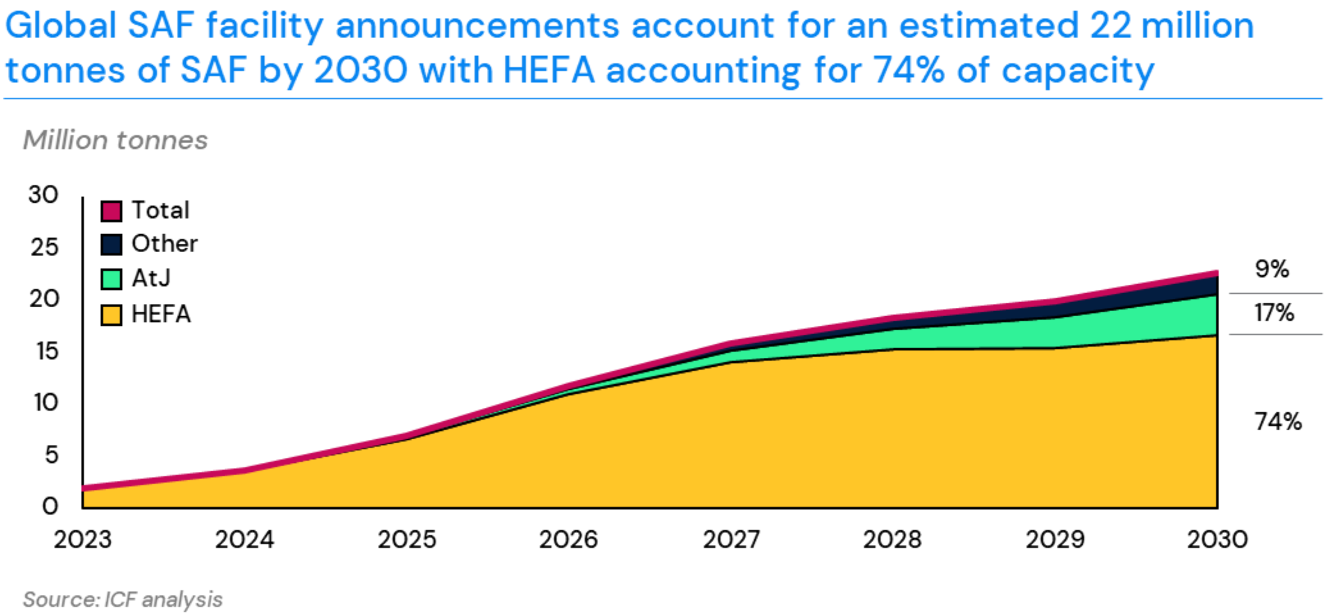
Figure 5: Global historical SAF production



The ReFuelEU and the UK SAF mandates' 6% and 10% 2030 goals would jointly represent an estimated 4.5 million tons of SAF. The U.S. has set an aspirational target of 3 billion gallons (9.1 million tons) of SAF by 2030 under the SAF Grand Challenge. Other countries, including Canada, Japan, Türkiye and India are also developing SAF policies, adding an estimated demand of 3.9 million tons by 2030. By 2050, an estimated 400 million tons of SAF is needed to achieve the global decarbonization targets.

Between 17 and 25 million tons of SAF are projected to be produced globally in 2030 based on the announced and existing SAF production facilities. As outlined in Figure 6, the majority of these SAF facilities will utilize HEFA technology (approximately 74% of capacity by 2030) which converts lipids into renewable fuels such as SAF and renewable diesel. HEFA's near-term dominance is due to its mature and commercially proven process, as demonstrated by its widespread use in the renewable diesel industry over the past decade. Additionally, HEFA benefits from an established supply chain and relatively significant existing production capacity.

Figure 6: 2030 SAF production estimation across the world



Despite the considerable growth, supply still falls short of ambitions, with the gap driven by the high cost, the lack of global support policies that specifically target SAF, and the slow commercialization of non-HEFA SAF technologies.

Co-processing of oils and fats has expanded rapidly as it presents a cost-effective opportunity for existing petroleum refineries to produce SAF with limited investment in infrastructure. Most refineries producing SAF via co-processing are in Europe as refiners require a rapid method to produce SAF in anticipation of approaching SAF blending mandates. Co-processing presents a further opportunity to leverage feedstocks such as MSW. This can reduce the investment required to build dedicated upgrading infrastructure while providing the opportunity to partly decarbonize existing petroleum refining and refinery products. Co-processing can also be used as a final upgrading step of oligomers in the AtJ process. There is also substantial research into using pyrolysis oils (e.g. residues, plastics or waste tyres) or hydrothermal liquefaction biocrudes (e.g. from sewage sludge or wet waste) for coprocessing. Within the context of SAF production in Israel, co-processing of oils and fats will be limited by the availability of domestic feedstocks, although these feedstocks have established global supply chains and could be imported.

The AtJ production pathway is forecast to contribute an increasing portion of global capacity later in the decade. This technology can use multiple alcohols as a starting feedstock, including ethanol produced from crops such as sugarcane or sugar beets, or from gas fermentation. Ethanol is a relatively energy-dense feedstock with existent supply chains, facilitating import opportunities. The opportunity in Israel is likely to be limited to gas fermentation as biological feedstocks availability for ethanol production are expected to be limited.

Multiple AtJ technologies are available for licensing worldwide and the LanzaJet pioneer facility in Georgia, U.S., has recently started producing SAF. Successful demonstration of this pathway could lead to multiple facilities based on this technology. A significant benefit of the AtJ technology is low CAPEX and a relatively short construction period, about two years, depending on the scale of the facility.

All other technologies (including conversion of municipal wastes (MSW), woody biomass, and power-to-liquids) remain a relatively small portion of global capacity by 2030. However, these opportunities are likely to be important for any domestic production in Israel, given the lack of agricultural feedstocks.

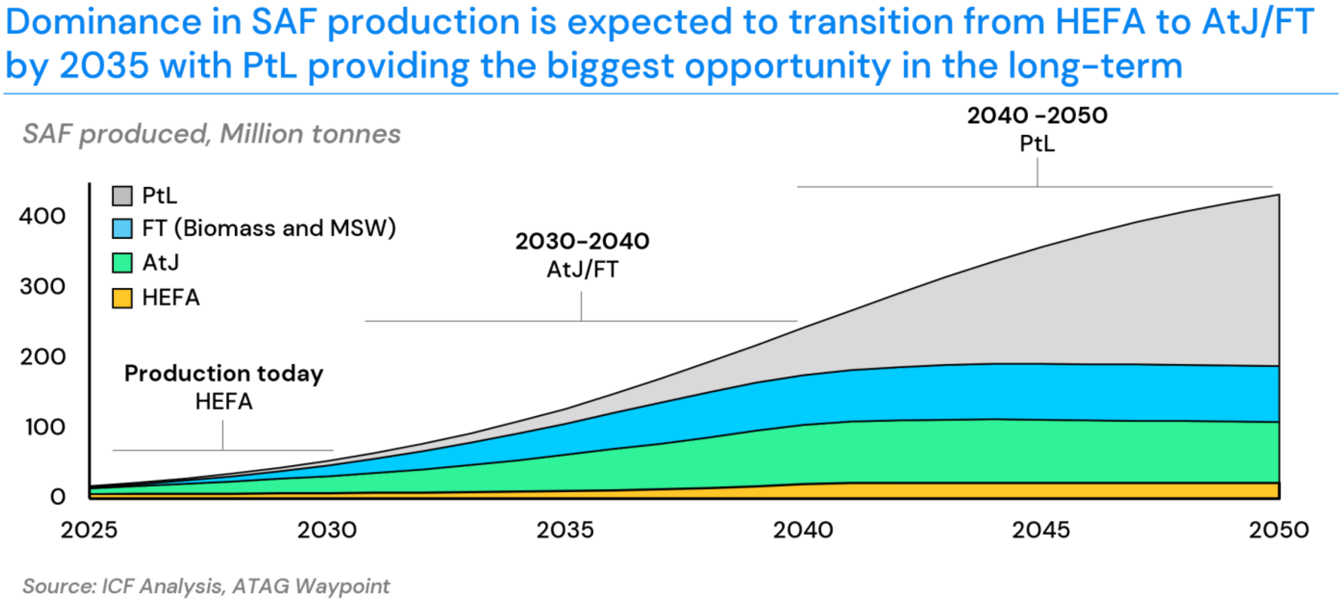
Gasification with Fischer-Tropsch (FT), a fuel technology that has been employed to produce liquid fuels for nearly a century, is a promising route for converting biomass, such as municipal solid waste (MSW) and agricultural residues, into SAF. This FT process involves converting syngas (CO and H2), which is derived from the gasification of biomass, into liquid hydrocarbons such as SAF at high temperatures and pressures. As this pathway is more technologically advanced, commercially proven and has a relative abundance of potential feedstock, FT is expected to play a significant role in the future development of SAF. However, the technology was originally commercialized based on coal and natural gas, and biomass-based feedstocks still have substantial technical challenges that have not been resolved. Syngas could potentially be produced from biogas (from landfills or anaerobic digestion of wastewater) and used in a gas-to-liquid process to produce synthesis gas, followed by conversion to fuels using Fischer-Tropsch. An alternative route to Fischer-Tropsch, namely gasification, methanol synthesis and methanol-to-jet conversion, is another option with several companies developing the methanol-to-jet process. This pathway is near ASTM certification. However, MSW gasification has encountered major technical challenges with the closure of the first commercial facility in the U.S. (Fulcrum Bioenergy). These difficulties will delay the commercialization of the MSW gasification technology. Gasification and FT require high investments as the initial CAPEX is very significant. At the same time, the construction timeframe for this technology is about five years, with additional time for commissioning and capacity ramp-up. Any SAF production based on gasification and FT should therefore be considered a long-term scenario.

PtL is a key pathway under the EU and UK mandates. This approach involves using renewable electricity to combine captured carbon dioxide with hydrogen produced via electrolysis of water ("green hydrogen") to produce SAF. This pathway is favorable due to the abundance of feedstock (air and water) and its potentially considerable carbon intensity reduction. Similar to the gasification pathway, the production of SAF proceeds through a synthesis gas intermediate, which can be followed up with FT synthesis of SAF or through a methanol synthesis and methanol-to-jet process.

However, some key challenges remain that will hinder PtL plants from penetrating the market in the near-term. Individual components of the PtL pathway are commercial, but the integrated process has only been demonstrated at small scale. One essential process step is the reverse water gas shift reaction that produces synthesis gas from CO_2, and this technology is only at a pilot scale. The PtL process requires an abundance of additional renewable electricity to not only produce the green hydrogen but also to capture CO_2 and to power the upgrading process. However, renewable energy demand for heat and power, electric vehicles, and decarbonization of industrial processes are all competing for the same electricity.

