BRIEF

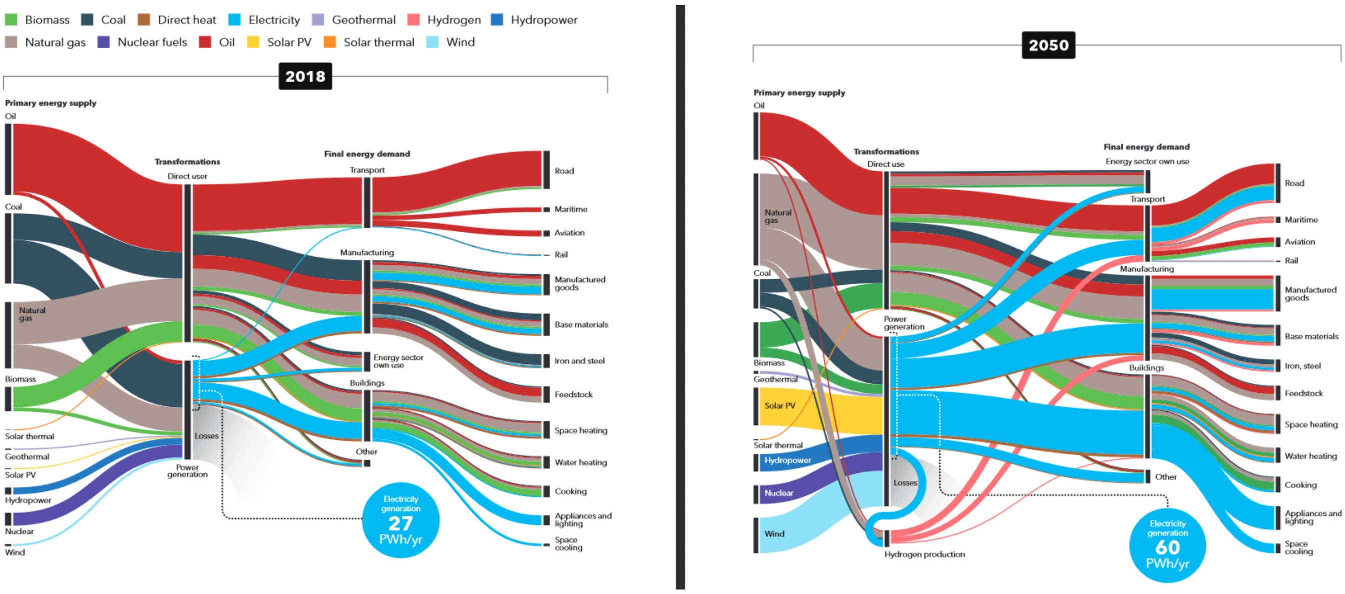
The Energy Transition

System transformation

Introduction

The world is engaged in the necessary but complex endeavor to decouple the global economy from its current, fossil-based energy supply and provide alternative, renewable, energy sources. This is a mammoth task as over 80% of global energy consumption is of fossil origin, illustrating how deeply embedded this form of energy is in nearly every form of human activity (Chart 1). The energy system enables technologies, infrastructures, markets, and institutions, and greases the cogs of production, transport, trade, and development - and these all evolve together. Their interlinkages create feedback loops that make simple, linear solutions fail.

Chart 1: The energy system, 2018 and a potential 2050 scenario



Source: DNVGL, “Energy Transition Outlook 2020”.

The energy system

The energy system consists of:

1. Supply: The core of the system is a primary energy source, such as oil, coal, natural gas, nuclear, wind, and solar.
2. Conversion, storage, and distribution: Infrastructure such as refineries and power plants converts raw energy into useable forms (electricity, fuel). The useable energy must then be distributed via electrical grids, pipelines, etc.
3. Demand: The end-users are all the final energy consumers – for residential, industrial, transportation, and commercial purposes.

Demand cannot be satisfied without the first two parts of the energy system being equipped to do so. That dictates how the energy transition must be tackled – from the energy source first.

