BRIEFING- December 2024

Finance, fuels and transport

Public funding for RFNBOs in shipping and aviation

Summary

Correctly designed, supply-side hydrogen subsidies can kick off the fuel transition in shipping and aviation

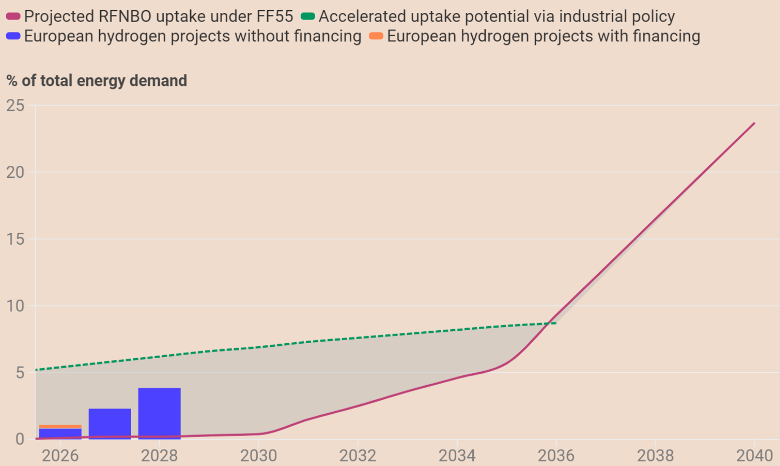
The uptake of sustainable and scalable fuels (hydrogen-derived fuels, known as 'RFNBOs') in shipping and aviation is currently hampered by competition with cheap and untaxed fossil fuels. The European Commission has therefore proposed to subsidise RFNBO production to kickstart the use of these fuels. In this context, Transport & Environment commissioned Ricardo to explore suitable design options for public support mechanisms to enable the shipping and aviation sectors to transition to RFNBOs. While this paper focuses on policy action in the EU and is relevant in the context of the ongoing discussions on the design of the EU's Hydrogen Bank auctions, the conclusions are equally relevant for policy-makers considering subsidising RFNBOs in these sectors in other jurisdictions, such as the UK, US and the IMO.

This briefing argues that **supply-side support** (where the subsidy is awarded to RFNBO producers) is most appropriate. For shipping, it can ensure the initial availability of renewable fuels in the select few ports where the lion's share of bunkering takes place. In aviation, supply-side support is necessary to secure business cases for nascent fuel production projects ahead of the 2030 RNFBO target. Lack of investment in aviation fuels projects means that public authorities should take more risk by using Contracts for Difference (CFDs), while more private interest in shipping projects mean that policy-makers could consider either CFDs or fixed premiums, where more risk is taken on by the private investor over the public authority.

Policy-makers should also consider bridging only a part of the price gap between RFNBO and conventional fuels so that the market absorbs some of the cost in the form of green premiums. This could be done by organising the auctions in the form of 'pay-as-clear', where the same subsidy amount is awarded to all successful bidders.

The analysis makes clear that the **surrounding policy framework** is key for the successful implementation of public financial support. Analysis of the shipping sector shows that using 25% of ETS revenues can help to significantly boost RFNBO uptake in the short to medium term, but

Shipping needs industrial energy policy for green fuels

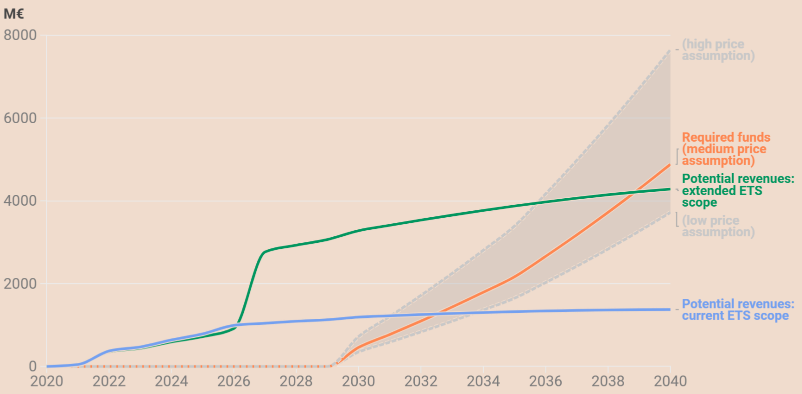


Source: T&E (2023) and Ricardo (2024) • Accelerated industrial policy calculations assumes 25% of maritime ETS revenues being used to support EU RFNBO production and supply.

from the late 2030s, existing targets under FF55 could be sufficient to make RFNBOs competitive with conventional fuels if early uptake drives economies of scale. The analysis demonstrates clearly that higher RFNBO mandates (under FuelEU Maritime) significantly reduce the amount of subsidies given to the sector to achieve the same climate targets.

Analysis of the aviation sector shows that using 25% of ETS revenues to fund a CfD would cover half of the mandated volumes until 2040, using a 20% price gap coverage level. This would strengthen the business models of the first projects and help them reach final investment decision, launching the sector.

Revenues required to meet ReFuelEU mandate with 25% of ETS under current, or extended scope



Source: Ricardo, T&E

More generally, policy-makers should explore deploying CfDs to prioritise marine and aviation RFNBOs as strategic net-zero technologies as part of the implementation of the Net-Zero Industry Act (NZIA) and the future development of the Clean Industrial Deal. T&E also argues that European policy-makers should set the right surrounding policy framework to increase ambition and to ensure a level playing field between firms receiving subsidies and those not. This means internalising the external costs of fossil fuels, for example through the Emissions Trading System (ETS) and Energy Taxation Directive (ETD); removing exemptions for international flights and smaller ships in the ETS and increasing the mandates for RFNBOs in FuelEU Maritime and ReFuel Aviation at the same time as implementing bespoke measures on energy efficiency improvements in shipping and demand management in aviation.

1. Context

Aviation and shipping are both highly emitting sectors, contributing roughly 3% each to global CO_2 emissions. Yet unlike almost every other industry in Europe, pollution from these sectors continues to increase year on year. Decarbonisation pathways differ slightly, but given both sector's high energy demand, there is broad consensus that they will both transition to depend on energy carriers derived from green hydrogen, also known as Renewable Fuels of Non-Biological Origin (RFNBOs). These fuels can be produced sustainably and do not have the issues related to biofuels of scalability and competing uses, meaning their production can be ramped up without negative environmental impacts.

However, the fledgling markets for RFNBOs in shipping and aviation suffer from lack of investment. The European Commission has proposed a number of policy and financial measures to ensure support for the sector. Firstly, the Commission put forward two laws, ReFuel Aviation and FuelEU Maritime, to ensure demand for green fuels. Both policies mandate the use of RFNBOs. While this gives producers predictable guarantees that the market for RFNBOs will grow in each sector, these laws only mandate significant amounts of RFNBOs in the 2030s, limiting their impact in the short and medium term. European legislators also agreed to channel revenues to RFNBO production with ETS revenues and included RFNBO production as a key strategic technology within the Net-Zero Industry Act (NZIA).

In this context, T&E commissioned Ricardo to evaluate how best public subsidies can accelerate the uptake of RFNBOs in shipping and aviation. This briefing summarises and expands on Ricardo's main findings, looking in particular at policy options on the table, guidance on scheme design based on these options and modelling of the impacts of the proposals.

2. What forms of public support are on the table?

None of the three instruments considered by the Commission - fixed premiums, CFDs and Carbon Contracts for Difference (CCFDs) - have been previously used to support hydrogen production. However, different versions of the instruments have been used for different purposes (most notably CFDs in the UK for renewable energy production). This section sets out concepts common to all three instruments before defining the main features of each individual instrument.

Concept	Explanation
Supply-side support	The receiver of the public support is an entity that produces or supplies the RFNBO, e.g. a hydrogen, e-kerosene or e-ammonia producer
Demand-side support	The receiver of the public support is an entity that buys and deploys the RFNBO, e.g. a shipping company or an airline. All of the three forms of support (fixed premium, CFD and CCFD) can either be on the supply-side or demand-side
Integrated projects	Projects where the bid includes both a supplier and an offtaker
Clearing house	Auctions asking for bids from both suppliers and offtakers where an intermediary body - a clearing house - is set up to act as the go-between and ensure an adequate balance between offtakers and producers
Counterparty	Usually government, but in theory could also be a private entity or fund
Strike price	The price a bidder proposes and the counterparty accepts. The strike price is usually the price at which the clean fuel/technology would compete with conventional fuels/technologies
Reference price	The market price for a conventional fuel or technology. The subsidy size of the public support is the difference between the strike and reference prices

Two-sided contract or put-option	In a two-sided contract, the bidder would pay the counterparty back in the scenario that the reference price went above the market price. In a put-option, the bidder would not have to pay the counterparty back
Pay-as-bid or pay-as-clear	In a pay-as-bid scheme, successful bidders are awarded subsidies based on the strike prices they proposed in their bids. This differs from pay-as-clear schemes where all successful bidders receive the same strike price (often that of the least competitive bid that passed the threshold to receive support)
Technology neutral or technology specific	The counterparty may base their auctions on specific technology that need funding or design the auction as technology neutral and base it on criteria like emissions reduction and cost
Total cost of ownership (TCO) or 'fuels only'	The counterparty can decide to award a subsidy that takes into account the capital costs of building new infrastructure, for example a new vessel or aircraft, as well as the operational costs for producing or deploying the new fuel (and maintaining the assets). This would be a TCO approach, in contrast to a 'fuels only' subsidy that only considers the operational costs of producing or deploying the fuel

2.1 Fixed premiums

Fixed premiums are the simplest form of public support administratively. Bidders ask for a set amount of subsidy per tonne of hydrogen/RFNBO. In return, counterparties provide *'a fixed subsidy per unit sold of a commodity in addition to the market price a producer can earn in the wholesale market. Fixed premium schemes thus allow market prices to provide price signals to producers while also providing producers with additional revenue to support the financial viability of its production (Ricardo, p.11).'* Fixed premiums therefore offer the most predictable from a budgetary perspective. Governments have full clarity on the amount of subsidy that will be paid out throughout the project's lifetime.