PtL also entails high capital costs for electrolyzers and carbon capture, and the production costs for PtL is expected to be several-fold higher than HEFA SAF for quite some time. As such, the output from PtL facilities is not expected to meaningfully contribute to the global supply of SAF until the 2040s. The scale-up of the various SAF production pathways has been outlined in Figure 7.

Figure 7: Global 2050 SAF production estimations



Overall, the slow commercialization of technologies other than HEFA will have an impact on the global availability of SAF. Depending on the pathway, progression from each step on the technology readiness scale to the next could take 2-3 years, and potentially longer if challenges are encountered. Many biofuel companies that have aimed for rapid scale-up have failed. Consequently, first-of-a-kind facilities for new technologies are small. The first commercial AtJ facility (Lanzajet, Freedom Pines, Georgia) is a 40 million liter facility. Similarly, the Fulcrum Bioenergy facility had a capacity of 40 million L. Therefore, getting large scale facilities on line based on still-developing technologies will only be feasible in the medium to long-term for second or third facilities based on the same technology. PtL technology is at a lower [18]TRL level than AtJ or gasification and is not expected to deliver substantial volumes until after 2030.

At a global level, the critical importance of policy support for SAF development has been emphasized by a general consensus that the aviation sector could not meet net zero by 2050 without supporting policies. SAF facilities imply high investment cost while the risk associated with still commercially unproven technologies is still deemed high. SAF prices are also substantially higher than conventional jet fuel, making it challenging for airlines to afford substantial purchases of SAF. The impact of policies on the SAF sector has been clear when considering the dramatic response in the industry after the EU and U.S. policies were announced. Within a few years, SAF production volumes have more than quadrupled and over 150 announcements for new facilities have been made. While the policy approaches in these major jurisdictions have been very different, there is no doubt that these are succeeding in driving SAF development through their respective mandates, and/or incentives.

[18] See Appendix for description.

Photo by Haley Black

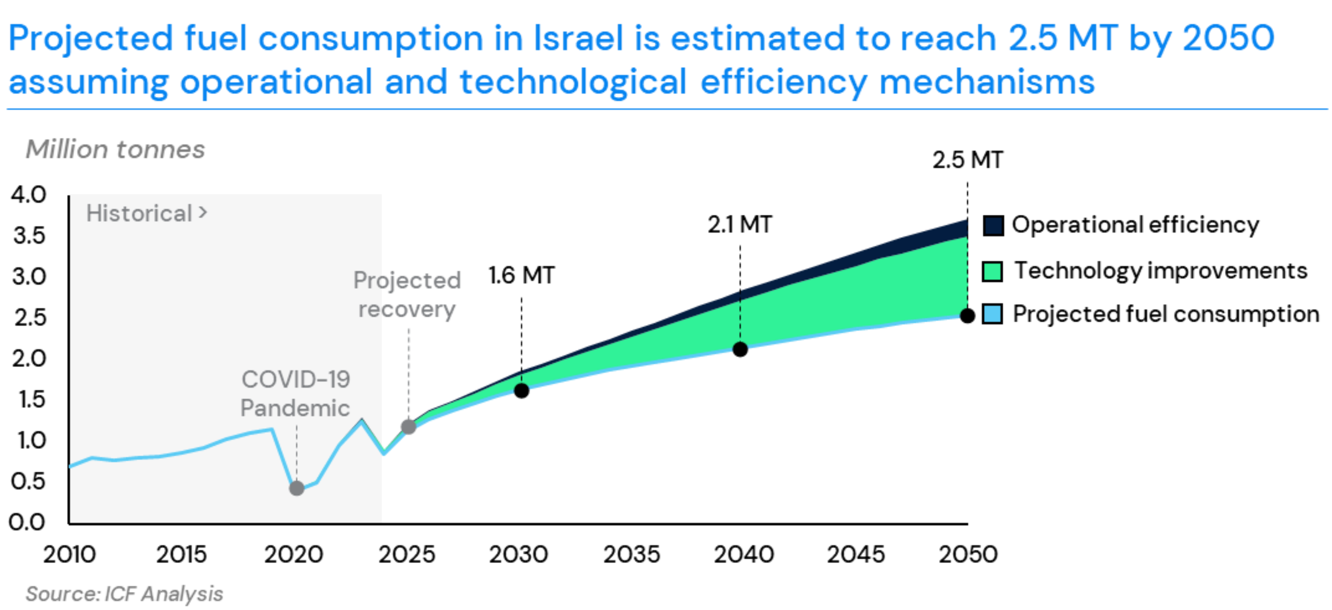
3 SAF Outlook in Israel

3.1 Projected growth in aviation

The demand for aviation has been steadily increasing in Israel over the past decade. Between 2010 to 2019, jet fuel consumption increased from 0.8 million tons to 1.2 million tons[19]. According to IATA, the aviation market in Israel is expected to continue to grow by 65% over the next two decades, resulting in a 3% CAGR increase in jet fuel consumption by 2050. The forecasted conventional aviation fuel (CAF) consumption was developed utilising IATA growth projections, as well as the Boeing Commercial Market Outlook (CMO) regional aviation traffic growth projection of 4.4% CAGR.

Improvements in fuel efficiency from operations (such as air traffic management) and technology (such as engine efficiency improvements) are expected to result in lower fuel consumption. In this analysis, ICF applied a 2.5% fuel efficiency improvement, aligned with ICAO's fleet efficiency targets.[20] As seen in Figure 8, this results in total jet fuel consumption of 1.1 million tonnes in 2025, increasing to 1.6 million tonnes in 2030, and 2.5 million tonnes by 2050. The fleet, operational, and technology improvements reduce this from a baseline fuel consumption of 3.7 million tonnes in 2050, equivalent to a decrease of 32%. While this is a significant reduction, there are considerable residual emissions that must be abated through SAF and other out-of-sector measures. It is important to note that the ICF's projected jet fuel consumption is higher than the projected jet fuel consumption by the Ministry of Energy and Infrastructure. The difference can be attributed to the different methodologies and assumptions, with ICF utilising air traffic passenger numbers rather than historical jet fuel consumption.

Figure 8: Projected jet fuel consumption in Israel



[19] https://www.eia.gov/opendata/browser/international

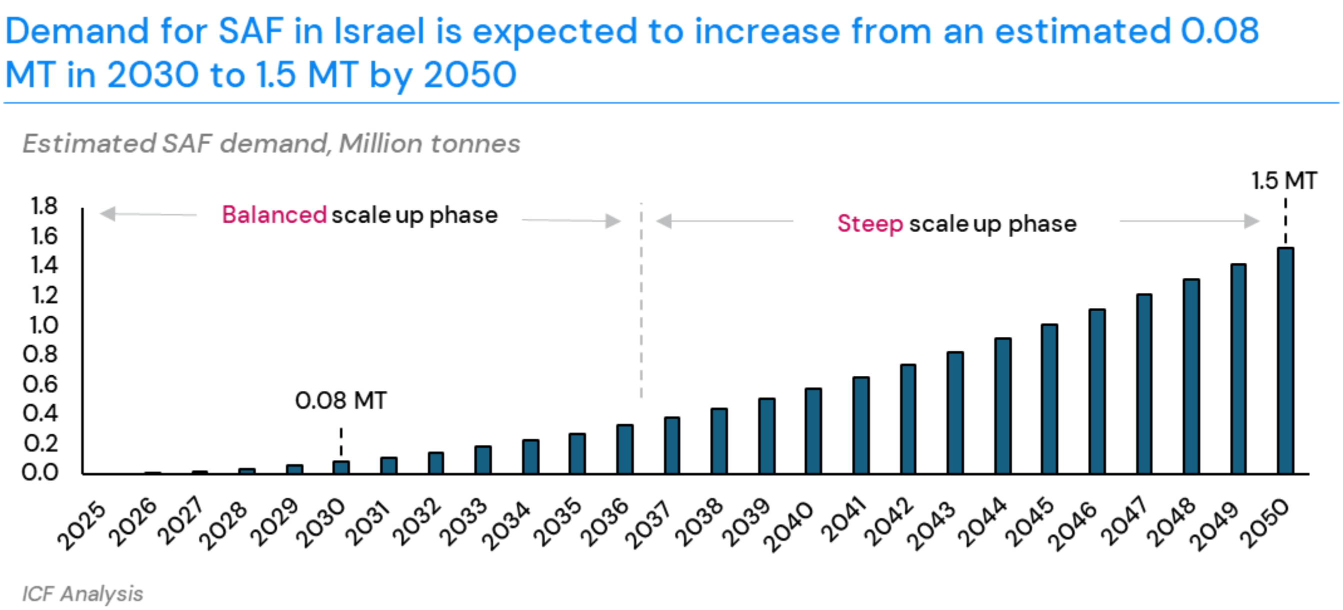
[20] Envisioning a "zero climate impact" international aviation pathway towards 2050: how governments and the aviation industry can step-up amidst the climate emergency for a sustainable aviation future (icao.int)

3.2 Projected SAF demand

Underpinned by the jet fuel forecast and national targets, a SAF demand scenario was developed. This was designed to align with the ambition of the EU-legislated mandate (ReFuelEU), although with a 2-year delay to the start to allow time for the development of legislation and supply chains, and with a slight reduction in volume to reflect the lower feedstock availability (as assessed in the following chapter). The alignment will be focusing on achieving a similar emission reduction with the EU SAF mandate targets, rather than matching the volumetric targets, given the much higher requirement for the PtL SAF in Israel. For example, the EU SAF target for 2050 is 70%, consisting of 35% PtL SAF, and 35% non-PtL SAF. Emission reduction for non-PtL SAF in the EU is 65%, and PtL SAF is assumed to provide 90% emissions reduction. This means the EU SAF emission reduction target by 2050 is 54%. Considering that PtL SAF supply will dominate the market in Israel with a previously assumed 90% emission reduction, 60% SAF would be required in Israel in a volumetric context to meet the EU target.