Before a refinery can produce renewable fuels, there must first be enough supply of renewable energy. There is an urgent need to scale up solar, wind, biomass. and other renewable energies, as well as the associated infrastructure. In fact, renewable energy availability and affordability are the ultimate binding constraints on renewable fuel production, and hence on the production of sustainable aviation fuels (SAF) for the airline industry.

Before renewable fuel can be used, the physical infrastructure must be equipped to distribute the fuel and this spans power grids, pipelines, ports, storage, etc. This infrastructure serves the whole energy system, and new energy products will compete with other products for access to these services.

The energy system is also impacted by markets, policy, and geopolitics. These forces shape prices, energy flows, and energy security, and interact with physical constraints. Moreover, energy assets are built over long investment cycles that are very capital intensive. Once built, options are locked in, shaping the future solutions for all.

Renewable energy

All industries will require renewable energy in the energy transition. Most notably is perhaps the demand for power by artificial intelligence and the associated data centers. This is having an important impact on demand for electricity of all kinds, stressing grids and pushing electricity prices higher. It is understandable in that context that investments of USD 479 billion were allocated to storage and grids in 2024, according to the International Energy Agency (IEA),[1] and renewable power received USD 780 billion. These dwarfed the investments in low-emission fuels which only attracted USD 40 billion out of a total of USD 2.2 trillion going collectively to the renewable energy space, representing a mere 1.8% of that total.

The IEA also reports USD 1.1 trillion worth of investments in oil, natural gas, and coal in 2024. Lower oil prices and demand expectations could result in a drop in upstream oil investment in 2025, which would be the first year-on-year decline since the covid-19 pandemic and the largest since 2016. Global refinery investment was set to fall to its lowest level in the past 10 years in 2025.

While these trends point in the right direction, they do highlight the need for more renewable energy production and its associated infrastructure because the share of renewable energy in total final energy consumption is still below 20%. To achieve a net-zero CO2 emissions economy in 2050, this share needs to rise to nearly 90%, requiring at least a six-fold increase. Simultaneously, the de-growth in the fossil energy sector is causing transformations in energy markets that require their own responses and needs to be coordinated over the entire energy complex.

Sustainable aviation fuel - SAF

A specific challenge for air transport is that of scaling up the supply of sustainable aviation fuel (SAF). Global production of SAF is limited to 2.4 million tonnes (Mt) in 2026, representing as little as 0.8% of total jet fuel consumption. The amount of SAF required in 2050 for air transport to reach net-zero CO2 emissions is 500 Mt. Clearly, SAF production is not increasing at the necessary pace. If the energy system is poorly understood, it is unlikely that this unfortunate situation will improve.

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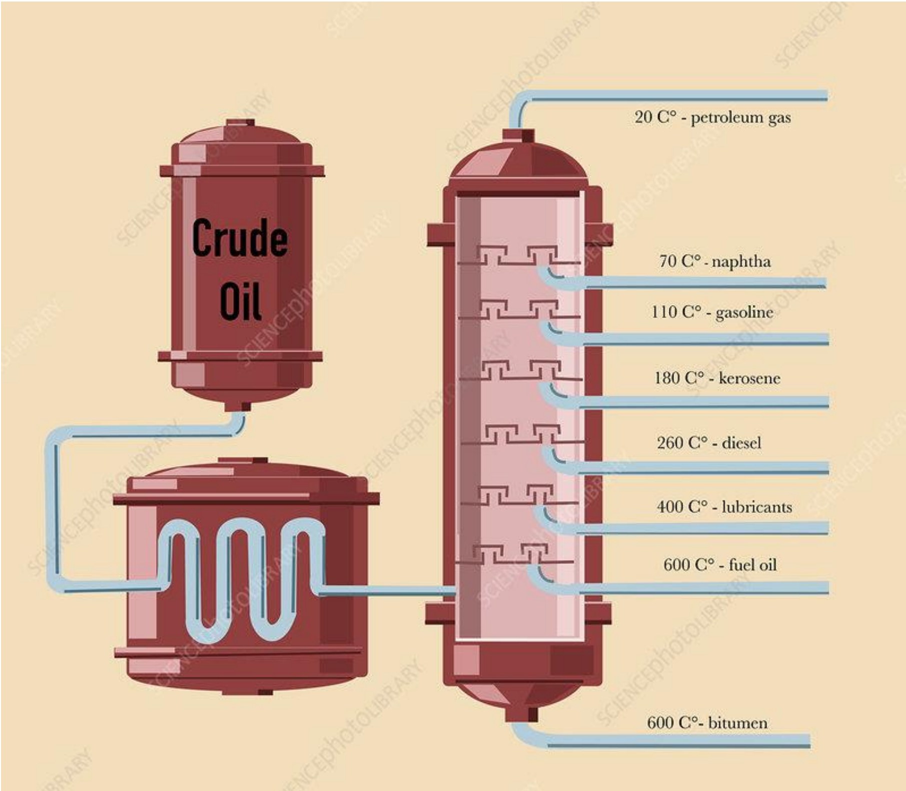
[1] IEA, "World Energy Investment 2025", June 2025.