Fixed premiums entail more risks for project developers. If the price of production suddenly increases (for example due to spikes in the price of electricity), the project will become less competitive with conventional technologies, but the subsidy will not get larger to compensate. They may not therefore offer private entities sufficient flexibility to hedge against price risks, in particular for projects with high capital costs or in offtake sectors where demand is sensitive to higher prices.

EU Hydrogen Bank

The European Commission opened its first call to support green hydrogen projects through the EU's Innovation Fund in November 2023. The Commission's 'Hydrogen Bank' supports producers - so is supply-side - and fossil (blue or grey) hydrogen is not eligible. Auctioning is 'competitive' - only the most cost-effective win funding - and 'pay-as-bid' - successful bidders receive the amount of support they specified in their bid. The first round includes a budget of €800 million over 10 years.

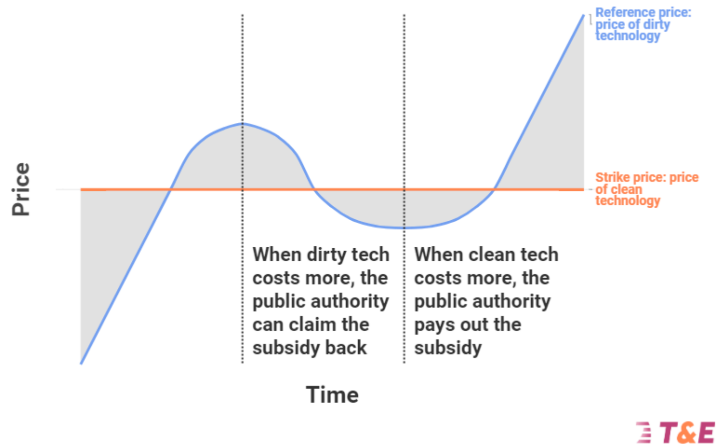
The form of support - a fixed payment per tonne of hydrogen produced - is the same as that provided under the USA Inflation Reduction Act (IRA). The European Hydrogen Bank is therefore a reflection of the need to prevent nascent hydrogen industries abandoning projects in Europe and choosing the USA. The EU has exempted its support from state aid rules and allowed Member States to take part in the auctions (through 'auctions-as-a-service'). Cumulation with other financial subsidies (for example provided by Member States for the same project or provided for renewable energy generation to be used within the hydrogen production project) is not allowed under the EU Hydrogen Bank, unlike the IRA.

The results of the first auction are significant: at least two of the seven successful projects committed to projects with shipping offtakers. No projects, however, had aviation offtakers or the production of e-kerosene. This was reflected in the results of a similar auction organised by the H2Global Foundation for hydrogen production outside Europe, where no e-kerosene projects won funding. This suggests **that fixed premiums may provide sufficient guarantee for some shipping projects, but not for aviation fuels.**

2.2 Contracts For Difference (CFDs)

In CFDs, bidders propose a strike price in euros per unit of RFNBO produced or deployed. This strike price is estimated at the price at which the bidder believes the RFNBO project can be competitive with the reference price. If successful, the counterparty pays the difference between the agreed strike price and the reference price for each unit of RFNBO. This price varies over time, given price fluctuations in the market for each given technology.

CFDs subsidise the price difference between clean and dirty technology



CFDs are more complicated administratively than fixed premiums and give less budgetary certainty to governments given that market prices for both RFNBO and conventional technology varies.

UK CFD scheme for renewable electricity

The UK has had a CFD scheme in place for renewable electricity production since 2014. A subsidiary agency of the government, the Low Carbon Contracts Company (LCCC) acts as the counterparty and runs the programme through competitive auctions. Successful bidders are awarded the clearing strike price (i.e. pay-per-clear, rather than the amount bid by each project) for 15 years. LCCC claims that the scheme has guaranteed investments in 30GW of renewable energy generating capacity, mainly offshore wind, saving just under 6

$MtCO_2$ over its 10 year operating lifetime. Partly as a result of the scheme, wind generation in the UK is now competitive with conventional power generation.

The success of the scheme is explained in large part due to the surrounding policy framework. The preexisting Renewables Obligation (RO) law meant that there was already an obligation on energy companies to supply renewables, ensuring certainty in investment for these technologies and a degree of maturity for that market. This has relevance for the deployment of RFNBOs in shipping and aviation: **it shows the importance of clear and ambitious targets in the accompanying fuels laws** (FuelEU Maritime and ReFuel Aviation).

2.3. Carbon Contracts For Difference (CCFDs)

CCFDs operate in a similar way to CFDs in that they offer a variable payment size to producers based on the optimum competition price and the market reference price, but CCFDs operate within a carbon market. This means that the reference price is the carbon price and the strike price is the carbon price at which the bidder believes their project would become competitive. The subsidy is paid out as a function of tonnes of CO_2 abated and is awarded in the form of carbon allowances (e.g. 'EUA's in the EU ETS).

Operating within a carbon market increases the complexity of the scheme for bidders and, in the same way as CFDs, the variable pricing scheme adds budgetary uncertainty for the counterparty. Both strike and reference price are relative to carbon, so price fluctuations in conventional fuel would not be taken into account in the simplest form of CCFD. CCFDs would therefore work best for entities for whom the price of carbon is the biggest risk factor (for example power generators). Finally, given that CCFDs operate as a function of CO_2 abatement, they would in theory prioritise sectors and projects with the lowest marginal abatement costs (MACs).

3. Public support for RFNBOs in shipping and aviation

This section sets out the common and specific issues related to the public support schemes. While the issues are diverse, there are common trends in the design options available to policy-makers, namely:

- The **need to get the surrounding policy framework correct** through: ambitious emissions reduction targets, clear green fuels supply and uptake mandates, removal of indirect subsidies for conventional technologies (i.e. lack of fossil fuel taxes) and the need to ensure R&D, CAPEX funds and operational support schemes;
- The need to restrict the support scheme to projects with offtakers who have no other viable decarbonisation option but hydrogen-derived fuels and to specify lead times no longer than 5 years to enable all the related infrastructure to come online.
- The higher capital risks for e-kerosene projects may mean that CFDs are preferable in that sector, while shipping could benefit either from CFDs or fixed premiums.

3.1.1. Common issues

Issue	Explanation and solutions
Fuel production capacity limit and infrastructure scalability	There are logistical limits to the scale-up of RFNBO supply and related infrastructure: RFNBO production involves a wide set of projects across the supply chain, from renewable energy projects and electrolysers to further refining/chemical processes and (in some cases) carbon capture, utilisation and storage (CCUS) or Direct Air Capture (DAC). Each of these phases requires lead times for the construction as well as applications and certification. Demand-side contracts may be too far up the supply chain to sufficiently drive all the necessary investments. Clear incentives, mandates and targets across the supply chain - from renewable energy production to electrolyser ramp-out and RFNBO production and deployment - can address this issue. Within the design of the hydrogen support scheme, policy-makers can give flexibility to bidders on the time needed to complete the contract (such as 5 years lead time in the first EU Hydrogen Bank auction). Additionally, policy-makers could offer strengthened monitoring and coordinated support with Member State governments to ensure projects come on line, e.g. through the NZIA.
Competition for RFNBOs across industries	Many industries require RFBNOs. Competition between sectors may lead to increased the price for offtakers. Policy-makers can mitigate this risk by ensuring RFNBOs go to sectors that have no alternative to decarbonisation. For example, that means ensuring that no hydrogen goes to road transport, heating or refineries.
Technology 'lock-in' and long life span of the fleet	The urgency of decarbonisation and long life span of vessels and aeroplanes means shipping and aviation companies are now making long-term investment decisions. Yet continued uncertainty about technologies complicates the choice to purchase an asset that will be around for decades. Policy-makers should apply strict monitoring and environmental criteria to the auctions to ensure no technology or RFNBO is funded that leads to adverse environmental impacts or stranded assets. Similarly, clear targets and mandates far into the future from policy-makers can help industry take decisions with certainty to choose certain RFNBOs over others.
Price inflation from producers	There is a risk that producers artificially inflate market prices for RFNBOs given high (and publicly-mandated) demand for RFNBOs. Policy-makers can address this by designing the support scheme to reduce each supplier's preference for higher offtake price or to use transparency mechanisms to ensure producers do not unfairly inflate their prices.

Higher production cost of H2 compared with traditional fuels means higher prices	Given the large price differences between conventional fuels and RFNBOs, there is a risk that the public subsidies for RFNBOs take up a large amount of government budgets over an extended period of time. To address this, policy-makers can include an 'accurate price setting mechanism', including 'multiple rounds and flexibility over time to allow for… efficiency'. Similarly, the size of the support for the projects could be limited. For example, the support could cover 60% of the cost gap (the top ceiling for public support used by the Innovation Fund in the past), be implemented as 'pay-as-clear' rather than 'pay-as-bid' and facilitate the companies to pass the rest of the costs on as green premiums (in particular for shipping projects). Alternatively, given that mandates exist for alternative fuels in both aviation and shipping, support could cover the difference in price between biofuels and RFNBOs, to push industry away from cheaper, but unscalable biofuels, towards investment into future-proof RFNBOs. Other policies will also need to play their part in reducing the price differential and so impact on government budgets, for example getting rid of the tax exemption for fossil fuels in the Energy Taxation Directive (ETD).
Vested interests and lobbying for specific technologies	Firms that have invested in certain infrastructure or technologies will have a vested interest to acquire funding for these technologies even if they are not scalable or sustainable, for example LNG in shipping or biofuels in both shipping and aviation. Policy-makers should be aware of these considerations and where possible propose technology-specific auctions to accelerate the deployment of future-proof technologies over others.