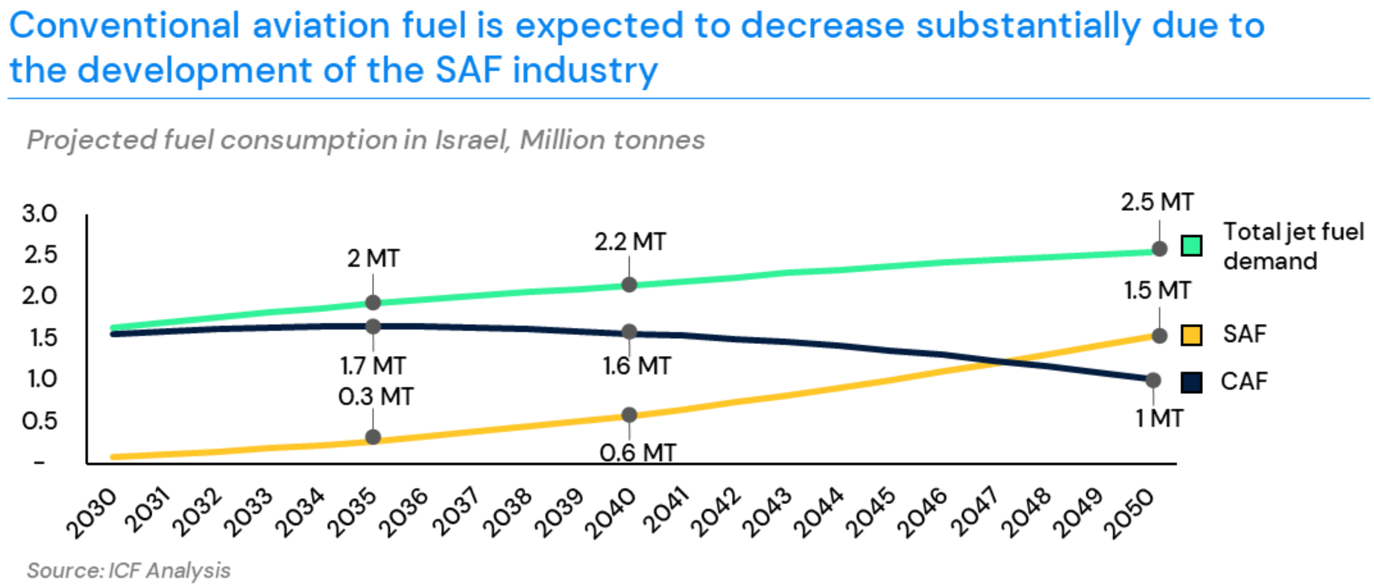
The EU mandate is set to start with initial obligations for 2% SAF in 2025, increasing to 6% by 2030, 20% by 2035, 34% by 2040, 42% by 2045 and 70% by 2050. The graph below shows the potential SAF production volumes from 2027-2050. As seen in Figure 9, with the selected scenario of 60% in 2050, Israel would require around 0.08 million tonnes of SAF in 2030, scaling up to 1.5 million tonnes by 2050.

Figure 9: Projected SAF demand in Israel



The projected growth of the SAF industry is expected to gradually reduce fossil jet fuel consumption. The shift is anticipated to reach a critical point around the late 2040s, providing the industry with enough time to transition from fossil-based jet fuel to SAF production. As seen in Figure 10, projections indicate that by 2050, this transition could result in fossil jet demand dropping to approximately 1 million tonnes.

Figure 10: SAF and conventional aviation fuel projection in Israel



To effectively meet the forecasted SAF demand in Israel, it is crucial to conduct a thorough assessment of appropriate feedstocks and production technologies. The following sections will provide an overview of the analysis of feedstock availability and explore the most suitable technologies for establishing Israel's inaugural SAF production facility.


Photo by Haley Black

4 Feedstock Opportunity in Israel

4.1 Methodology

Feedstock selection

To structure this assessment, ICF utilised the CAAFI system of feedstock classification, which categorizes available feedstocks into five distinct groups: (1) Fats, Oils, and Greases (FOGs), (2) Cellulose, (3) Carbohydrates and Sugars, (4) Industrial waste streams, and (5) Electricity (not included by CAAFI, but an important extension to reflect the increasing focus on PtL SAF, particularly in the EU). Within these categories, CAAFI lists at least 135 different possible feedstocks, which are likely to grow as additional pathways are certified and technology continues to develop.

ICF prioritised feedstocks that are aligned with sustainability guidelines and policies that are developing across the aviation sector. These guidelines include the ICAO framework utilised for CORSIA and policies such as ReFuelEU (aligned with EU RED III), the U.S. IRA, and the UK SAF mandate. Policies such as the EU RED III state a target to achieve 14.5% carbon intensity reduction and list allowable feedstock categories in Annex IX. It specifically excludes feedstocks that compete with food sources. By comparison, policies in the U.S. require SAF to meet specific greenhouse gas (GHG) reduction thresholds but do not specifically exclude any feedstocks.

The two broad categories of feedstocks are biological and non-biological. Many countries in the Middle East can only access a limited volume of biological feedstock, due to climate conditions, and limited agricultural activity. An example of biological feedstocks that are available in Israel is biological MSW. Non-biological feedstocks, especially PtL SAF from low-carbon renewable electricity, are likely to offer greater potential to scale-up. Due to these considerations, the following feedstocks and associated technologies were analysed and evaluated for this study:

Table 3: Feedstock considerations for Israel

Feedstock Category		Sub-Category	Feedstocks	Technology
Biological	Waste and residue lipids	N/A	Used cooking oil (UCO) and Tallow	HEFA
	Agricultural residues	N/A	Corn stover, rice residues, bagasse	FT or AtJ
	Municipal solid waste (MSW)	N/A	Black bin and industrial solid waste	

Feedstock Category		Sub-Category	Feedstocks	Technology
Non-Biological	Renewable fuels of non-biogenic origin (RFNBO)	Power-to-Liquid (H2 from electrolysis and CO_2 from DAC)	Renewable electricity	FT or AtJ

Detailed feedstock definitions can be found in the Appendix.

Feedstock availability

Feedstock availability is an essential consideration to determine the most suitable pathway for Israel's future SAF industry. Different countries and regions have access to distinct feedstocks, directly affecting the volume and specifications for SAF technology opportunities. For this high-level feedstock analysis, ICF used a feedstock assessment methodology which considers three stages:

- **Technical availability** – refers to the total amount of potential feedstock available in a region. This includes availability for SAF production, and other potential uses of the feedstock, such as biodiesel or energy production. Technically available feedstock amounts vary widely as they are highly dependent on the environmental dynamics of the region.
- **Sustainable availability** – refers to the portion of the total possible feedstock supply that would be unsustainable to collect or produce. Deducting unsustainable quantities from technically available feedstock amounts gives the sustainably available feedstock quantity. For example, a portion of agricultural waste must be left in the field to protect soil quality, and the fossil portion of municipal solid waste should be avoided.
- **Allocation to the aviation industry** – refers to the available feedstock quantity dedicated to the aviation industry. As feedstocks can be utilised in a variety of industries, such as alternative fuel production (biodiesel), the chemicals industry (naphtha) and energy production, only a portion of the sustainably available feedstocks are typically allocated to the aviation sector.

This information was further utilised to develop three scenarios: low-scenario, medium-scenario, and high-scenario. These scenarios outline the various assumptions regarding the projection of each feedstock category to 2050, with the low scenario assuming a conservative projection, and the high scenario assuming an ambitious projection.

To enhance accuracy, each feedstock category was calculated in kilotonnes and converted into energy in terms of petajoules ($x10^{15}$ Joules), to provide a more effective and comparable metric.

4.2 Assessment of feedstock availability

Waste and residue lipids

Due to competing uses and low technical availability, Israel has limited potential to utilize UCO and tallow for SAF production. UCO availability was determined based on domestic vegetable oil consumption; UCO is estimated to be 20-30%[21] of the total vegetable oil consumption per year. In recent years, 89% of vegetable oil in Israel was consumed for food purposes. This figure is expected to grow slowly over time, based on long-term historical data. Utilising collection rates for households, restaurants and industrial use, an estimated 0.01 to 0.02 million tonnes (0.4 to 0.9 Petajoules) of UCO are expected to be available by 2050.

Meat consumption has increased by 50% within a period of 6 years, from 2015 to 2021. However, majority of meat consumed is imported with only 40% produced domestically. [22] With poultry being the most popular meat consumed in Israel,[23] the number of chickens being raised and slaughtered is the most significant factor in Israeli waste animal fat production. Based on slaughtering numbers of cattle, chickens, sheep, pigs, and turkeys, and competing uses (such as animal feed and chemical industry) the total availability to aviation is assumed to be 0.02 to 0.11 million tonnes. This translates to an estimated 0.8 to 4.5 Petajoules.

Agricultural residues

Israel has a reasonably strong agricultural sector given only 20-30% of the country is suitable or adapted for agriculture due to limited fertile land and scarcity of water. Over the last decade, the land that has been agriculturally utilised has steadily increased to over 0.6 million hectares, equating to around 30% of Israel's land area. The land used specifically for crop farming, temporary and permanent crops, has risen from 13% to 18% of Israel's total land area. While Israel's largest agricultural output is dominated by food produce (including fruits and vegetables), Israel has a sizable annual crop yield. The largest of these that have agricultural waste feedstock applications are barley, wheat and maize. In 2022, the yields were 0.2 t/Ha, 0.2 t/Ha and 2.3 t/Ha, respectively.

Using the Residue-Product Ratio (RPR) this gives total residues of 352 kilotonnes, and 310 kilotonnes of dry residues (assuming 10-15% moisture content). This must be reduced by the volume that will remain on the fields to ensure soil health and a further portion which is utilized for competing use. Estimating a range of 40%-67% that must be left on the field and an additional 20% that is assumed to be used for competing use. Utilizing historical data trends, the total amount of residues available by 2050 is projected to be 0.1 to 0.2 million tonnes with minimal competing use. Applying the lower heating value (LHV) for each crop gives an estimate of 1.6 to 3.6 Petajoules available by 2050.

Municipal solid waste (MSW)

In 2023, Israel produced approximately 6.9 million tonnes of MSW, resulting in 4.13 million tonnes of collected biogenic waste (food, paper, and cardboard waste). An estimated 26% (1.1 million tonnes) of biogenic waste was recycled with an additional 59% (2.44 million tonnes) landfilled. The fraction of waste sent to the landfill represents the core opportunity for conversion into SAF as its use as a feedstock would generate a considerable emissions reduction (due to avoided methane emissions), reduce land needed for landfill, and create economic value.

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[22] https://www.gov.il/en/pages/ministry_of_agriculture_in_analyzing_the_beef_market_in_israel
[23] https://data-explorer.oecd.org/vis?df[ds]=dsDisseminateFinalDMZ&df[id]=DSD_AGR%40DF_OUTLOOK_2023_2032&df[ag]=OECD.TAD.ATM&pd=2023%2C2032&dq=OECD.A....&to[TIME_PERIOD]=false

Due to a significant increase in MSW generation in Israel (21% increase from 2010) [24], the Israeli Ministry of Environmental Protection has initiated a National Strategy for a Circular Economy aimed at reducing landfill use and increasing recycling rates.[25] This strategy includes ambitious targets such as achieving zero landfilling of paper and organic waste by 2030 and enhancing methane collection from landfills, with the ultimate goal of transitioning to a circular economy by 2050.

The average Israeli contributes about 1.8 kg of waste daily, with total waste production growing at an annual rate of 2.6%, primarily due to population growth. A portion of the collected waste is expected to be recycled. Aligned with Israel's ambitious waste targets the recycling rate is expected to increase from 25%[26] to 50% by 2050. Therefore, ICF has assumed that the portion of recycled waste from collected waste would rise from 25% in 2023 to 45-50% in 2050. Incinerated waste is estimated to continue to take up negligible amounts.

Amongst the remaining amounts of MSW, the biogenic portion is assumed to be around 30%. This results in an estimated 1.1 to 2.3 million tonnes of biogenic waste available annually for SAF production in 2050. The energy contained in this waste stream will vary with the materials and moisture content. Using a lower heating value (LHV) of 10 MJ/kg resulted in total energy availability of 7 to 35 Petajoules.