Regarding the conversion stage of the energy system, fuels such as diesel, heating, and jet kerosene are refined products, and all refineries produce an array of fuels because making just one product would waste molecules and potential revenue (Box 1). This is true also in renewable refineries. It is possible to tweak yields between products, but you cannot make everything land in the jet range. This is a system constraint, not a lack of ambition.

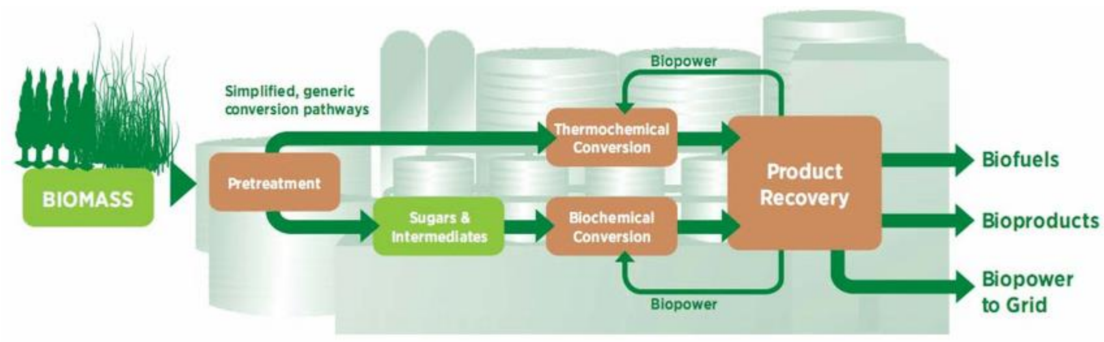
Chart 2: An oil- and a bio-refinery and their output