3.1.2 Shipping

Two themes are important when considering subsidies for shipping RFNBOs. Firstly, the policy framework. In its current iteration, FuelEU Maritime fails to give unambiguous clarity on RFNBO demand needed by the industry despite the law including certain positive signals for preference for these fuels. Policy-makers should therefore **urgently clarify, strengthen and bring forward the RFNBO sub-target** in FuelEU Maritime. Secondly, the vast majority of bunkering occurs in a handful of large ports. As a consequence, **supply-side auctions that guarantee the availability of RFNBOs in these ports** can have the most impact with the smallest administrative burden.

Non-liner trades do not have certainty over where they will bunker	Vessels operating in the tramp trade - where companies do not have a fixed route or schedule - face the challenge of not being able to predict where they can bunker. These companies may therefore not be able to benefit from demand-side subsidies. To establish a level-playing field between all companies, public support could be designed in the form of a supply-side auction. This has added value given the concentrated nature of global shipping bunkering and the likelihood that

	new fuels will develop in a handful of large ports, which have the ability to supply a majority of shipping energy demand. If policy-makers consider demand-side contracts in the future, they could expand the flexibility requirements for the use of the contract. In the European Commission's first fixed premium auction, it allows subsidies for up to 140% of the agreed production. A similar, but extended e.g. up to 200%, flexibility on use or non-use of the contract - or sharing the contract between vessels/operators - could be considered to make the contracts feasible to tramp trade operators.
FuelEU Maritime mandate lacks certainty	FuelEU Maritime includes a subtarget for RFNBO use, but this mandate would only come into force in 2034, dependent on the fuel mix in 2031. Clarifying, strengthening and bringing forward this target would simplify the design of the auction by reducing risk and allowing all parts of the supply chain to direct investments to RFNBOs.
Competing RFNBOs will fail to scale symmetrically	There is uncertainty as to which RFNBO will become dominant, if any. There are also significant doubts that fuels with currently growing market share - like LNG and biofuels - have the necessary sustainability and/or scalability for a zero-emission future. The Commission should take an active role in evaluating the environmental risks of all RFNBOs. As soon as evidence is clearer on life-cycle impacts, the Commission should tailor the support it gives to whichever RFNBO presents the best climate benefit.

3.1.3 Aviation

Unlike the shipping sector, European aviation has a clear RFNBO mandate within ReFuelEU. However, **public support is necessary to support the first e-kerosene projects given their high upfront capital cost**. Importantly, airlines that use SAF will be given free allowances under the ETS. 20 million allowances (€1.5-2 billion at carbon prices of €75-100) will be available for airlines until 2030 under this programme. The allowances would serve to reimburse 95% of the difference in price between conventional fuel and RFNBO. This scheme has some elements in common with a CCFD scheme, given that free allowances will be awarded depending on the use of clean fuels.

Support for fuel producers	Supply-side CFDs for RFNBOs could be misused by fuel producers if they pass on costs but use the subsidy to fund other projects (such as the biofuel mandate in ReFuel Aviation). This would undermine the aim of the subsidy: to improve the competitiveness of RFNBO compared to other fuel options. Policy-makers should ensure transparency and stringency on the bids from fuel suppliers and monitor implementation to ensure fair pass on of prices and combat cross-subsidisation.

Market concentration	Public support will only be able to fund a relatively small number of projects. If only companies that receive subsidies are able to continue within the fuel market, there is a risk of market concentration. This risk is mitigated in that the market is already concentrated to a certain extent, and the ReFuel mandate sets a level playing field, so all players will have to comply with the environmental targets. If necessary, however, policy makers could consider policy interventions to ensure 'available land, available financing, and risk mitigation for new entrants to the market.'

4. Modelling

To evaluate the impacts of a public support scheme on RFNBO uptake, emission and costs, Ricardo modelled scenarios based on the T&E position that 25% of ETS revenues from that sector go to CFDs in that sector. Ricardo modelled four scenarios per sector, starting with scenarios with existing policies (as per the fit for 55 policy package), then with other scenarios building on these policies but with more stringent policies or extra action (e.g. with higher fuel targets, or energy efficiency in the case of shipping and demand management in the case of aviation). The modelling proposes two rounds of support, both of 10 years length; one starting in 2025 and the other in 2030. This section highlights the main findings from the analysis.

The modelling describes the impact of a CFD as this option was designated as the most promising design option for aviation and shipping (although fixed premiums also have potential in the shipping sector). However, in practice the analysis looks at funding to cover varying cost gaps between conventional fuels and RFNBOs. As such, the results are relevant for both supply- and demand-side subsidies, as well as CFDs or CCFDs. It should be noted that **the analysis did not consider a 'feedback loop',** where lower costs for RFNBOs due to subsidies result in higher uptake of those fuels. In reality, subsidies will affect the demand displayed in each scenario, increasing the consumption of RFNBOs.

4.1. Shipping

The following table indicates the scenarios used in the analysis of the maritime sector:

Scenario	Description
FEUM (based on FuelEU Maritime)	baseline scenario: emission intensity reduction target of 80% by 2050 and RFNBO sub-quota of 2% in 2034, as per the EU's FuelEU Maritime (FEUM) Regulation.
FEUM+	FEUM scenario with additional energy efficiency measures as per the IMO 4th GHG Study by vessel type until 2023 and then interpolating up to 38.6% additional energy efficiency by 2050.
DE_DK (based on a joint German/Danish proposal	100% emission intensity reduction by 2050 in FuelEU Maritime and RFNBO sub-quota of 2% in 2030 rising to

during the FuelEU Maritime negotiations)	70% in 2050.
DE_DK+	DE_DK scenario with the same additional energy efficiency measures as FEUM +

T&E's inhouse modelling concluded in the baseline 'FEUM' scenario that fossil fuels will remain dominant in European shipping until the 2040s (Fig. S.1).

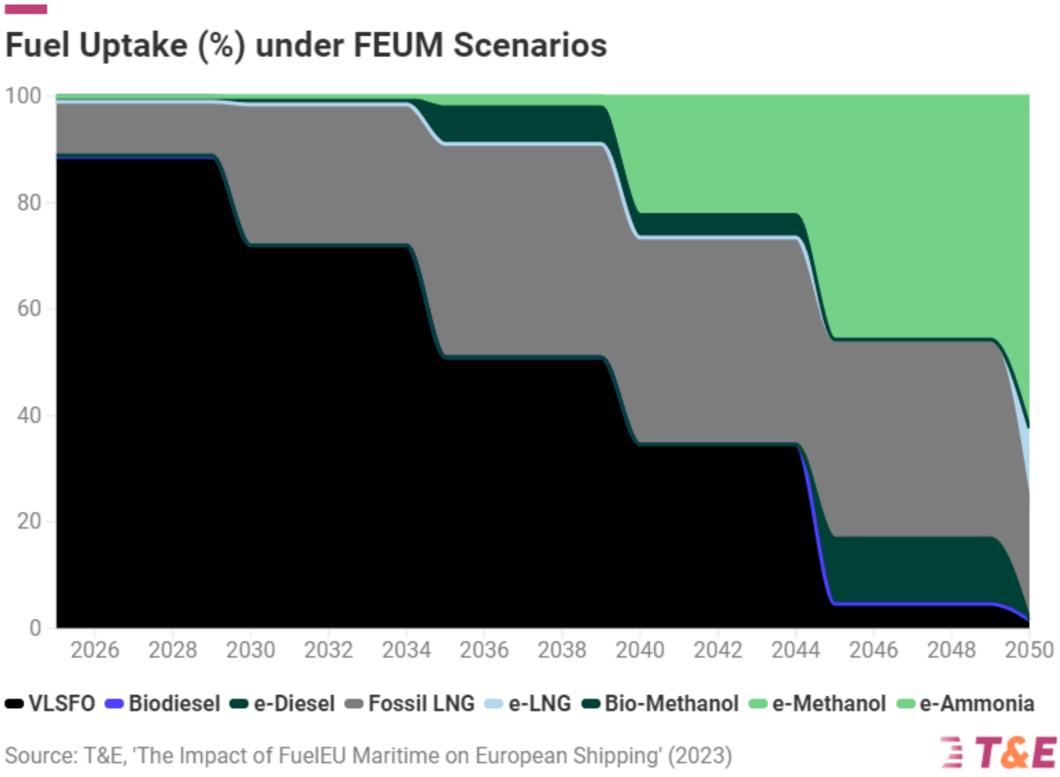


Figure S.1: Fuel mix under FEUM Scenarios

Under the 'DE_DK' scenario (Figure S.2), where FuelEU Maritime targets are higher than currently agreed, the uptake of LNG is limited. Higher volumes of e-ammonia (and some biomethanol) appear in this scenario compared to the FEUM scenario from the mid-2030s, with no fossil fuels in the fuel mix by 2050.