Innovative feedstocks

While substantial research and development efforts are focused on advancing conversion technologies for biofuels, there is a significant opportunity to support the exploration of innovative feedstocks. In Israel, several promising areas of research for novel feedstocks and technologies have emerged:

- **Algae:** Israeli companies like Univerve, Algatech, and Brevel are at the forefront of developing algae-based biofuels. Univerve is working on cost-effective systems to cultivate algae strains suitable for third-generation renewable biofuels, leveraging Israel's arid climate and saline water resources. Algatech has achieved industrial-scale algae production, using advanced technologies to grow algae in controlled environments for various high-value products, including biofuels. Brevel, a startup specializing in microalgae, has developed a high-yielding process that combines LED lighting and dark fermentation. This innovative method significantly enhances the profitability and scalability of algae production, making it a viable feedstock for biofuels and other high-value ingredients.

- **Castor bean seeds:** An element of Israel's advanced agriculture industry is its agri-tech sector where Israeli companies and institutions are developing new and genetically engineered plant and crop varieties. Casterra, a subsidiary of Evogene Ltd., is revolutionizing the castor oil market by developing high-yielding castor bean seeds as a cost-competitive, sustainable, second-generation feedstock for biofuel production. Casterra's integrated solutions include advanced breeding methods, mechanical harvesting, and proprietary dehulling machines, enabling efficient and industrial-scale cultivation of castor beans. These efforts support the biofuel production of major energy companies and highlight the potential of castor oil as a significant renewable energy source.

[24] https://unfccc.int/sites/default/files/resource/2nd%20Biennial%20Update%20Report%202021%20final.pdf
[25] https://www.gov.il/en/pages/waste_strategy_2030
[26] https://openknowledge.worldbank.org/entities/publication/d3f9d45e-115f-559b-b14f-28552410e90a

- **Sewage sludge:** Applied CleanTech, an Israeli environmental start-up, has developed a Sewage Recycling System (SRS) that extracts solid waste from sewage to produce Recyllose, a cellulose product usable in biofuel production. This technology not only reduces waste management costs but also creates a valuable resource from sewage. Additionally, Applied CleanTech has partnered with US biofuel firm Qteros to further develop technology for producing biofuels from sewage.

These innovative feedstock developments demonstrate Israel's commitment to advancing sustainable and efficient biofuel solutions, addressing challenges such as land use, water scarcity, and waste management while exploring new avenues for fuel production. However, it is important to note that these feedstocks were not included in the analysis as available feedstocks for SAF production due to the ongoing nature of research.

4.3 SAF opportunity from biological feedstocks

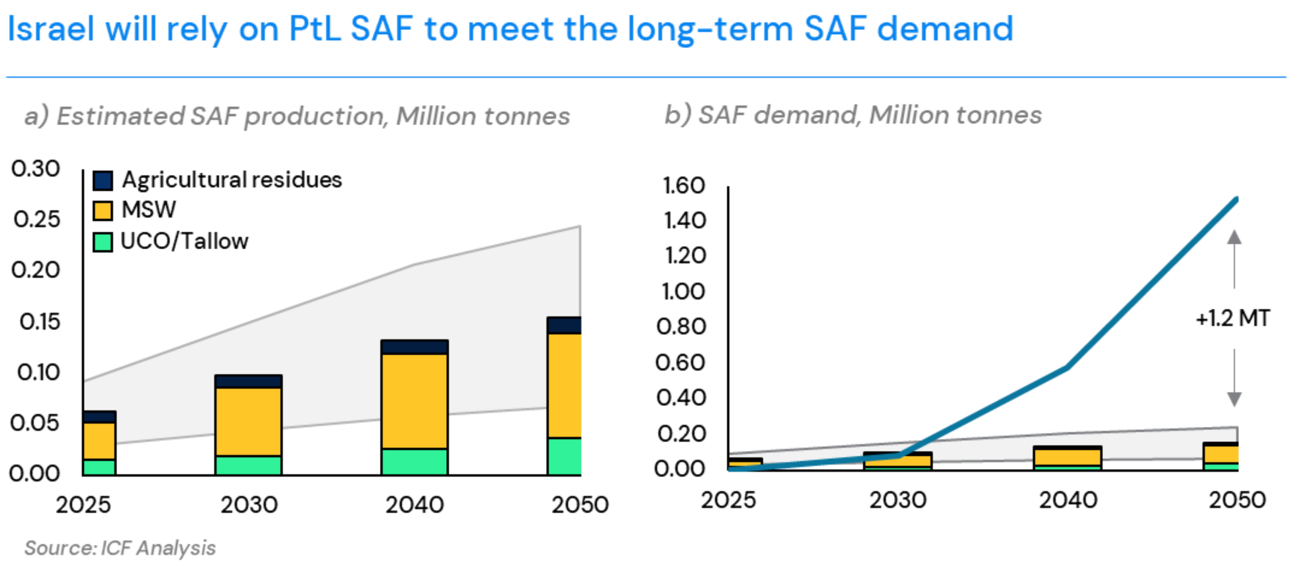
SAF production utilising domestic feedstocks is contingent upon the implementation of favourable policy mechanisms that prioritize SAF production over renewable diesel and naphtha and facilitate the development of robust supply chains for feedstock. Assuming various policy deployment scenarios, ICF determined the potential volume of SAF production in Israel, as follows:

- Low-scenario**:** Estimates that available feedstocks would be sufficient for approximately 0.04 million tonnes of SAF in 2030 and 0.07 million tonnes of SAF in 2050.
- Medium-scenario: Estimates that available feedstocks would be sufficient for approximately 0.1 million tonnes by 2030 and 0.2 million tonnes by 2050.
- High-scenario: Estimates that available feedstocks would be sufficient for approximately 0.2 million tonnes by 2030 and 0.3 million tonnes by 2050.

As seen in Figure 11, the total SAF availability from each respective feedstock is as follows:

- Waste and residue lipids: Estimated SAF production of 0.01 to 0.03 million tonnes by 2030 and 0.01 to 0.07 million tonnes by 2050.
- Agricultural residues: Estimated SAF production of 0.01 to 0.02 million tonnes by 2030 and 0.01 to 0.02 million tonnes by 2050.
- Municipal solid waste: Estimated SAF production of 0.03 to 0.15 million tonnes by 2030 and 0.04 to 0.22 million tonnes by 2050.

Figure 11: Estimated SAF supply from domestic biological feedstocks in Israel



While there is favourable opportunity for domestic SAF production utilising biological feedstocks (Figure 11a), additional volumes will be required to meet the proposed SAF demand (1.5 million tonnes by 2050) (Figure 11b). Imported feedstocks and fuel will provide the highest opportunity in the short term as the SAF market and advanced SAF technologies continue to develop. In the long term, PtL SAF production will provide a significant opportunity for SAF production in Israel. This opportunity is explored in the following section.

4.4 Opportunity for Power-to-Liquids

Power-to-liquids is a technology that uses CO_2 and H_2 to produce SAF. CO_2 can be sourced by carbon capture from point-emission sources (industrial or biogenic) or from direct air capture. Ideally, use of so-called 'green' hydrogen is made, where the H_2 is produced from renewable electricity and electrolysis of water. However, 'blue hydrogen' from natural gas with carbon capture and storage (CCS) can be used as an interim step towards green hydrogen as additional renewable electricity develops.

The syngas (a mix of carbon monoxide and hydrogen) from these sources can be combined to synthesize hydrocarbons via the Fischer-Tropsch pathway or used to produce methanol that can further be converted to long-chain hydrocarbons via the AtJ technology. Of note is that while the former has ASTM D7566-approval, the latter is yet to receive it. Carbo dioxide sourced from biogenic or unavoidable industrial point sources, is concentrated and cheaper than direct air capture, and will likely be used initially. but will be a limited source, while direct air capture will be an unlimited source for expansion of PtL volumes in the long-term.

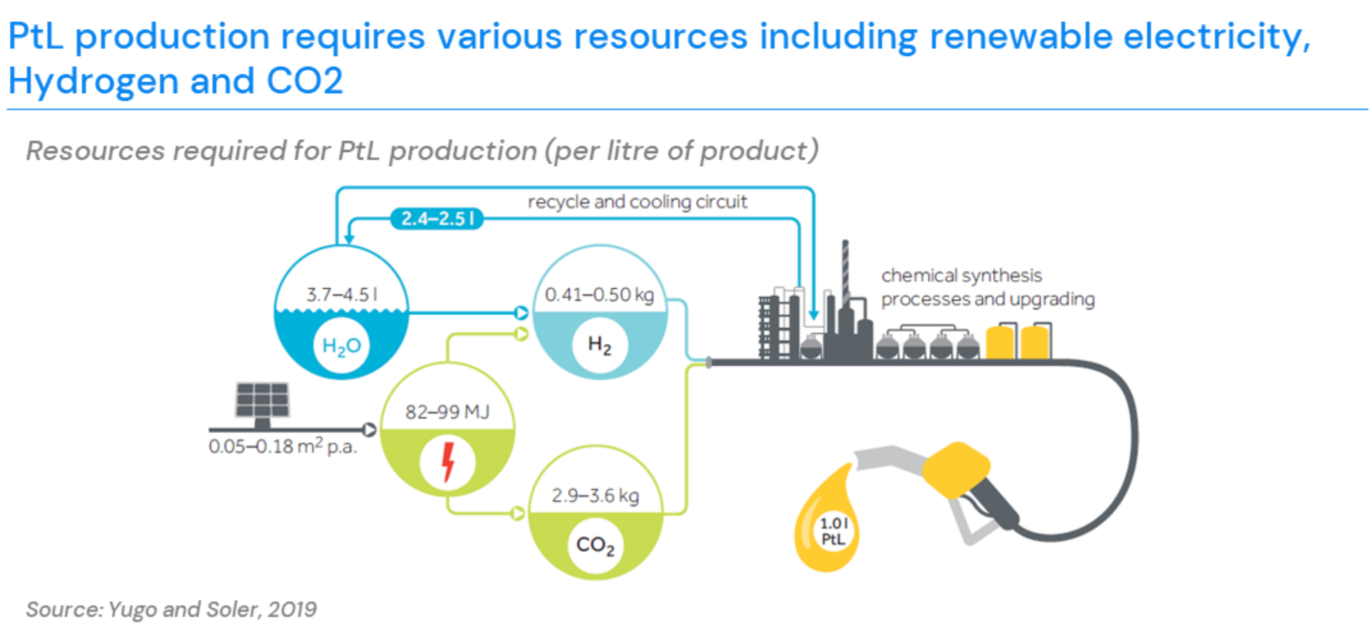
The PtL technology is still under development, with the reverse water gas shift (rWGS) reaction to convert CO_2 into CO still at a lower technology readiness level. The fully integrated pathway has yet to be demonstrated. Several of PtL facilities have been announced, mainly in Europe, but the speed of commercialization will need to accelerate substantially to for final investment decisions (FID) to be reached for these projects.