- A simple oil refinery



Source: Science Photo Library, Spencer Sutton

- A simple bio-refinery

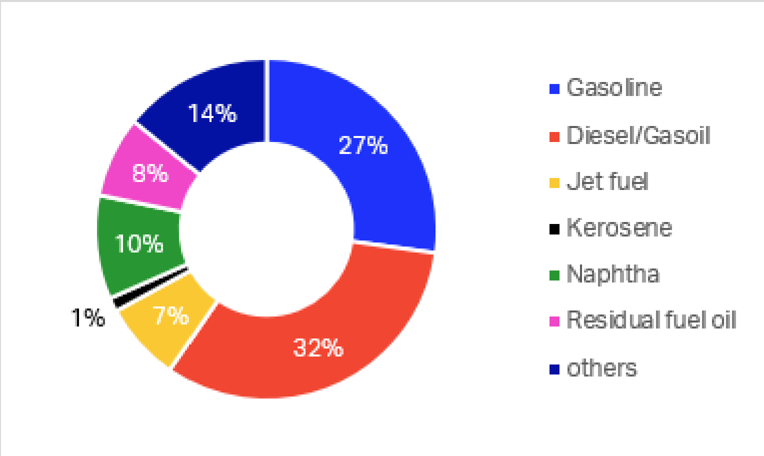


Source: ResearchGate, Adelou Adesoji Adediran

Box 1: The refining process
All refineries must produce multiple products. This is because inputs (crude oil, fatty acids, etc.) are a complex mixture of various hydrocarbons that cannot be used in their raw state for a single purpose. The refining process separates and breaks down the hydrocarbon chain into different, valuable, and usable components based on their physical and chemical properties, such as boiling point (Chart 2). In short, a refinery cannot simply produce just one thing (such as gasoline) because the raw material is inherently a mixture of many, and the market demand for a wide variety of fuels and materials makes producing a diverse product slate necessary for the economic viability of the refinery.

A result of this system constraint can be that progress in one area challenges the viability of another part of the system because each refined product enables – or disables - the other. The rapid growth in electric vehicles is reducing demand for fossil-based diesel. Diesel also competes with liquefied natural gas (LNG, a non-refined product), further curtailing demand. The de-growth in demand for refined products such as diesel and gasoline, which generate most of a refinery's profits, must be managed across the energy system, or the supply of jet fuel (and other products with a low share of total refined output) could be imperiled. Jet fuel's share of total refined output cannot be tweaked enough to make up for the rapid decline in demand for the dominant refined products. Jet fuel makes up less than 10% of global refined output, dwarfed by diesel's and gasoline's dominant shares (Chart 3). This means that rapid scaling up of SAF production would not only help airlines decarbonize but at the same time it would support the energy transition in road transport and provide a strategic safeguard against the risk of a shortage of jet fuel. The relevance of this point is unambiguously demonstrated by the events since 28 February 2026 as the armed conflict in the Middle East escalated. This has caused a sharp increase in the price of brent crude oil and pushed the jet fuel crack spread, i.e., the premium that airlines pay for jet fuel over crude, to historic highs. Much of the price increase relates to the reduced access to shipping lanes, which can produce shortages in oil-importing countries. Clearly, greater local and regional production of SAF and other renewable fuels would have provided alternatives and reduced the impact of the current conflict on energy procurement.