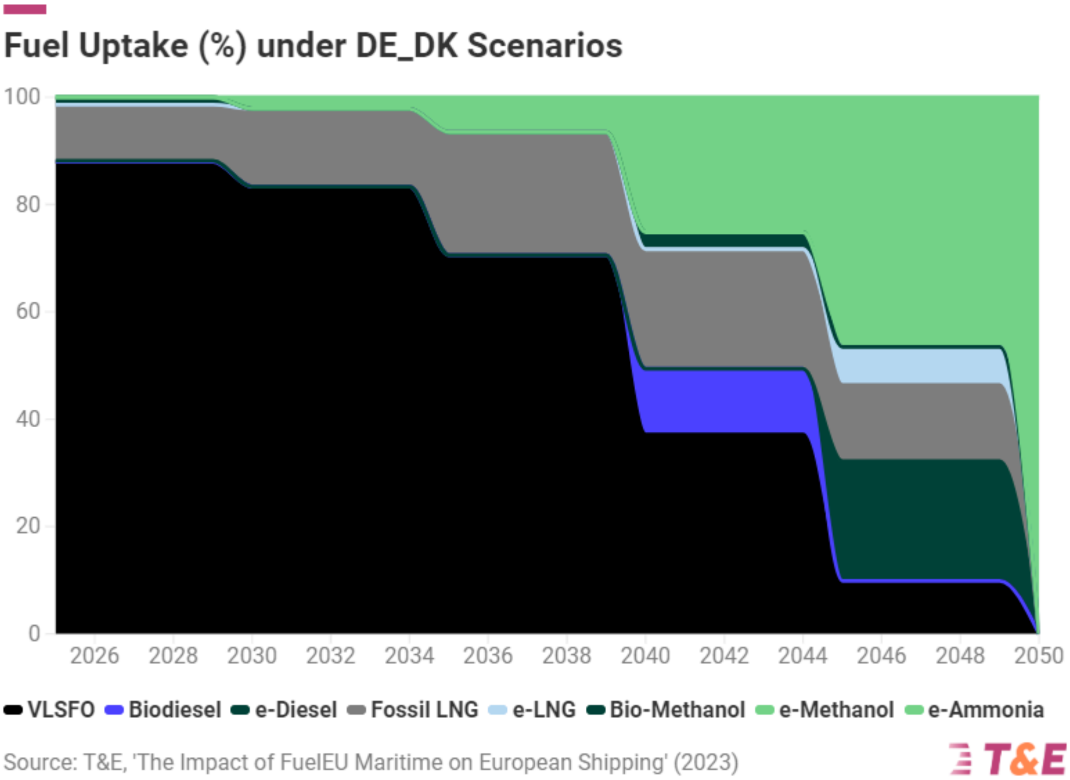


Figure S.2: Fuel mix under DE_DK Scenarios

In the two scenarios with energy efficiency improvement (FF55+ and DE_DK+) the fuel mix remains the same as the original variation, but total emissions are lower (Figure S.3). In 2032, emissions are around 20MtCO_2 lower in the scenarios that consider energy efficiency improvements. In these scenarios, peak emissions occur in 2023, compared to 2026 in the scenarios without energy efficiency improvements. While both DE_DK scenarios mandate zero-emissions from 2050, 22MtCO_2 and 18MtCO_2 remain in the FEUM and FEUM+ efficiency scenarios in 2050.

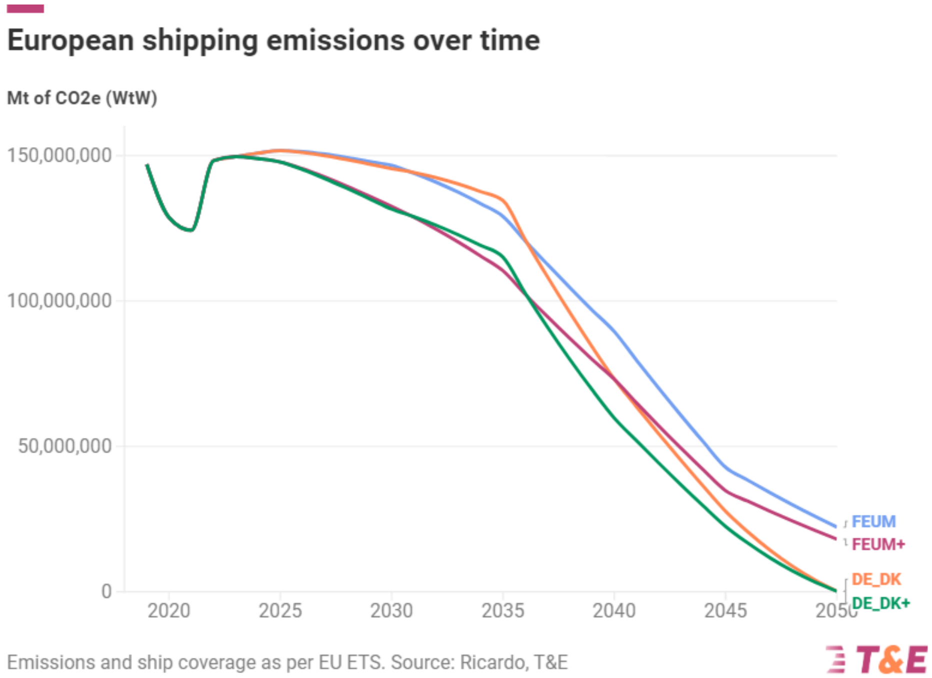


Figure S.3: European shipping emissions over time by scenario

Figure S.4 demonstrates the amount of absolute revenue geared to funding in each scenario (assuming 25% of total shipping ETS payments are used for in-sector decarbonisation). Revenue generation peaks in 2035 at just over €3 billion in the scenarios with no efficiency improvements and just over €2.6 billion in the scenarios with energy efficiency improvements. After this point, emissions decline (mainly as a result of stricter FuelEU Maritime targets), so ETS revenues also decrease, in spite of higher carbon prices. In 2040, the FEUM scenario has the highest revenues, at €2.7 billion, followed by DE_DK and FEUM+ at around €2.2 billion then DE_DK at €1.8 billion.

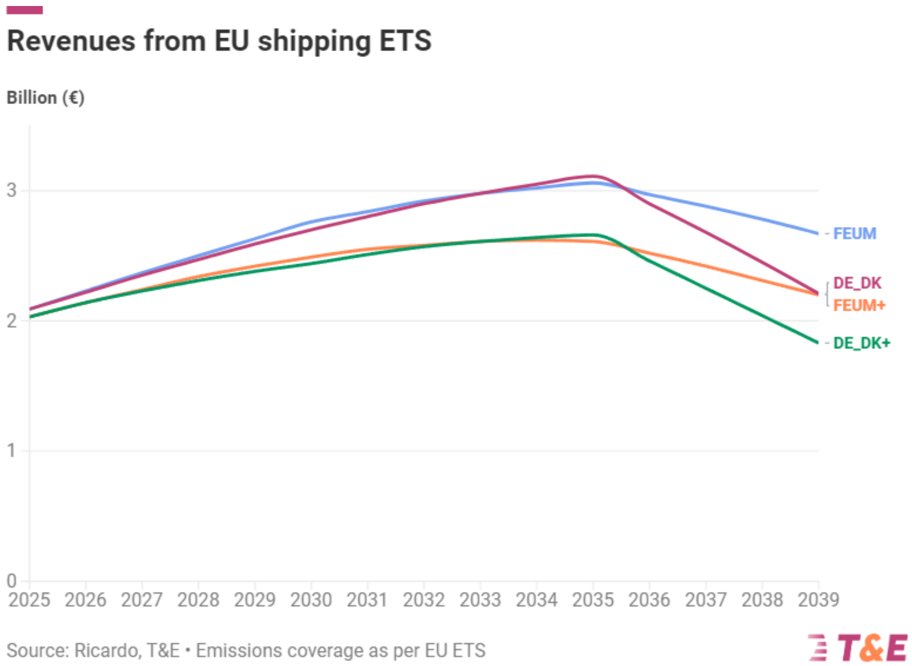


Figure S.4: Comparison between scenarios of annual EU ETS revenue generated (capped at 25% of the total) during auction periods

Directing limited revenues to the shipping industry means policy-makers will have to take a decision on which RFNBOs in particular to support. The analysis considered two options: proportional allocation of subsidies to all different types of RFNBOs (i.e. hydrogen, e-ammonia, e-methanol, e-methane and e-diesel) based on expected fuel uptake in each scenario. This, however, runs the risk of promoting stranded assets, in particular for expensive e-fuels like e-methane, which would benefit from existing infrastructure and historical investments in spite of continuing climate issues related to methane leakages. The modelling also considers an alternative allocation based on one RFNBO becoming dominant, with the literature suggesting that this is most likely to be e-ammonia. In this case, ammonia receives the most amount of funding (T&E modelling suggests e-ammonia may become the dominant RFNBO in the long-term).

As Figure S.5 shows, in the scenarios related to existing policies: FEUM and FEUM+, e-ammonia is the only subsidised RFNBO. A total of 77 Mt of e-ammonia is subsidised across both auctions in the FEUM scenario, and 68 Mt in the FEUM+ scenario. In the scenarios with more ambitious policy targets (DE_DK and DE_DK+), e-ammonia remains the most supported RFNBO, at a total of 68 Mt (DE_DK) and 60 Mt (DE_DK+).Small amounts of e-methane also receive funding in the DE_DK and DE_DK+ scenarios (0.3Mt of e-diesel in both scenarios, but only in the first auction and just over 1Mt of e-methane, over 90% of which comes from the first auction).

Figure S.5: RFNBOs supported by scenario and auction round with proportional allocation by fuel type (tonnes)

Figure S.6 compares the volumes of RFNBO that can be produced through CFD support (capped at 25% of maritime ETS revenues) with potential unsubsidised RFNBO demand under the existing policies. The modelling demonstrates that - from the 25% of the ETS revenues spent to support RFNBOs - in 2030, it would be possible to subsidise 115 million GJ (6 Mt) of ammonia, or around 7% of the maritime sector (in energy terms); more than the expected uptake of 6.6 million GJ (0.4 Mt) of ammonia. By 2036, the higher FuelEU mandates (and lower ETS revenues) mean that expected uptake of ammonia exceeds the amount that can be subsidised (the former is 148 million GJ - 8 Mt - in 2036, compared to 138 million GJ for the latter). This is relevant as it demonstrates that the European Commission and member states can ensure early uptake of green fuels with a small portion of shipping ETS revenues. This may further lead to a positive feedback loop of reduction in price for the fuel and technology not considered in the supply and demand models.