The limited availability of biogenic feedstocks in Israel will necessitate an accelerated adoption of PtL. which benefits from theoretically unlimited resources. PtL production in Israel can take advantage of relatively favorable conditions for solar renewable energy as a key input for the 'green' hydrogen needed for the process. Alternatively, Israel's substantial natural gas resources can be used to make 'blue' hydrogen by capturing and storing the CO_2 produced when extracting hydrogen from natural gas via reforming. Israel has low electricity prices and a strong environment for academic research and industry-driven innovation supported by the Israeli government. Innovative technologies have been developed in the fields of electrolysis, as well as hydrogen production and supply, and can contribute to the development of a PtL value chain in the country.

Resources required for PtL production

The following figure illustrates the various inputs required for PtL production based on individual technologies for electrolysis or carbon capture.[27] The availability of these resources within Israel is assessed and specific considerations are highlighted.

Figure 12: PtL SAF feedstock requirements



Utilizing the resource requirements for PtL production the following table outlines the resource requirements per ton of product.

Table 4: Resources required for PtL production per tonne of product

Input	Low	High
CO_2 (kg)	3,606	4,477
Solar PV energy (GWh)	0.03	0.03

[27] https://www.concawe.eu/wp-content/uploads/E-fuels-article.pdf

Hydrogen (kg)	510	621
Water (litres)	4,601	5,597

Sources of CO_2 for PtL production and availability in Israel

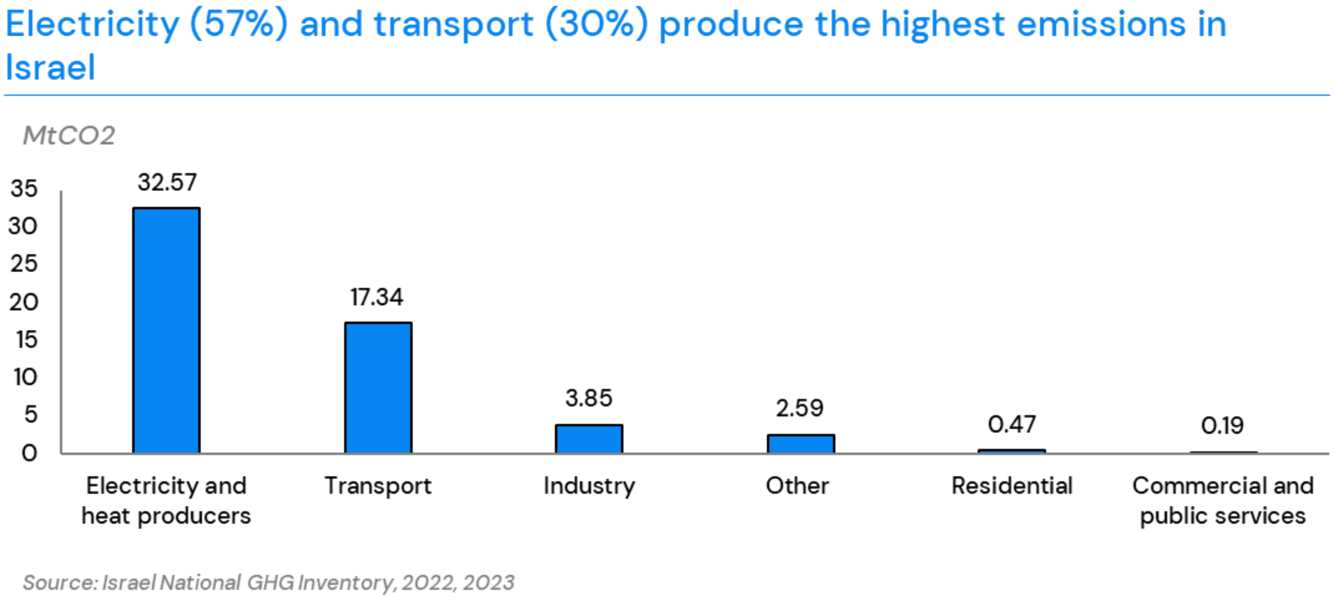
Any source of CO_2 can potentially be used to produce PtL, including CO_2 captured directly from the air, CO_2 from industrial sources, and CO_2 from biogenic sources. Capture of CO_2 from point sources has a high concentration of CO_2 which makes it more economical than direct air capture, even though the latter is preferred from a sustainability perspective. Point sources of CO_2 can be divided into industrial sources and biogenic sources. Examples of biogenic CO_2 emissions include: (1) CO_2 from the combustion of biogas collected from biological decomposition of waste in landfills, wastewater treatment, or manure management processes, (2) CO_2 from combustion of the biological fraction of municipal solid waste or biosolids, and (3) CO_2 derived from combustion of biological material, including forest-derived and agriculture-derived feedstocks. Biogenic CO_2 sources are preferential for the production of PtL as the carbon emitted is from renewable sources.

CO_2 from industrial sources are further divided into unavoidable emissions and other industrial sources. CO_2 from industries such as steelmaking and cement production are considered unavoidable and using these sources of CO_2 to support PtL production will be suitable. CO_2 from sources such as electricity from fossil fuels is considered unfavorable as it is often perceived as perpetuating the use of fossil fuels in the industry.

The relevant EU Regulation on Renewable Fuels from Non-Biological Origin (RFNBO) specifies the types of CO_2 that can be used for PtL production. CO_2 captured from fossil-based power stations counts as zero emissions until 2036, and CO_2 from all other fossil industrial sources until 2041. After 2041, PtL SAF producers will need to source CO_2 from direct air capture or biomass combustion, although this is not applicable in the UK. EU and UK legislation will be relevant for any PtL producers in Israel who want to export their products to these jurisdictions, but different policies may be implemented in Israel. The CO_2 emissions in Israel from all sectors are shown below, with the greatest emissions coming from electricity and heat producers (57%), and transport (30%).[28]

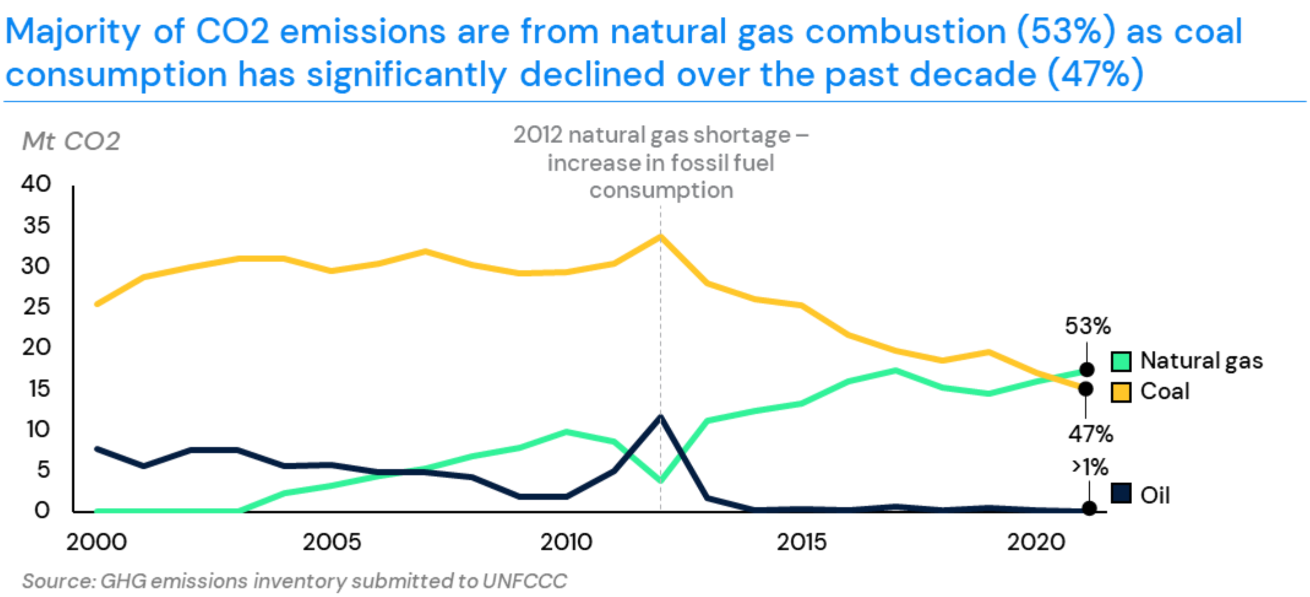
[28] https://unfccc.int/documents/633031

Figure 13: GHG emissions by industry



The majority of CO_2 emissions from power generation come from natural gas combustion, as coal electricity has declined. Coal-generated power accounted for only 22% of Israel's power in 2022 compared with 61% in 2012.

Figure 14: Israel's GHG emissions, historical change



The following sources of CO2, provide the highest opportunity for PtL production in Israel.

Table 5: Available CO_2 sources (2022)

Source	Quantity Available (Million Tonnes CO_2)
Direct air capture (DAC)	Unlimited
Energy industry	32.5
Manufacturing and construction industries	5.8
Cement production	1.8

Approximately 41 million tons of CO_2 are available as concentrated CO_2, with over 80% of this amount emitted by the energy industry. Based on this analysis, between 6.1 and 7.6 million tons of CO_2 will be required to produce sufficient PtL SAF to meet demand.