Chart 3: Average global refinery output by product type in 2023



Source: S&P Global Energy Platts

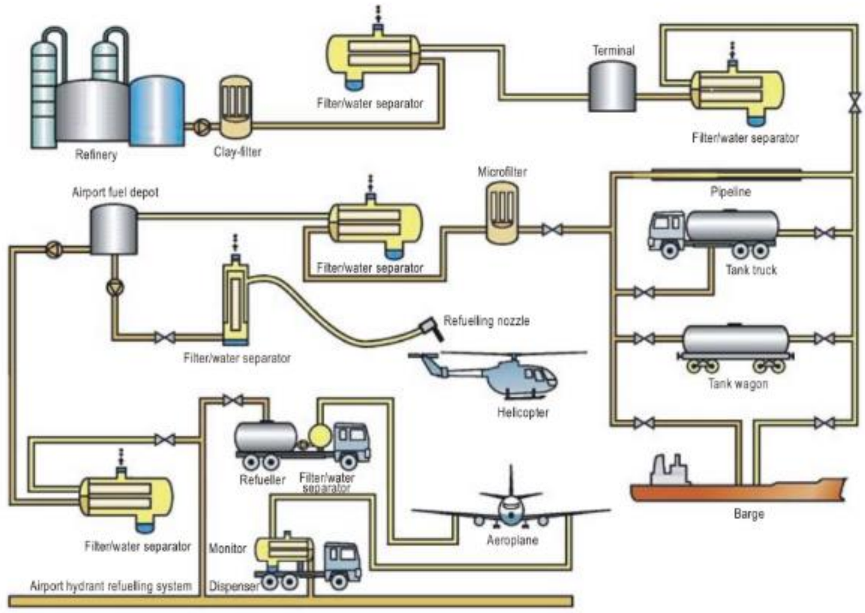
Access to airport fuel infrastructure

Once the SAF has been produced, it must make its way to the airport for uplift in aircraft. Fuel infrastructure serving airports includes pipelines, storage tanks, and hydrant systems and is usually separate from the airport terminal operator (Chart 4). The ownership model of this infrastructure determines the access given to it, and this is as true for fossil-based jet fuel as it is for SAF.[2] Regarding the latter, this issue must be addressed urgently because any investment decision to launch SAF production will require access to fuel infrastructure. There is obviously no point in producing SAF that cannot make it to the aircraft reliably and at a fair price.

A very common form of ownership is a supplier consortium made up of a restricted number of participant owners. This tends to limit access to the infrastructure by suppliers that are not part of the consortium, and make their access to it more expensive, as the consortium can exploit their pricing powers. However, there are also consortia that provide open access, such as Los Angeles International Airport.

Airport authorities can be owners of the fuel infrastructure. This is the case regarding the Port Authority of New York and New Jersey, the Airport Authority Hong Kong, and the Airports Company South Africa. Upstream infrastructure for pipelines feeding the airports can be owned by pipeline operators, energy infrastructure funds, public utilities, and public-private partnerships. Governments can require any type of infrastructure owners to provide access and publish access tariffs, capacity allocation rules, and provide independent oversight. This prevents the formation of fuel monopolies and lowers prices through competition among fuel suppliers. Greater access can also be achieved by ownership unbundling that separates fuel supply companies from infrastructure ownership, reducing conflicts of interest and ensuring equal treatment of suppliers. Open-access infrastructure concessions are also used, where agreements include open-access clauses, the obligation to serve all licensed suppliers, and capacity rules are pre-defined. This is often used in India, Brazil, and the United Arab Emirates, with varying degrees of effectiveness and transparency. Regulators can opt to regulate tariff structures: cap storage fees, regulate hydrant system charges, and approve cost-recovery models, all helping to reduce the risk of excessive access fees.

Chart 4: Illustration of the fuel infrastructure into aircraft



Source: Aviation Stack Exchange

[2] **A case study of the Kingsford Smith Airport in Sydney, Australia, can be found here:** https://www.iata.org/en/publications/economics/reports/competition-in-jet-fuel-infrastructure-and-supply/

High risk, low returns

A potential SAF producer will of course need to know that the SAF can be delivered to the airport fuel infrastructure. There are a number of other forms of risk to consider for the producer: if the feedstock will be available, if there are supply chains in place to bring the feedstock to the production site, the technology risk, whether any SAF policies and regulation will remain in place, if the customers will be able to pay the end price, etc. This adds up to a considerable amount of risk while the returns on SAF projects tend not to exceed 5%. For the airlines, risks are also high. Pricing is opaque in this very nascent market, and policy fragmentation favors the suppliers. Airlines need certainty regarding whether they will be able to claim the environmental benefits against their obligations, and whether the supplier will be able to deliver the SAF, etc. In a high risk – low return market, investments will not scale unless the risk is managed.

It is important to focus on how risk can be transferred across the SAF value chain, instead of it being concentrated on SAF producers and on airlines, both of which tend to be undercapitalized and unable to shoulder these system risks on their own. The notion of de-risking is erroneous. Risk cannot be eliminated. Instead, risk can be transferred, which is the shifting of financial consequences of a risk from one party to another through contracts or financial arrangements. Forms of risk transfer that do exist include insurance, contractual risk transfer (performance guarantees), financial risk transfer (hedging, fixed-price contracts, derivatives), and more. Today, risk-transfer solutions that are capable of spreading risk-taking across the whole SAF value chain do not exist. This curtails project finance and prevents system transformation. Project finance is essential, but without system solutions, the market will not scale. What is needed is a solution that allows diverse risk-takers to each take on a slice of the total risk. In this way, the risk that each part shoulders will be commensurate with the returns on offer. Low risk, low return is a very attractive investment proposition to the world's dominant investor population – that of the institutional investors, such as pension funds and insurance companies.