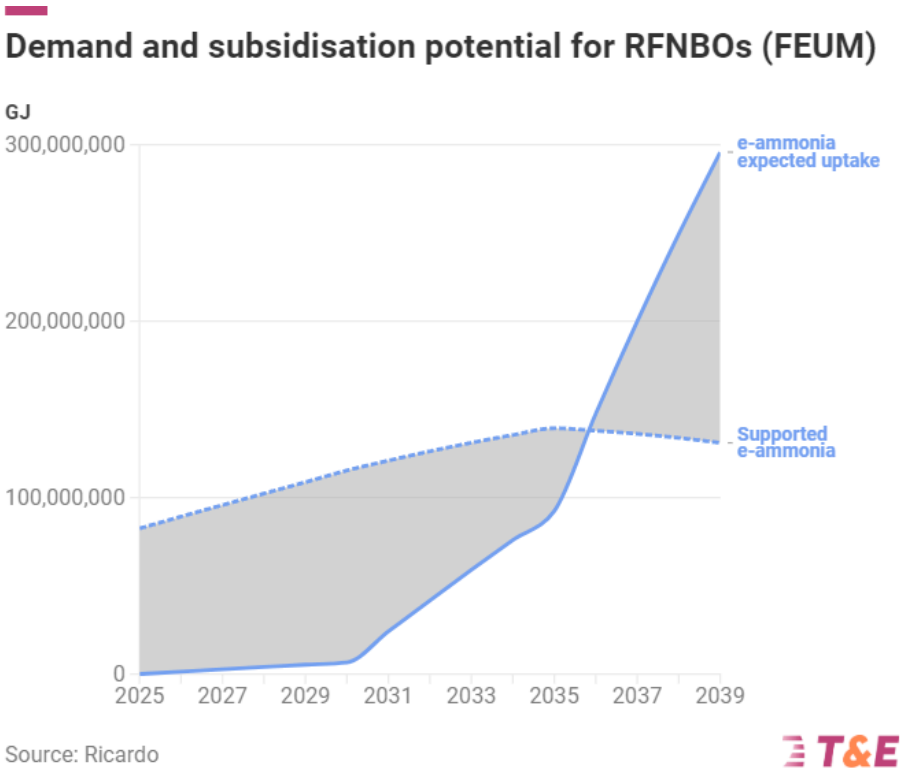


Figure S.6: Volume of RFNBO supported under CfD scheme vs expected uptake of RFNBOs under FEUM scenario (proportional ETS funding allocation)

Figure S.7 shows volumes of RFNBO that can be supported compared to demand for the more ambitious DE_DK scenario. The amount of ammonia that can be supported peaks in 2035 (with ETS revenues) at 142 million GJ (7.6 Mt). Minor amounts of e-LNG and e-Diesel (25 million GJ - 0.5 Mt - and 6 million GJ - 0.1 Mt) can be supported in 2025, but they are quickly replaced by e-ammonia, falling to zero by the start of the second auction as e-ammonia becomes dominant in the market for its lower costs.

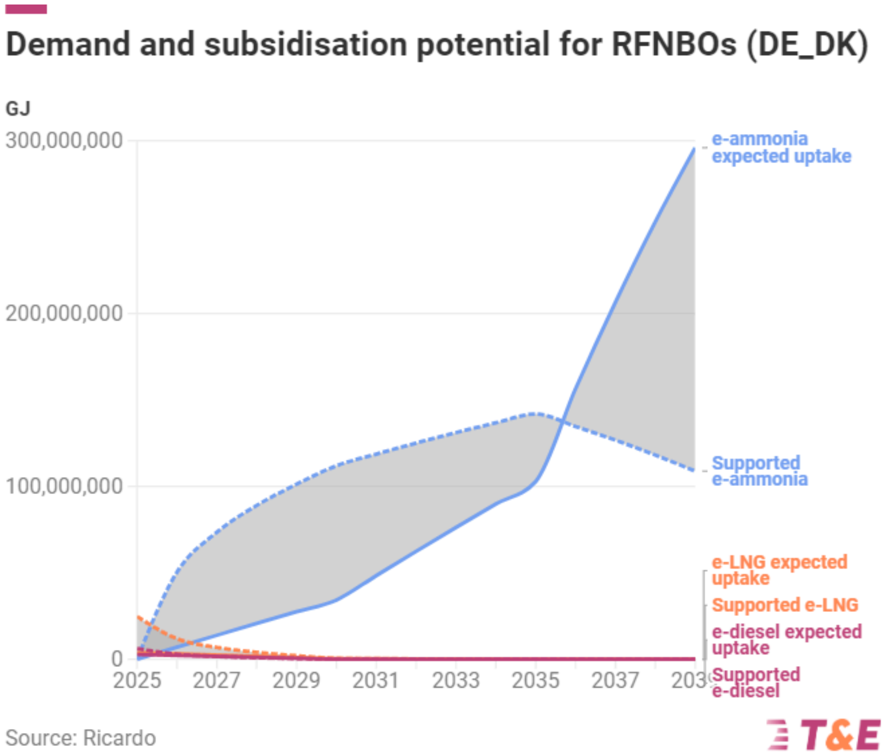


Figure S.7: Volume of RFNBO supported under CfD scheme vs expected uptake of RFNBOs under DE_DK scenario (proportional ETS funding allocation)

Figures S.8 and S.9 similarly demonstrate demand against available revenue, but this time with funds equally divided among all possible e-fuels types expected to be feasible for shipping. In the FEUM scenario (S.8) ammonia is marginal until the beginning of the second auction. Before this point, revenue is allocated to the other fuels. Uptake for ammonia reaches 92 million GJ (4.9 Mt) in 2035 and 296 million GJ (15.9 Mt) in 2040. In 2032 ammonia uptake surpasses the amount that can be supported (at around 30 million GJ - 1.6 Mt).

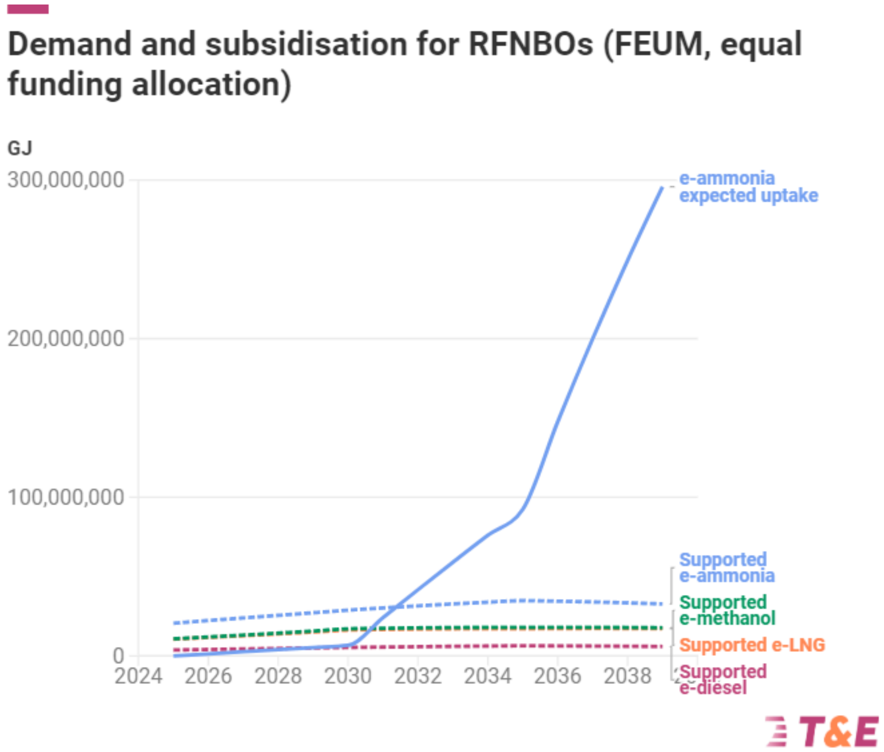


Figure S.8: Volume of RFNBO supported under CfD scheme vs expected uptake of RFNBOs under FEUM scenario (equal ETS funding allocation)

In the higher targets under the DE_DK scenarios, demand for ammonia outstrips subsidised volumes already in 2029, at 27 million GJ (1.5 Mt). Overall around 4.5% of total fuel consumption is supported by public funding over the two rounds of funding. Marginal amounts of e-LNG (below 4 million GJ, 0.1 Mt) and e-diesel (below 3 million GJ, under 0.1 Mt) can be supported from 2025. E-diesel is no longer supported in 2030, while e-LNG support falls to zero by 2035.