Electricity demand for PtL production and availability of renewable electricity in Israel

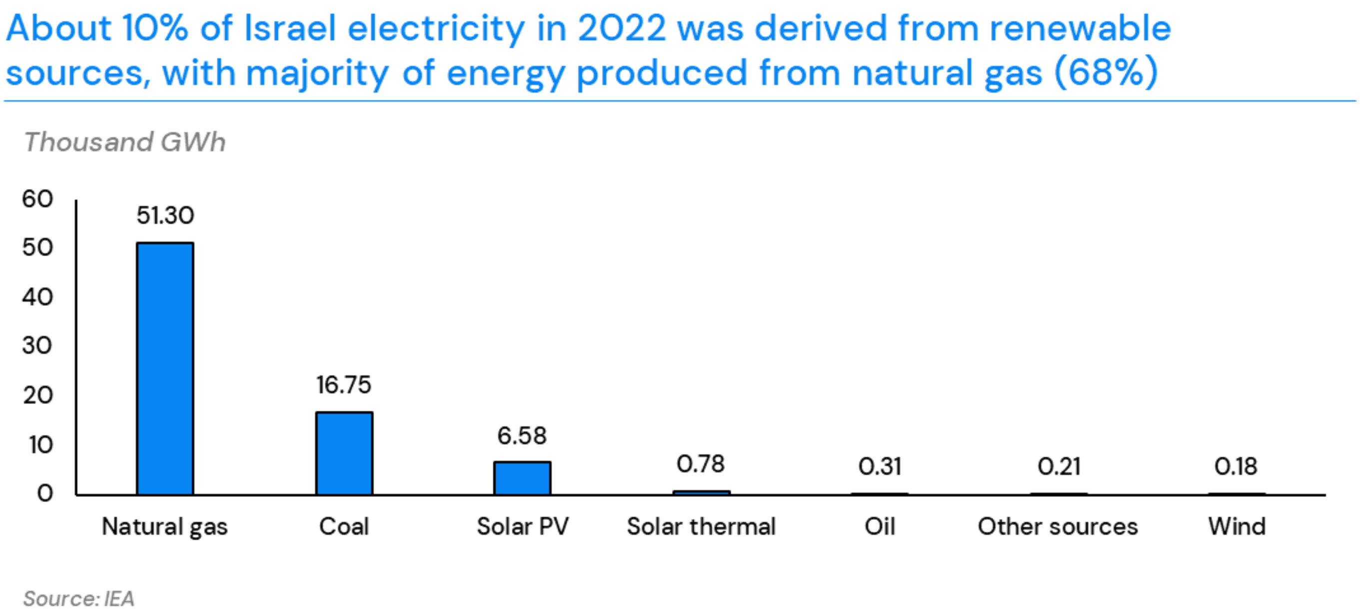
The projected population growth in Israel will contribute to a doubling of electricity demand by 2040 (International Trade Administration, 2023). The overall installed capacity of electricity in 2021 was 21.5 GW, with the Israel Electric Corporation (IEC) accounting for 61% of production, and independent power producers accounting for the remainder. According to the Electricity Authority, installed capacity in 2025 should reach 27.9 GW to meet the electricity consumption forecasts.[29]

Israel has gradually shifted from generating power from coal which accounted for only 21.8% of Israel's power in 2022 compared to 61% in 2012. The Israeli Ministry of Energy has set a goal of entirely displacing coal-generated electricity, with renewables supplying 30% and natural gas 70% of electricity in 2030.[30] As seen in the figure below, only about 10% of Israel's electricity in 2022 was derived from renewable sources, with solar photovoltaic (PV) forming the bulk, followed by solar thermal and wind.

[29] https://www.trade.gov/country-commercial-guides/israel-energy#:~:text=According%20to%20the%20Electricity%20Authority,years%20(2018%2D2026).

[30] https://www.trade.gov/country-commercial-guides/israel-energy#:~:text=According%20to%20the%20Electricity%20Authority,years%20(2018%2D2026).

Figure 15: Israel's electricity supply routes



The majority of the renewable electricity the Israeli government aims to produce by 2030 is based on solar energy. To meet the goal of 30% electricity generation from renewables, 25-28 TWh of renewable energy is required in 2030, with an additional 17-20 TWh based on current production levels.

Israel's renewable electricity industry and future projections

The current sources of renewable electricity in Israel are mostly solar PV (87%), solar thermal (10%) and wind (3%). Increasing renewable electricity is an important target for the Israeli government based on commitments under the Paris Agreement and an initial target of 30% renewables by 2030. Israel currently has both thermo-solar and photovoltaic solar commercial facilities with a capacity of over 500 MW, with facilities totalling over 250 MW of capacity under construction. Wind energy plays a smaller role in Israel and currently only makes up 3% of total renewable energy in Israel with four operational onshore wind farms providing 325 MW of capacity.[31] The potential for expansion of both onshore and offshore wind power would need to be evaluated based on more extensive data. In 2022, solar generated 7.4 TWh of electricity, an increase of 2 TWh from 2021, with wind generating 0.17 TWh.[32]

Table 6: Wind power facilities in Israel

Facility	Energy Capacity (MW)	Turbines
Emek Habacha	109	34
Genesis Spirit	189	39
Gilboa	11.9	14
Golan Heights	6	10
Sirin I	9.35	11

[31] https://www.thewindpower.net/country_windfarms_en_60_israel.php
[32] https://www.iea.org/countries/israel/electricity

Other forms of renewable electricity are also available but provide a lesser extent of power generation. Tidal power has potential for Israel, but further data is needed to carry out an analysis. The first wave energy project in Israel started sending electricity into the Israeli National Electrical Grid in 2023. The project, located in the Port of Jaffa, has a 100 kW installed capacity and was developed by Swedish-Israeli wave energy developer, Eco Wave Power.[33] Two hydroelectric facilities are operational in Israel, Ma'ale Gilboa (300 MW, operating) and Kokhav Ha'Yarden (344 MW, operating), with the Manara Cliff facility (156 MW) under construction. All three facilities are pumped hydroelectric and generated 20 GWh of electricity in 2022.

Meeting the government commitment of 30% renewable electricity by 2030 will require a substantial rollout of additional renewable electricity capacity. Electricity demand for PtL production must be considered in addition to the renewable electricity target of the government. PtL production will require additional renewable energy capacity. Based on the targeted volumes of SAF for 2040 and 2050, PtL production will require additional renewable electricity output of 11 to 13 TWh in 2040 and 56 to 68 TWh in 2050. Israel's renewable electricity sector is predominantly powered by solar PV technology. To meet the country's ambitious target of 30% renewable electricity by 2030, significant expansion of solar PV capacity is necessary. Based on a 20% capacity factor, an additional 11 GW of solar PV installations will be required, necessitating between 109 and 547 km^2 of land area. However, the actual land requirements may vary, particularly when solar PV is integrated into existing buildings and infrastructure.

Solar PV expansion and land scarcity

A major challenge for the expansion of renewable electricity is Israel's acute scarcity of land and various land use designations.[34] Several studies have investigated the land requirements for the expansion of solar PV. Effective solar radiation distribution illustrates substantial radiation in the south, but actual suitability must be calculated based on a variety of criteria.[35] When examining the potential expansion of solar PV for integration into the existing electrical grid, its adverse effect on the stability of the system, its reliability and quality of supply must be taken into account.[36]

A study conducted on Israel's site suitability for solar PV highlighted that grid and land saturation are major concerns for large-scale PV integration and several regions across the country have already reached their maximum hosting capacity capabilities, while others have very limited capacity reserves.[37] An estimated 1.2% of land area in Israel is suitable for medium voltage, ground-mounted, PV installations, based on specifically selected criteria covering various techno-economic, environmental and electrical factors. The study further outlined an estimated availability of about 29 GWh based on medium, high and very high suitable land areas. It should be noted that grid integration potential is an important factor in these studies and that further capacity may be available when evaluating the potential for off-grid solar PV potential solely for PtL production. Another study estimated that 1,129 km^2 of open land area will be required for solar PV to meet future renewable electricity

[33] https://www.offshore-energy.biz/eco-wave-powers-significant-milestones-keep-optimism-for-future-energy-project-opportunities-alive/
[34] https://ideas.repec.org/a/eee/renene/v205y2023icp105-124.html
[35] https://ideas.repec.org/a/eee/renene/v205y2023icp105-124.html
[36] https://cris.bgu.ac.il/en/publications/methodology-for-estimating-the-potential-of-ground-mounted-solar-
[37] https://ideas.repec.org/a/eee/renene/v205y2023icp105-124.html

demand. Where 1,286 km^2 is based on agriphotovoltaic (APV) solar rather than open land, 72 GWh of power can be available with only 158 km^2 of open land for solar PV.[38]

For this analysis, ICF indicates that for PtL production to meet SAF demand by 2050 additional renewable electricity capacity (based on solar PV) of 27 to 33 GW will be required, with an estimated land area between 275 to 1,660 km^2, depending on the specific energy requirements of the PtL technology, the efficiency of the module and the efficiency of the module to the system (assuming 10 to 50 km^2/GWh).

Off-grid renewable electricity installations and potential storage

With renewable energy generation predominantly based on solar PV, intermittency remains a challenge and storage capacity will be required in the case of isolated grids to provide a stable electricity supply. The two predominant, and most advanced, technologies are pumped hydroelectric storage and batteries.[39] The Israel Hydrogen Strategy report supports the potential role of hydrogen as a form of energy storage for renewable energy.[40] The first micro-grid power pilot project in Israel is currently under construction and will allow the formation of energy islands across Israel.[41] While this is not connected with SAF production, experience from this pilot could inform the broader challenge of dealing with off-grid power.

Hydrogen sources

Hydrogen sources are broadly categorized as grey hydrogen (from natural gas), blue hydrogen (from natural with combined with carbon capture and storage), and green hydrogen (from electrolysis of water based on renewable electricity) with green hydrogen being the most sustainable followed by blue hydrogen. From a PtL perspective, green hydrogen is the preferred source as it can provide the lowest carbon intensity fuels.

The Israel Ministry of Energy and Infrastructure released the Israel Hydrogen Strategy in 2023 to outline a roadmap for the role of hydrogen in Israel's energy sector into the future. While electrofuels are not mentioned, the government strategy to advance hydrogen in the energy sector provides important insights into the broader role of hydrogen and must be integrated with potential PtL production. A key strategy outlined in the roadmap is the investment in research, development and demonstration of hydrogen technologies and investment in solutions that will address critical challenges such as high costs, logistics and security difficulties and the efficiency of the hydrogen production, storage and use cycle.[42]

The report estimates a demand of 382,000 to 442,000 tons of hydrogen for the aviation and maritime sectors for hydrogen-based derivatives while recognizing that import of hydrogen derivatives may be necessary. The roadmap also acknowledges that blue hydrogen, based on natural gas and carbon capture and storage, is preferable. Importantly however carbon capture is not mature enough at this stage and using natural gas directly may be more more efficient.

[38] https://www.sciencedirect.com/science/article/abs/pii/S030626192300689X?via%3Dihub
[39] https://www.sciencedirect.com/science/article/abs/pii/S030626192300689X?via%3Dihub
[40] https://www.gov.il/BlobFolder/news/news-150523-2/en/israel-hydrogen-strategy-english.pdf
[41] https://www.reuters.com/world/middle-east/how-energy-islands-could-help-israel-build-resilience-wartime-2024-07-18/
[42] https://www.gov.il/BlobFolder/news/news-150523-2/en/israel-hydrogen-strategy-english.pdf

As a commodity, hydrogen is extensively used in petroleum refining to upgrade crude oil into transportation fuels. At the same time, hydrogen can also be used directly in hydrogen vehicles or fuel cells. Hydrogen is also seen as a viable commodity for export to the EU where dedicated PtL targets have been mandated under the ReFuel EU Aviation policies. PtL production will therefore be competing with these uses of hydrogen. Bazan, one of two petroleum refiners in Israel, is pursuing hydrogen as a direct fuel for vehicles and Israel's first hydrogen fuel station opened in May 2023 at Kibbutz Yagur.[43]

Other companies, such as H2Pro, are advancing hydrogen production through new electrolyzer design technologies. H2Pro is also involved in an initiative for a green hydrogen hub in the south of Israel with Doral and Eilat-Eilot Renewable Energy, and the hydrogen is intended for industrial and transport applications. Further academic research in the hydrogen sector is ongoing and multiple start-ups in this space have been formed in the last five years.[44] Regardless of the electrolyzer technology or the application of hydrogen, the limiting factor in 'green' hydrogen production will be the availability of renewable electricity.