Of course, the returns could also be boosted. Subsidies (tax credits, etc.) can lift returns on SAF projects to 20% or more, making such projects as attractive as oil projects, and achieving a better relationship between risk and return. This policy has enabled the US to be the world's largest SAF producer. However, it creates a market which is dependent upon the subsidy, and if the policy is revoked, the market viability can vanish. It would be most helpful if the world were to stop, reduce, and redirect the subsidies that currently benefit oil and gas companies. The vast majority of countries in the world provide some form of support to fossil energy companies, whether through direct financial aid, tax breaks, etc. The value of the support for the oil and gas sector is estimated to be around USD 1.5 trillion globally in 2022.[3] This amounts to a competitive distortion that skews the investment case in favor of fossil energy production. At the very least, these subsidies should be removed to create a level playing field across the energy system. If a policy bias should be introduced, it should obviously be in favor of renewable energy. Redirecting these subsidies to renewable energies would go a very long way towards the financing of the transition.

The appeal of low returns can be improved using tried and tested tools to provide greater revenue certainty. Tools such as contracts for difference were used to great effect in the development of the wind, solar, and nuclear energy markets. These are financial agreements that stabilize revenue by paying the difference between a fixed price (the strike price) and the market price of a product – most commonly electricity. Such solutions shift price risk between investors and consumers, provide greater price certainty, and maintain exposure to market signals. Appropriate risk transfer and increased revenue-certainty could transform the SAF market into a utility or infrastructure-style investment and access the approximately USD 70 trillion investment pool held by institutional investors. This dwarfs the USD 500 billion or so of the venture capitalists, which

[3] **Hannah Ritchie, "How much in subsidies do fossil fuels receive?", Our World in Data, January 2025.**

community will never be able to finance the energy transition on its own. The mission must be to turn SAF into a reliable asset class which would relieve the financing constraints that are clearly not a function of insufficient capital in the world, or of weak demand signals, but of mis-managed risk transfer.

Book-and-Claim

Potential SAF producers need access to fuel infrastructure and to financial services that can help manage the risk and return of projects, but more than anything they need access to customers. A SAF plant project might not be economically viable if the customer base is too weak or too geographically dispersed, which can happen in underdeveloped air transport markets. The opposite might also occur, in that airlines with potentially high demand for SAF can be located where there are not any SAF producers.

The SAF market will only scale if the geographical constraint can be lifted in such a way that all SAF producers can sell to all airlines, and all airlines can buy from all SAF producers. Adopting a book-and-claim system is essential in early market creations where physical delivery is constrained. It can turn the fragmented and highly localized SAF market into a global marketplace for the benefit of all – lifting volumes, creating liquidity, contributing to price transparency, and fostering harmonization and standardization. This is achieved in the book-and-claim system by allowing the physical SAF to be delivered to where that makes sense, minimizing transport emissions, while the environmental attributes of the SAF can be bought by any airline anywhere. With a system that allows proper tracking and auditing, the integrity of the transaction can be ensured. Essentially, book-and-claim allows demand to grow before full physical infrastructure exists. Successful examples of book-and-claim systems include the Renewable Energy Certificates in the US and the UK, and in shipping it is used for biofuels, e-methanol, and green ammonia. Germany and Japan use book-and-claim to address similar issues in renewable hydrogen and e-fuels. Book-and-claim systems are also used in the European Union through Guarantees of Origin for renewable energy and Renewable Energy Units for biofuels.

Low-hanging fruit

In spite of the many challenges, the energy transition is possible to achieve, and the targets set for the airline industry can be met. There is low-hanging fruit that is being neglected. For instance, fuel standards allow fossil-fuel refineries to co-process crude oil with additives of biological origin, up to a limit currently set at 5%. It would be physically possible through this process alone to achieve the 2030 target of 5%, immediately and with few investments in upgrades to refineries. The UK took the inspired step to lift its limit on co-processing to 30% in 2025, illustrating the upside potential of this solution were it to be widely adopted.