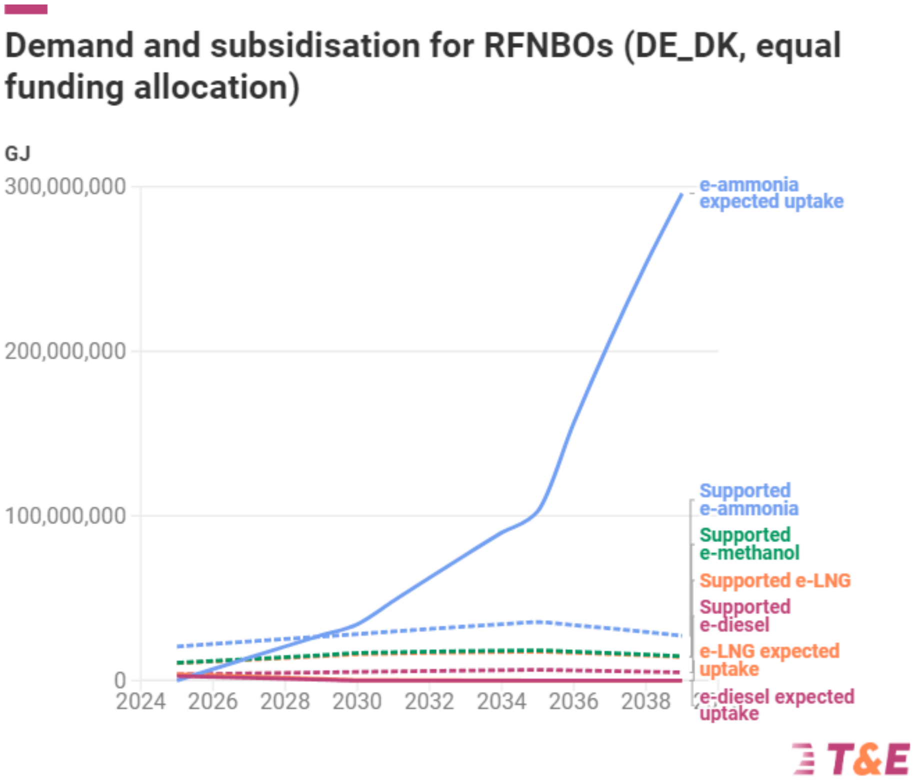


Figure S.9: Volume of RFNBO supported under CfD scheme vs expected uptake of RFNBOs under DE_DK scenario (equal ETS funding allocation)

The analysis on maritime emissions and funding shows:

- Using 25% ETS revenues can help significantly boost RFNBO uptake in the sector in this decade. But beyond 2036, existing targets under the FF55 would be sufficient to drive additional unsubsidised volumes;
- Revenues generation, fuel uptake and, most importantly, total emissions are lower under the scenarios modelled with energy efficiency;
- Revenue generation from the ETS peaks around 2035 in all scenarios in spite of a continually growing carbon price due to the uptake in zero-emissions RFNBOs;
- A similar amount of RFNBOs can be supported in the FEUM and DE_DK scenarios. The higher fuel targets in the latter means less revenues are available, but this implies less carbon costs for the industry with higher emissions reduction for society;
- Fuel uptake highest in FEUM scenario, lowest in DE_DK +EE scenario on a mass basis (26Mt RFNBO, of which the large majority is ammonia);
- In all scenarios there is sufficient revenue to support RFNBO uptake in the early years: in FEUM scenarios, this is until 2032, with total of 3% of RFNBO uptake supported, in DE_DK scenarios this is until 2029 with a total of 4.5% RFNBO uptake supported across the whole period.

4.2. Aviation

With the recent adoption of ReFuelEU, European aviation has clear e-kerosene mandates starting in 2030. While this European regulation gives a clear certainty to the clean fuels market and visibility for the levels of production in the coming decades, bringing first mover projects to final investment decisions requires targeted financial support. Investors remain reluctant to take on the burden of the first mover risks, with large price differentials compared to fossil kerosene. To compete with US-based production, public support must bridge a levelised cost gap of from 1,000 € to 4,000 € per tonne e-SAF, according to a SkyPower report.

Creating a CfD could help strengthen business models of the first projects and thus kick-start the e-kerosene value chain. The analysis evaluated the ability of a CfD scheme to support the development of the first e-kerosene projects at EU level. It therefore assesses to what extent a CfD funded with ETS revenues can support e-kerosene uptake. By filling a given part of the price gap between e-kerosene price (between ~ 5,000 €/t and 9,000 €/t) and fossil kerosene price (~1000 €/t), the CfD provides a clear signal which can be taken into account in these projects' business models and therefore help convince investors of its viability.

We explore four different scenarios:

1. **"Scenario FF55"** - The first one evaluates the share of the e-kerosene mandate that could be filled by a CfD covering 20% of the price gap (~1,000 €/t), using 25% of the revenues of the current ETS.
2. **"Scenario FF55+"** - The second one evaluates the same, but in the case of an extended scope of the ETS, which increases revenues to finance the CfD.
3. **"Scenario FF55+ using all funds"** - In the third scenario, we take a different approach: as extending the scope of ETS clears a significant amount of money, we look at how much we can fill the price gap beyond 20%, assuming in that particular case that all of the mandated volume of e-kerosene could be covered by the CfD.
4. **"Scenario T&E"** - The last scenario corresponds to our roadmap to decarbonise European aviation, which includes the need to reduce air traffic growth, a different fuel mix and increased fuel pricing.

To model a CfD that would function like the Innovation Fund for hydrogen production, we simulate two auctions where projects can apply for a 10 year support:

- Auction 1 from 2025 to 2034
- Auction 2 from 2030 to 2039

In the overlap period (2030 to 2034), it has been assumed that the available funding would be split equally between the two auctions.

Except in scenario 3. "Scenario FF55+ using all funds", the CfD scheme used is an annual scheme, with no ability to carry excess funding over to a future year or to anticipate additional funding from a future year. This reflects the case where the revenues collected a given year are considered to be used the same year. If 25% of ETS revenues exceed what is needed to fund the CfD for one year, it is considered that they are used elsewhere.

4.2.1 Scenario FF55: with current regulation, a CfD would help strengthen the business model for the first years

We model a CfD that fills 20% of the price gap between e-kerosene and fossil kerosene, which corresponds to a public support of around 1,000 € per tonne. We assume that the CfD is funded by 25% of ETS revenues, with current ETS scope. We take a business as usual growth of air traffic to model the fuel demand.

With that set of assumptions, we determine what part of the e-kerosene mandate could be covered by the CfD. We therefore compare the available funding with the level of spending required to cover the e-kerosene mandate from 2030 to 2040. We display the results with the medium assumption of e-kerosene price of 6075 € /t.

In the first auction, dedicating 25% of ETS revenue into the CfD covers 87% of the e-kerosene volume mandated. That represents 2,5 Mt of e-kerosene covered by the CfD and 2,5 bn€ of ETS revenues used for that purpose. In the second auction (2030 - 2029), the CfD would cover 48% of the e-kerosene volume mandated, or 9.1Mt, for a cost of 9,3 bn€. If we take it globally, this scheme would cover 55% of the mandated volume of e-kerosene until 2040.

These results show that, with current ETS scope, channeling 25% of the market's revenues towards an e-kerosene CfD would cover most of the first mandated volume. That financial support would clearly represent a useful financial tool to strengthen the business models of the first projects and help them reach final investment decision.

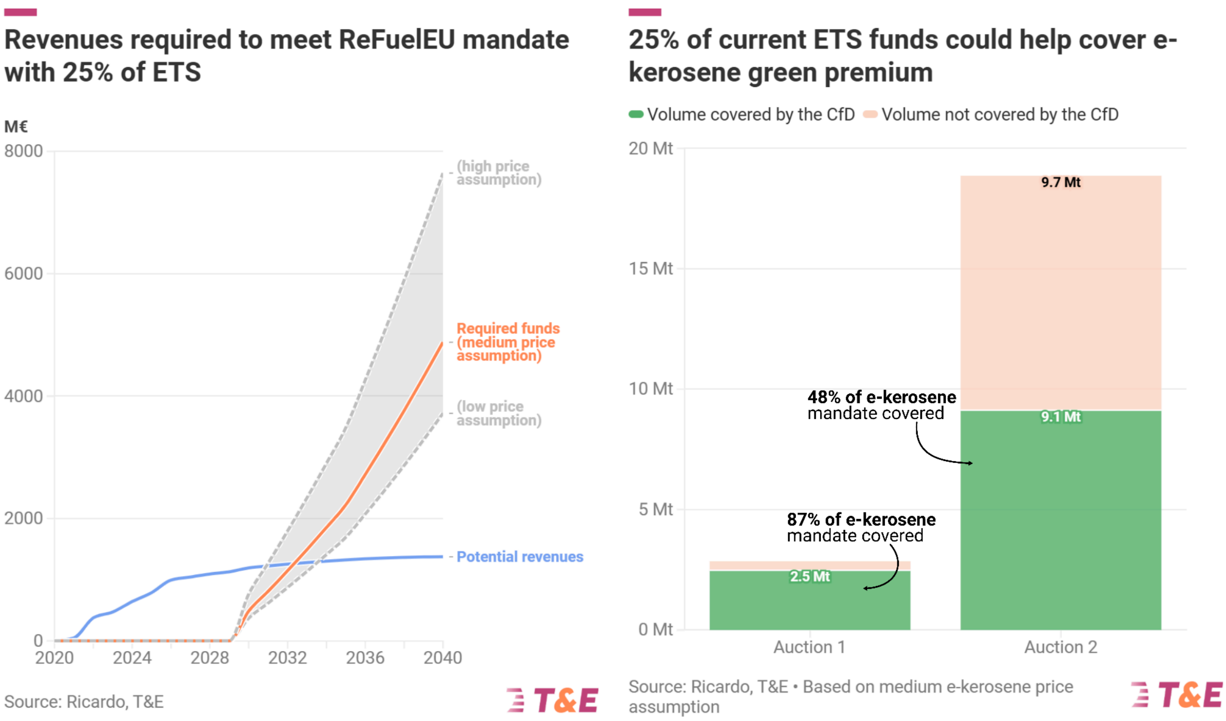


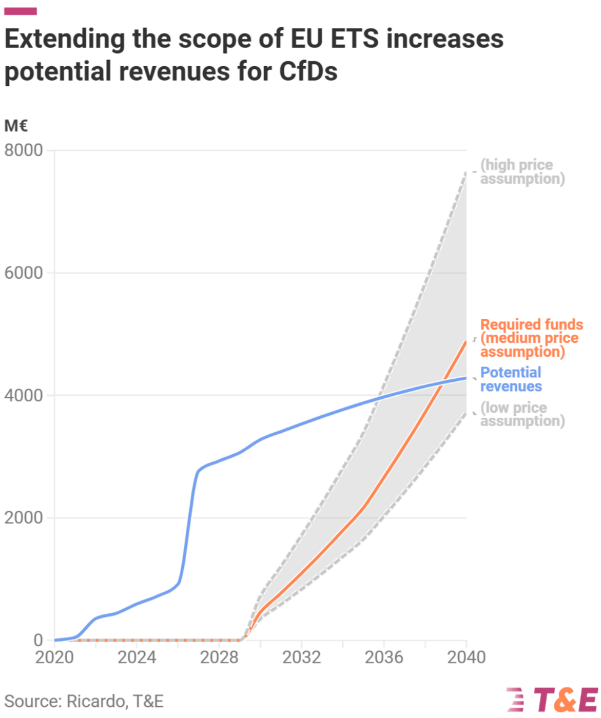
Figure A.1: Scenario FF55 annual CfD scheme to cover 20% of price gap

4.2.2. Scenario FF55+: extending ETS scope would clear revenues to support all of the mandated volume of e-kerosene

Extending the scope of the ETS to all departing flights would lead to significant increase of revenues. As presented in the graph below, in this case, 25% of ETS revenues would largely surpass funds required to cover the mandated volume of e-kerosene, using the 20% price gap level of coverage (~1,000 €/t) between e-kerosene price and fossil kerosene.