Based on the analysis in this report, an estimated 1,012 to 1,234 thousand tons of hydrogen will be required to produce the estimated PtL SAF volumes by 2050. The main limitation of green hydrogen production will be the availability of renewable electricity. Blue hydrogen is potentially unlimited, provided that infrastructure is put in place for CO_2 capture and storage. However, green hydrogen will deliver lower carbon intensity SAF and is considered more sustainable.

Water demand for green hydrogen production and water scarcity in Israel

Water scarcity is an ongoing challenge in Israel and about 50% of Israel's potable water is produced via five desalination plants. These are listed below, indicating total capacity and project costs[45]. Wastewater treatment is also carried out, but treated wastewater is primarily used for irrigation in the agricultural sector.

Table 7: Desalination plants in Israel

Project	Capacity (Cubic meters per year)	Cost ($USD)
Sorek	150,000,000	$400 Million
Hadera	127,000,000	$292 Million
Ashkelon	118,000,000	$212 Million
Ashdod	100,000,000	$390 Million
Palmachim	90,000,000	$180-200 Million (estimated)

An in-depth study on future water demand in Israel projected total water demand between 3.8 and 6.2 billion cubic meters by 2065, from 2.4 billion cubic meters in 2020.46 The majority of this water will be derived through desalination. Current desalination capacity is 0.585 billion cubic meters and 1.9 – 3.75 billion cubic meters will be required by 2065, depending on population growth. Based on a capacity of 100 million cubic meters, 19 to 37 new desalination plants will be required by 2065. As the population expands, the availability of wastewater

[43] https://www2.deloitte.com/content/dam/Deloitte/il/Documents/finance/Hydrogen-Sector-report-V2%20.pdf
[44] https://www2.deloitte.com/content/dam/Deloitte/il/Documents/finance/Hydrogen-Sector-report-V2%20.pdf
[45] https://water.fanack.com/israel/water-infrastructure-in-israel/
[46] https://www.nature.com/articles/s41545-022-00215-9

will also increase and the projection for treated wastewater will increase from 0.5 billion cubic meters to between 0.9 and 1.5 billion cubic meters by 2065.[47] While treated wastewater is primarily used in the agricultural sector, the study indicates that the treated wastewater volumes will be more than the sector's requirements.

Power-to-liquid production requires about 3.7 to 4.5 litres of water per litre of e-fuel produced. Where direct air capture is used to source CO_2, water can simultaneously be captured from the air to provide the input water for green hydrogen production. However, where point-source capture is used, an existing water supply will be needed. Due to the scarcity of water in Israel, water demand and supply must be considered in choosing sites for PtL production and the source of water. It is unlikely that existing freshwater sources will be considered suitable for PtL production.

Alternatively, a PtL plant could source desalinated water or water from wastewater treatment facilities rather than fresh water. Depending on the volume of water required, PtL facilities might have to invest in their own desalination capacity which would increase the investment cost of the PtL plant. Treated wastewater is currently used for agricultural purposes in Israel and diversion of this water to PtL production will need to be evaluated thoroughly. Wastewater is not treated to drinking water quality, still has a high salt content and may need further treatment.[48] A PtL plant will likely have to invest in further water treatment infrastructure to get a suitable quality of water for hydrogen production.

Population growth is expected to place additional demand on Israel's water supply and increased desalination capacity will be required to fulfil water demand by 2050.[49] Desalination requires high pressures and therefore has a high energy demand. About 3 to 3.5 kWh is required to desalinate one cubic meter of seawater.[50] This excludes the energy for pumping desalinated water to distant locations. Where PtL plants are using desalinated water, the energy demand for desalination should ideally be derived from renewable sources. Even so, it will likely place an additional demand on resources. This excludes the energy for pumping desalinated water to distant locations. Under high population growth estimates, Israel will need an additional 11 TWh per year, or 15% of current electricity generation to expand desalination capacity.

Based on the projected demand for PtL volumes required by 2050, 7.8 to 9.5 million cubic meters of water will be required. If desalination is used to produce this water, about 0.03 GWh of electricity will be required for desalination. Water demand is therefore not considered a limiting factor for PtL production and accessing water will not place an undue burden on water supply. As indicated, excess treated wastewater, superfluous to agriculture water demand, will be available by 2050 and could be diverted towards PtL production.

[47] https://www.nature.com/articles/s41545-022-00215-9
[48] https://www.nature.com/articles/s41545-022-00215-9
[49] https://www.researchgate.net/publication/366606246_Effects_of_population_growth_on_Israel's_demand_for_desalinated_water
[50] https://www.nature.com/articles/s41545-022-00215-9

Photo by Haley Black

5 Deployment Roadmap

5.1 Opportunity summary

The development of a domestic SAF industry offers the potential to grow the Israeli economy, diversify the energy supply, and meet the national ambitions for aviation decarbonisation. While the country brings multiple strengths, the opportunity set is constrained by the limited domestic feedstock availability. A carefully targeted approach to deployment will be crucial to ensure success.

The most immediate opportunity is to mature the waste lipid supply chain and investigate opportunities for co-processing in one of the domestic refineries. While this offers a relatively limited scaling potential, it requires very limited additional infrastructure investment, provides valuable opportunities to develop systems to track the life-cycle emissions reduction and other 'soft' infrastructure, and contributes to emission reductions today.

The feedstock analysis highlights municipal waste as a key opportunity. This can be directly gasified, although anaerobic digestion to methane followed by gas-to-liquid conversion may be more suitable for the Israel context. This approach would consist of centralizing the methane collected from landfills (either physically or virtually through a book-and-claim system) and using a gas-to-liquid facility to convert this to paraffin wax for further refinement into jet fuel. This approach is particularly suitable for Israel given the numerous landfills, developing methane collection systems, and the fossil natural gas industry, which provides a backup fuel to ensure consistent volumes and quality of feedstock. This approach effectively represents the conversion of a widely available domestic fuel (natural gas) into jet fuel, which is currently all imported.

Other pathways, such as CO_2 fermentation into ethanol, followed by AtJ, may also be valuable to explore in more detail. These opportunities can kick-start the Israeli SAF industry but will only be able to meet a fraction of jet fuel demand.

In the longer term, meaningful decisions will need to be made between scaling domestic PtL production, importing SAF or feedstocks, or alternatives such as carbon capture, with a blend of all options likely to be the most feasible. This analysis has presented analysis on each of these options and recommends the initial strategy diversifies between the options to reserve an ability to react and exploit beneficial developments in technologies and markets as they occur.

The expertise innovation, research and industry position Israel to be a potential leader and beneficiary from the development of this global industry, and building governmental momentum provides a unique opportunity to reap the benefits of a domestic market while using it as a springboard for technologies and exports that will be in demand globally.

5.2 Israel SAF Industry Deployment

Based on the analysis in this study, projections for SAF demand were developed, indicating that substantial volumes of SAF will be required in Israel. SAF consumption in Israel could be based on imports of SAF, the development of a domestic SAF industry, or a combination of the two approaches. Basing a decarbonisation goal in the aviation sector on SAF imports will encounter a substantial obstacle, namely the lack of SAF availability on a global scale. In June 2024, IATA projected that SAF production in 2024 will reach 1.5 million tonnes, amounting to 0.53% of jet fuel demand in 2024. While an estimated 22 million tonnes of supply have been announced by 2030, as seen in Figure 16, the majority of the supply will be required to meet the announced 1.5 demand within those regions. In the near term, many airlines have set voluntary targets of 10% SAF blends by 2030, while various regulatory frameworks have set similar targets, e.g. the UK, Canada, Japan, and the U.S., and the EU set a target of 6% SAF by 2030. From the perspective of airlines, over 50 billion litres of SAF are under offtake agreements, illustrating the high demand for SAF on a global basis. Airlines are investing in SAF producers to secure long-term supply, while heavy penalties for non-compliance with the ReFuelEU blending mandates will divert SAF to the EU. Therefore, limited SAF volumes are expected to be available in the market in the near term. SAF supply may potentially be secured through the signing of offtake agreements with potential SAF producers.

Figure 16: Global SAF production by region

Building a domestic SAF industry will likely be essential to meet future climate targets. Very limited domestic sources of UCO and tallow for the production of HEFA are available based on this analysis. As this is the only fully commercial technology, the speed at which domestic SAF production based on available feedstocks can be established will be constrained by the commercialisation of other technologies such as AtJ, gasification with FT, etc. Based on this analysis, the greatest opportunity from biogenic feedstocks lies in the valorisation of MSW through technology such as gasification and FT. However, the expected commercialisation of this technology is delayed. That, combined with the high investment cost and long construction phase, means that it is unlikely that a gasification and FT facility based on MSW could be established in Israel before 2030. Several technology providers for this technology are engaged in commercialisation, and once technical challenges have been addressed, it is expected that these technologies could be readily licensed.

MSW gasification could also be used to produce methanol for conversion via the AtJ pathway. However, similar technical challenges on the gasification side will delay the full commercial rollout of this pathway. The company Enerkem operated an MSW gasification to methanol demonstration-scale facility in Canada and is currently constructing a large commercial-scale facility for methanol production from the gasification of forest residues. Several technology providers are commercialising the methanol-to-jet process, and this route is very close to ASTM certification, with the technology readily available for licensing. Methanol in itself is further considered one of the most promising biofuels for decarbonising the shipping sector. Methanol can also be produced at dispersed locations with the methanol aggregated to support large-scale methanol-to-jet production.

Limited agricultural residues are available, but the small volumes available could potentially be used to produce cellulosic ethanol through a biochemical process and the ethanol can be converted to SAF through AtJ. However, cellulosic ethanol production is not commercial and there are few large-scale operating facilities.

Ethanol production through gas fermentation may be more viable in Israel, e.g. the LanzaTech process. Off-gases from industrial sources can be used in this pathway which makes it very sustainable. Many facilities based on this gas fermentation technology are in various stages of planning, but successful demonstration of this technology is essential. Once this technology has been commercialised, multiple sources of industrial emissions could be utilised for ethanol production. Ethanol production can take place at multiple locations with a central and large-scale AtJ facility converting this to SAF.

As an alternative to producing ethanol on a domestic basis, this intermediate could be imported to support a domestic SAF production facility. However, global production of ethanol is predominantly crop-based with corn and sugarcane being the main feedstocks. About 150 billion litres of first-generation ethanol are produced globally and this is seen as an opportunity for establishing AtJ SAF facilities. Ethanol has been serving as a blendstock for gasoline and demand for gasoline is expected to decline as electric vehicles become more prevalent. Ethanol is chemically identical, regardless of the feedstock used for its production. Thus, an AtJ facility can be established based on first-generation ethanol and later replaced with advanced ethanol.