There are also lower carbon aviation fuels (LCAF). These are fossil-based jet fuels that achieve a reduction in the life-cycle greenhouse gas emissions of at least 10%. LCAF are considered CORSIA Eligible Fuels but are not labeled "sustainable fuel" because they are derived from fossil sources. LCAF are, however, recognized as a necessary, immediate, and cost-effective means to reduce aviation emissions. While the framework for LCAF exists, as of late 2025, no specific Sustainability Certification Scheme was yet officially approved by ICAO to certify LCAF producers.

Policy

Armed with the above insights, it should be clear that, today, policies are generally not addressing bottlenecks in the energy system.

Many governments are tempted to impose mandates. They can work in mature markets but tend to fail in early market creations. Optimal policymaking must consider not only which tools to use for what purpose, but also when to use them. Policy sequencing is a key part of policy design, and all new market-development policies must start at the beginning. Mandates are ineffective and even harmful in immature markets because:

- Mandates do not improve the investment case – they do not reduce the cost of capital and do not transfer risk.
- Mandates do not boost the creation of missing infrastructure. The missing market and physical infrastructure will not self-assemble just because a mandate is imposed. Addressing scarcity must be planned for, not simply wished away.
- Mandates in early markets with few suppliers and scarce output will bid up the price, protect incumbent producers, favor existing technologies at the expense of innovation, and discourage voluntary markets. In Europe and in the UK, this has been the case, resulting in higher costs per unit of CO2 emissions reduction and slower progress on decarbonization.
- Hence, mandates should not be used before:
  - Supply exists
  - Cost curves decline
  - Infrastructure is operational and accessible

Public procurement, on the other hand, deserves to be at the center of demand-side policies for new markets. Public procurement of SAF for public fleets would be most effective as an early demand signal as it would anchor demand and signal long-term policy commitment. A sequenced approach to the policies that can be used in market formation aiming at system transformation could be articulated as follows:

1. Remove, reduce, and redirect direct corporate subsidies in favor of fossil energies to renewables
2. Promote and enable co-processing and LCAF
3. Conduct public procurement for public consumption
4. Ensure open access to airport infrastructure
5. Provide capital support such as tax credits, grants, loan guarantees, concessional finance
6. Accelerate new technologies and production pathways
7. Develop, harmonize, and simplify certification, standards, and related processes
8. Introduce a book-and-claim system
9. Stabilize revenue: contracts for difference, production tax credits
10. Transfer risk: create a global SAF risk-transfer vehicle
11. Invest in infrastructure: pipelines, storage
12. Consider mandates and carbon pricing
13. Avoid policy volatility at all times

Markets fail when policy tools are used in isolation and at the wrong time. They succeed when tools are sequenced and integrated, addressing bottlenecks in order of what they enable, and with keen attention paid to the wider energy system and ripple effects.

As the world increasingly turns to me-first policies, the resulting fragmentation and regulatory complexity stand in the way of the necessary system transformation. Coordinated solutions are difficult to achieve when multilateralism is challenged. However, the upside would be system-wide efficiency gains and cost minimization whereas the industry-by-industry approach will waste resources and lead to incompatible systems where nobody wins.

For airlines this means that the debate needs to break the shackles of the Transportation Ministries and involve the Energy Ministries, Agriculture, Treasuries, Trade and Commerce, Economic Development, and more, as a whole-government strategic priority. The rewards are potentially unprecedented. Governments can expand their countries' agriculture, improve soil health, preserve nature, bolster local communities, build energy security and independence, lift productivity, and produce sustainable growth across the entire economy, improving livelihoods for all. Any efforts that are directed at an individual industry can seem hard to justify politically, in addition to proving futile. Placed firmly in the context of whole economy system transformation, they become necessary, separately and together.