Except in the last years of the second auction where the financial needs go slightly beyond available funding, the CfD covers all the mandated volume. In the first auction, 2.7 Mt of e-kerosene could be covered for a cost of 2.7 bn€. In the second auction, 18.45 Mt is covered for a cost of 18.7 bn€.

We see here that an extension of ETS with the current modeled CfD scheme could offer greater support to the first e-kerosene projects' business models. By clearing a lot of revenues for such a scheme, it guarantees that 20% of the price gap between e-kerosene and fossil kerosene could be covered by a CfD until 2040, even in the worst case scenario where e-kerosene price is up to 9,000€.



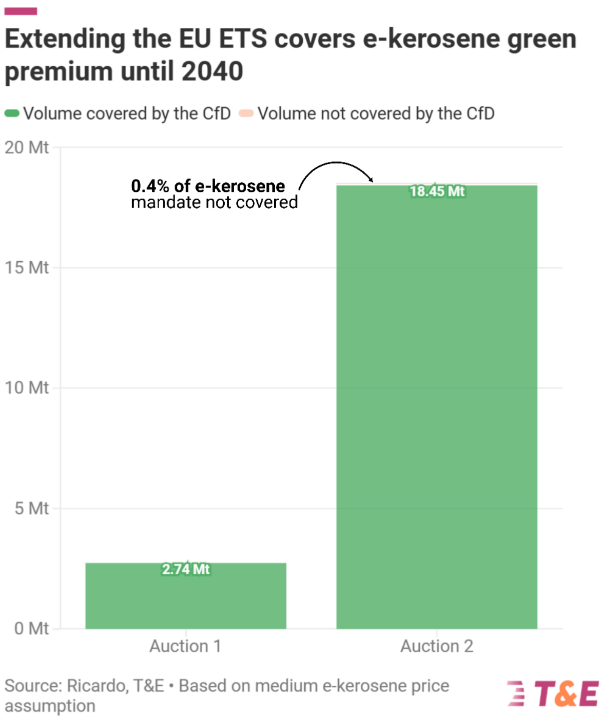


Figure A.2: Scenario FF55+ annual CfD scheme to cover 20% of price gap

4.2.3 Scenario FF55+ using all available funds: more money to go further

As we saw above, extending the scope of ETS increases significantly the revenues available for the CfD. This result opens the possibility to cover more e-kerosene volume, beyond the European mandate, or a bigger part of the price gap between fossil and e-kerosene. We explore that last option in this scenario. This modelling approach looks at how much of the price gap can be filled, assuming that 100% of the mandated e-kerosene volume is covered by the CfD scheme.

As we can see in the last graph (A.2), during the first year of the CfD, the mandate of e-kerosene is still quite low and leads to a small amount of funds required. During these years, the 25% of ETS revenues largely exceed the funds required for the CfD. Being able to use this money not spent the first years for the last years of the 10 year auction allows to better spread the revenues to match the bigger needs of last years, which would exceed revenues otherwise. Contrary to the two precedent scenarios, we therefore assume here that the CfD is no longer an annual scheme where only the ETS funds raised a given year can be used in the CfD the same year. Here, we take the assumption that all the funds raised during a given auction are usable during the auction. Concretely, that means that ETS revenues which are beyond the funds required by the CfD a given year are kept in reserve to be spent later.

Using all the funds cleared with 25% of ETS revenues allows the CfD to cover 100% of the price gap for the first auction, and 31% of the price gap for the second auction. Such a CfD could therefore make e-kerosene as competitive as fossil kerosene for 10 years, unlocking all barriers for airlines to sign offtake agreements and therefore drastically accelerate the uptake of e-kerosene. This theoretical modeling shows how far a CfD can go, when it's financed with 25% of ETS revenues, extended to all departing flights. However, the full coverage of the green premium by public funds could be detrimental in the long run and lead to poor investment returns, as it risks creating a dependency on state aid. A smaller and more balanced coverage of the green premium, as modeled in the previous scenarios, would certainly be sufficient to help launch the sector, and cover the first mover disadvantage of launching a nascent industry. The modelling shows that using the additional revenues from the extended ETS and covering less than half of the green premium, could still allow policy makers to cover the deployment cost of e-kerosene beyond the mandated volumes and help airlines commit on a voluntary basis to use e-kerosene rather than dubious biofuels[1].

[1] *UCO (Unknown Cooking Oil): High hopes on limited and suspicious materials*, T&E, June 2024

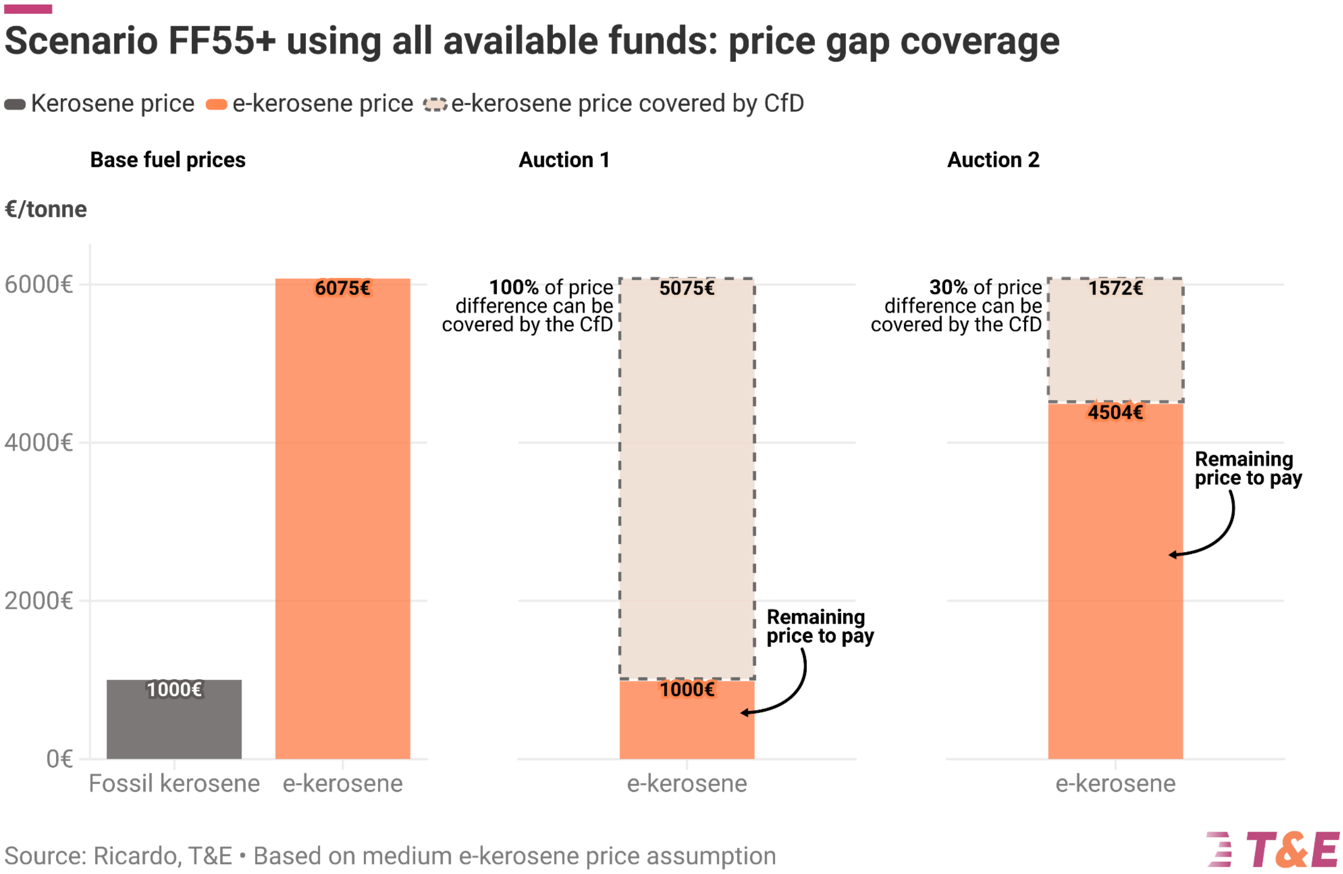


Figure A.3: Scenario FF55+ using all funds to cover 100% of e-kerosene mandated volume

4.2.4 Scenario T&E: going beyond ReFuelEU mandates in combination with demand management is the only way to significantly cut emissions

We showed that extending the scope of ETS allows CfD to fill all of the price gap between e-kerosene and fossil kerosene for mandated volumes during the first auction, and offers comfortable support for the second auction. That would help launch the e-kerosene sector. Yet, it appears that remaining at current ReFuelEU Aviation mandates is not sufficient to achieve satisfying emissions reductions.