In the long term, the lack of biogenic feedstock availability in Israel will focus domestic production efforts on PtL SAF. This technology presents the best opportunity to deliver on Israel's net zero ambitions for aviation. However, as mentioned earlier, the technology is not at commercial scale. Production cost estimates show that PtL will be much more expensive to produce than many other SAF technologies. However, the ReFuelEU dedicated blending mandate for PtL is driving the commercialisation of this technology as fuel suppliers will have to pay substantial penalties if they are unable to meet these blending mandates. The high production costs and the high risk associated with a still unproven, integrated technology pathway have hampered the ability of PtL companies to reach a final investment decision. Arcadia eFuels reached the FID stage earlier in 2024, but other planned facilities are still trying to finalise investments, with the HySkies project in Sweden stalled after Shell pulled out. Thus, it will still take many years for PtL to become commercial, while the higher production costs may remain a barrier to airlines unless a policy such as a dedicated blending target is in place for PtL.

In the long term, the production cost of PtL is expected to rapidly decrease as the cost of renewable electricity comes down. Israel has substantial sources of CO_2 for PtL production and CO_2 capture technology is near commercial status. The challenge in Israel will be to expand renewable electricity production to meet government targets while also supplying sufficient renewable electricity for PtL production. About 10% of Israel's electricity supply is currently derived from renewable sources, and the government has set a target for 30% renewable electricity supply by 2030. While further renewable electricity targets to 2050 have not been announced, the government report to the UNFCCC indicated that Israel aims to reduce CO_2 emissions by 85% by 2050. As the greatest volume of CO_2 emissions result from energy production, expanded targets for renewable electricity supply in Israel will contribute to a reduction in CO_2 emissions, unless CO_2 capture, storage and utilisation is employed at existing power plants. Direct decarbonisation of the electricity supply is considered more efficient than using electricity for the production of PtL, and electricity for PtL should ideally be additional.

As described in the report, the bulk of renewable electricity is currently derived from solar PV while other forms of renewable energy play a smaller role. However, limited land availability may be a challenge for the extensive expansion of solar PV. Supplying renewable electricity to the grid has different constraints and desert areas with high solar radiance could be utilised for off-grid solar PV to produce PtL, although there is not sufficient information on the maximum scope for solar PV in these areas. Besides solar PV, renewable energy technologies such as offshore wind, which do not require land, could be investigated. The main purpose of renewable electricity in the PtL process is to produce hydrogen. If sufficient renewable electricity cannot be deployed for PtL, Israel could potentially import hydrogen for domestic PtL production based on local CO_2 capture. This is the approach taken by Germany as they are investing heavily in wind farms in other countries for the production of hydrogen which is then shipped to Germany for PtL production. Alternatively, Israel could rely on imports of PtL SAF to meet all or some of the projected SAF demand, provided that significant commercial volumes are available on a global level. However, this may encounter challenges such as slow commercialisation, high cost, and high demand in other regions such as the EU. Israel will have a greater opportunity to meet SAF targets through establishing domestic production capacity while this will also enhance energy security and reduce imports of crude oil for fuel production.

5.3 Supporting policies

Building a domestic SAF industry in Israel presents some unique challenges that must be addressed, and supporting policies will be critical. The rapid increase in SAF production over the past few years and the announcement of over 150 planned SAF facilities are a direct result of policies that were introduced in the U.S., EU, with additional policies implemented in the UK, British Columbia, etc.

While the EU has taken a demand-side approach by creating blending mandates imposed on fuel suppliers, the U.S. has taken a supply-side approach by providing for fixed-cost financial incentives in the form of tax credits, combined with policies that allow earning of credits with fluctuating value under the Renewable Fuel Standard or low carbon fuel standards.

Demand-side policies create a structural demand for SAF and provide security for investors as market access is guaranteed, provided that the blending mandates are put in place for at least the lifetime of a project, e.g. 20 years. Blending mandates also create a level playing field for airlines as they all must access the same fuel supply and competition is reduced. Mandates will initially favour technologies that are already at commercial scale and do not address the supply side that supports the commercialisation of technologies.

Supply side policies assist technologies to go from lower TRL levels to support construction of demonstration and pioneer facilities. Initial production costs of fuels for pioneer facilities are substantially higher compared to production facilities where the technology has been optimised. Policies such as loan guarantees and grants are therefore used as financial mechanisms to support the commercialisation of technologies.

In Israel, substantial support is provided for the development of technologies at the research level and early-stage development up to TRL level 6, but policies that support further development for demonstration and pioneer facilities are not in place. The existing policies supports innovative technology development and some of the projects include, for example, novel electrolyser technology (H2Pro), but little support seems available for integrated SAF production processes. At demonstration and small commercial scale, financial policy mechanisms such as grants, and loan guarantees are successfully employed in other countries.

Despite the strong demand signal from the ReFuelEU Aviation mandates, SAF producers in Europe have indicated that this is not sufficient to overcome some of the other critical challenges for developing SAF. Apart from HEFA, other technology pathways present a high risk that is delaying the progress to final investment decisions. The high-cost difference between SAF and conventional jet fuel is a challenge for the financial viability of projects. Policies that can support bridging this price gap may be essential at first. Biofuel producers have indicated that firm offtake agreements from airlines are critical to reach final investment decisions for construction of facilities. Although airlines have signed offtake agreements amounting to over 50 billion litres of future SAF production, the vast majority of these agreements are merely MoUs rather than agreements guaranteeing future offtake with a price point and therefore has limited impact for biofuel producers. Airlines operate in a very competitive environment with low profit margins, while jet fuel cost can be 30% of operational costs. In this environment, an airline that is using SAF will be at a disadvantage as neat SAF costs much more than conventional jet fuel. Bridging this price gap will also assist airlines to afford purchasing SAF while remaining competitive.

The perception of EU policies that support SAF is that it is limited to a blending mandate. However, this is not entirely correct as the impact of the EU Emissions Trading Scheme (ETS) must also be considered as the use of SAF can reduce ETS obligations for airlines and this acts as an indirect incentive. The individual actions of states can also be considered, for example, Germany committed ten billion euros towards development of hydrogen production and the German government is investing in hydrogen supply chains on the East Coast of Canada, Namibia and North Africa. This will be able to directly supply PtL production within Germany and can serve as a model for Israel.

The U.S. policy approach, on the other hand, is viewed as an incentive-based approach, but this does not reflect the bigger picture. Renewable Volume Obligations under the Renewable Fuel Standard act in a similar way to a blending mandate while Renewable Identification Number (RINs) act as a credit to demonstrate compliance with the “mandate” with the flexibility that fuel suppliers may purchase credits in lieu of blending. The RIN credit market acts as an incentive that assists biofuel producers, but these are not government subsidies. Similarly, low carbon fuel standards, by setting compulsory reduction targets for reducing the carbon intensity of various fuel categories, are essentially mandating biofuel blending which can result in such reductions. However, fuel suppliers have the flexibility to choose which fuels they blend, and suppliers may also purchase credits to demonstrate compliance. The credits can therefore act as an incentive for fuel producers as they enhance the value of their biofuel products. Unlike a volumetric blending mandate, the LCFS approach is directly linked to emission reductions and credits consist of a ton of CO_2 reduced per credit. This favours the use of low-carbon intensity fuels.

These examples illustrate the more nuanced complexity of policies that can be used to support SAF production. Some form of financial support mechanism is recommended, and this can be adapted to a policy framework acceptable and suitable for the specific conditions in Israel. A different type of financial support mechanism is used in conjunction with ambitious mandates, namely a revenue certainty mechanism that guarantees a certain price point for SAF. In addition, the UK government has established an Advanced Fuel Fund to support the construction of SAF facilities in the UK.


Photo by Lio Voo

6 Closing Statement

Decarbonizing Israel's aviation industry over the next three decades is a challenging yet achievable goal, given the country's history of innovation and technological advancement. The aviation sector is a significant contributor to Israel's economic growth, impacting GDP and supporting numerous jobs. As global demand for air travel rises, transitioning to sustainable energy sources is essential to mitigate climate change impacts.

Israel's aviation industry has evolved alongside global advancements, marked by technological innovation and strategic growth. As a significant step forward, Israel's Ministry of Energy and Infrastructure published a policy document, establishing an inter-ministerial committee to promote SAF use through incentives and regulatory support, aligning with international standards like those from the International Civil Aviation Organization (ICAO) and the European Union's ReFuelEU initiative. However, Israel has a unique environment that must be considered and therefore a unique policy framework should be developed. In particular, the lack of biological feedstocks will require Israel to use considerable volumes of PtL SAF. A lower but more robust target will enable production to scale using the available resources and balance economic and environmental considerations.

Despite promising developments, Israel faces challenges in scaling up SAF production and integrating it into existing infrastructure. These challenges include securing adequate feedstock supplies, developing cost-effective production methods, and establishing a comprehensive policy framework supporting both demand and supply. Overcoming these obstacles requires continued collaboration between government, industry, and academia to accelerate SAF technology development and deployment.

In conclusion, while decarbonizing Israel's aviation industry is complex, it offers significant potential for innovation, economic growth, and environmental stewardship. By embracing this challenge, Israel can set a precedent for other nations and significantly contribute to global decarbonization efforts


Photo by Kostiantyn Stupak

7 Appendix

Feedstock definitions

Table 8: Feedstock definitions

Feedstock	Definition
Used Cooking Oil (UCO)	UCO is typically collected from households, restaurants, and food processing centres, and refers to oil that has been previously used for cooking, frying, or food production. UCO collection and use are mainly driven by regulation and differ across countries. Collected UCO volumes are limited by food use, collection, and re-use rates.
Animal waste fat (tallows)	Tallows are usually a rendered form of animal fat sourced from livestock (such as cattle, poultry and pigs). Rendering is an essential process to enable sustainable resource management within the meat industry through extracting fat, allowing utilisation of animal resources to be maximised while minimising waste. The availability of animal waste fat is constrained by animal population and the size of the meat industry.
Agricultural residues	Agricultural residues are a by-product of harvesting and processing agricultural crops. Examples of AgW include stalks, husks, straw, cobs and stems
Municipal Solid Waste (MSW)	Municipal solid waste includes all waste items from homes and businesses, such as paper, cards, food, wood and greens, plastics, glass, metals, rubber, and other detritus. Amongst all MSW produced, a fair portion is classified as biogenic waste, which can be utilised for SAF production. Examples of biogenic waste include food, paper, cardboard, wood, and greens.

Technology readiness level (TRL)

Table 10: Technology readiness level descriptions

Technology Readiness Level (TRL)		Description
1	Basic Principles observed and reported	Scientific research begins to be translated into applied research and development.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology
4	Component and/or breadboard validation in a laboratory environment	Basic technological components are integrated to establish they will work better together.
5	Component and/or breadboard validation in a relevant environment	The fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment.
6	System/subsystem model or prototype demonstration in a relevant environment	The representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment.
7	System prototype demonstration in an operational environment	Prototype near or at the planned operations system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype and operational environment (i.e. aircraft of the vehicle)
8	The actual system was completed and qualified through tests and demonstration	Technology has been proven to work in its final form and under expected conditions.

9	Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational tests and evaluation.

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