Both FF55 and FF55+ scenarios only deliver between 44% and 47% emissions reduction compared to 2019 by 2050, with emissions broadly plateauing between 2025 and 2045. With higher fuel targets and reduced traffic growth through capped demand and stronger carbon pricing, aviation can benefit from sustained emissions reduction from the late 2020s to 2050.

We used the scenario developed in T&E's decarbonisation roadmap, which forecasts a greater proportion of alternative fuel, with a gradual ramp-up reaching 100% SAF by 2050, comprising 63% of e-kerosene, 19% of bio-SAF and 18% of pure hydrogen.

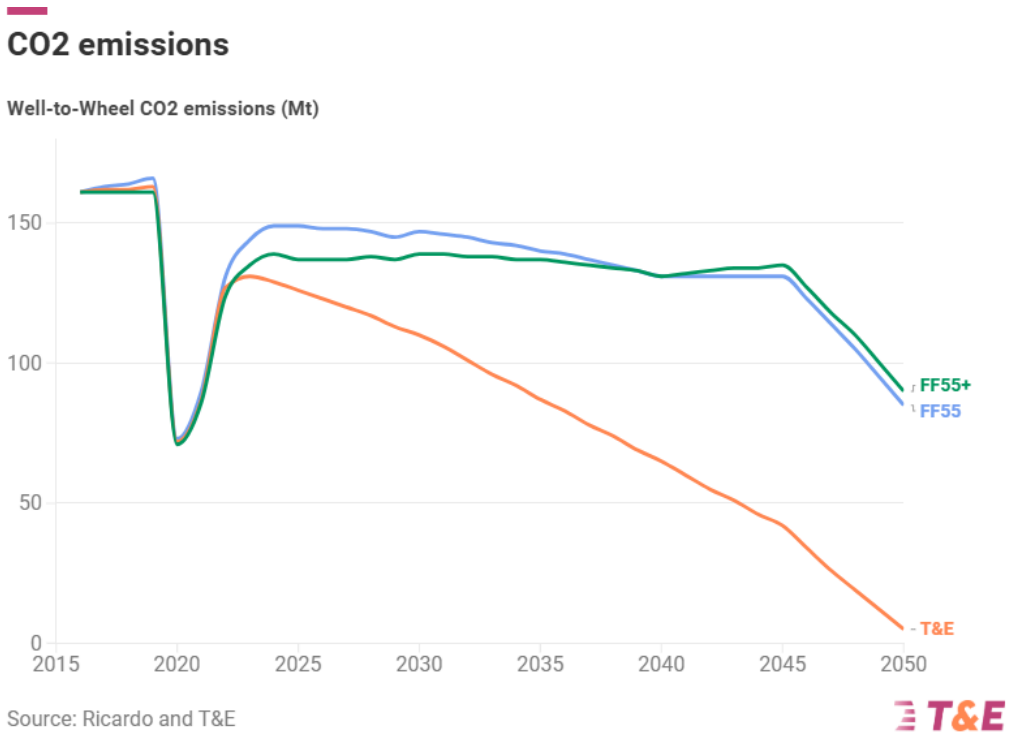


Figure A.4: Comparison of emissions between scenarios

This scenario includes the extension of ETS to all flights departing EEA airports. The results of the modeling show that ETS revenues are more than sufficient to fund a CfD that supports a steeper e-kerosene uptake. This results in a total e-kerosene uptake between 2025 and 2039 of 25.4 Mt (at a scheme cost of 25.9 bn€), which is 17% more volume than what is currently planned under ReFuelEU.

The more ambitious fuel mix makes it possible to reach net zero by 2050. Demand management allows, for the same amount of e-kerosene supported, to increase the share of e-kerosene in the fuel uptake, and so the potential emissions reduction. Or, to look at things differently, if we let the traffic continue to grow without control, it will cost a lot to support a great quantity of e-kerosene, without significantly curbing emissions. Thus, it appears profitable to the EU to adopt a more balanced vision of the growth of the sector.

For a quasi same amount of CfD cost (21,5 bn€), FF55+ scenario only delivers around 44% emissions reduction compared to 2019 by 2050. This shows how demand management allows to make public spending more efficient to decarbonise aviation.

5. Discussion and conclusions

The quantitative and qualitative analysis of public support schemes for RFNBO provide a number of lessons for policy-makers on the design of support schemes for shipping and aviation, as well as the legislative framework around which to apply the support.

In the short- and medium- term, limited public support for RFNBOs will be useful to guarantee private investments in novel projects and RFNBO deployments. Public support in the forms listed can kickstart the uptake of new fuels in the first years, promoting the ramp-up of a critical mass of new fuels and technologies to achieve widespread uptake.

- **CFDs offer a secure guarantee to the private sector, in particular for aviation,** where private sector investment in e-kerosene is severely lacking. CFDs provide greater flexibility and simplicity than CCFDs for both private investors and governments and are therefore preferable, especially given that both shipping and aviation companies have so far limited connection with carbon markets (shipping only entered the EU's carbon market in 2024 and a large amount of aviation emissions are still exempt from the ETS). However, **fixed premiums can be considered in the shipping sector**, which has less price elasticity of demand than aviation, meaning that the sector can better absorb higher costs with negligible impact on demand.
- **Supply-side contracts** for RFNBO producers are preferable to demand-side contracts for a number of reasons. They ensure all the necessary economic signals to be passed on to every stage of the supply chain. They similarly avoid particular issues in each sector: some airlines may not always be able to attain RFNBOs in every airport (mainly those that are not large international hubs), while in shipping a handful ports provide bunkering facilities to the lion's share of shipping companies, meaning that supply-side contracts similarly provide the most efficiency and simplicity. Supply-side contracts will in nature only focus on RFNBO, and leave out extra costs due to the building of new technologies (such as ammonia vessels or hydrogen aircraft). The European Commission should consider facilitating access to subsidies for capex for companies that win opex funding for their hydrogen or derivatives.

The limited funding means that policy-makers will need to make choices on which energy carrier to subsidise. In this case of aviation, it is clear that e-kerosene production should be partly subsidised, given the mandate creates effective demand and that the development of hydrogen aircraft is still not mandated through regulation.. In the maritime sector, there is a greater choice of fuels, which increases the risk of **stranded assets.** For T&E it is then clear that policy-makers should focus financial support on fuels most likely to remain competitive and part of the maritime energy mix in decades to come. For the moment this appears to mean hydrogen for short sea shipping and ammonia and methanol for transoceanic shipping, although policy-makers will need to make sure every environmental issue related to the fuels (i.e. ammonia and nitrous oxide emissions, methanol and sustainable CO_2 sources) are considered.

Policy-makers should also consider the level of funding. As per previous Innovation Fund calls, they could put the **limit of funding at 60%** of the costs needed so that the market can valorise the remaining part as green premiums. Alternatively, the Commission should consider a **'pay-as-clear'** design (where all bidders receive the level of subsidy proposed by the one winning bidder) to encourage competition and limit government spending. To ensure RFNBO projects in shipping and aviation have sufficient lead time, the Commission could allow a **maximum of 5 years** for the projects to come on board after bidding.

Finally, and most importantly, this study has demonstrated **the need for policy-makers to optimise the regulatory framework** within which the public support operates to ensure impact. While scenarios without demand management in aviation or energy efficiency in shipping generate more revenue, they limit emissions reduction and lead to a greater dependency of the transition on state subsidies. Furthermore, they increase demand and therefore competition for RFNBOs, thereby driving up prices.

T&E therefore recommends that policy-makers focus on the efficiency of their public support:

- Prioritise RFNBOs in shipping and aviation as strategic net zero technologies within the EU's **Clean Industrial Deal,** including through specific subsidy calls for RFNBOs for these sectors. This should include earmarking a percentage of revenues going from shipping and aviation to the EU ETS towards RFNBOs and simplifying administrative processes to approve RFNBO projects.
- Implement **demand management through aviation** policy and legislation to mandate **energy efficiency improvements in shipping**. Internalise the external costs of shipping and maritime fuels, for example through the **Energy Taxation Directive (ETD);**
- Put in place clear mandates (at national or European level) for the supply of RFNBOs to the maritime sector in the **Renewable Energy Directive (RED);**
- Increase and bring sooner the RFNBO sub-target in **FuelEU Maritime**;
- Increase the scope of the **ETS** to end exemptions for international departing flights and smaller vessels.

Further information

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Appendix

Summary of aviation scenario results

	Scenario FF55		Scenario FF55+		Scenario T&E		Scenario FF55+ using all funds		
Auction	1	2	1	2	1	2		1	2
ReFuelEU e-kerosene mandate (Mt)	2.8 Mt	18.9 Mt	2.7 Mt	18.5 Mt	3.7 Mt (T&E fuel mix)	21.7 Mt (T&E fuel mix)		2.7 Mt	18.5 Mt
Revenues required to fill the 20% price gap	2,9 bn€	19,1 bn€	2,8 bn€	18,8 bn€	3,8 bn€	22,1 bn€	**Revenues required to fill the full price gap**	13,9 bn€	94,0 bn€
Part of revenues available for the CfD, with no annual carry over	2,5 bn€	9,3 bn€	2,8 bn€	18,7 bn€	3,8 bn€	15,3 bn€	**Revenue available during the whole auction periods**	19,2 bn€	29,1 bn€
Share of mandated e-kerosene covered (in %)	87%	48%	100%	99.60%	100%	69%	**Price gap level supported by the CfD**	100%	31%
Share of mandated e-kerosene covered (in Mt)	2.5 Mt	9.1 Mt	2.7 Mt	18.45 Mt	3.7 Mt	15.1 Mt			
Emissions reduction (2050 / 2019)	47%		44%		97%			44%	