Incentivizing low-emissions fuels: policy options and trade-offs

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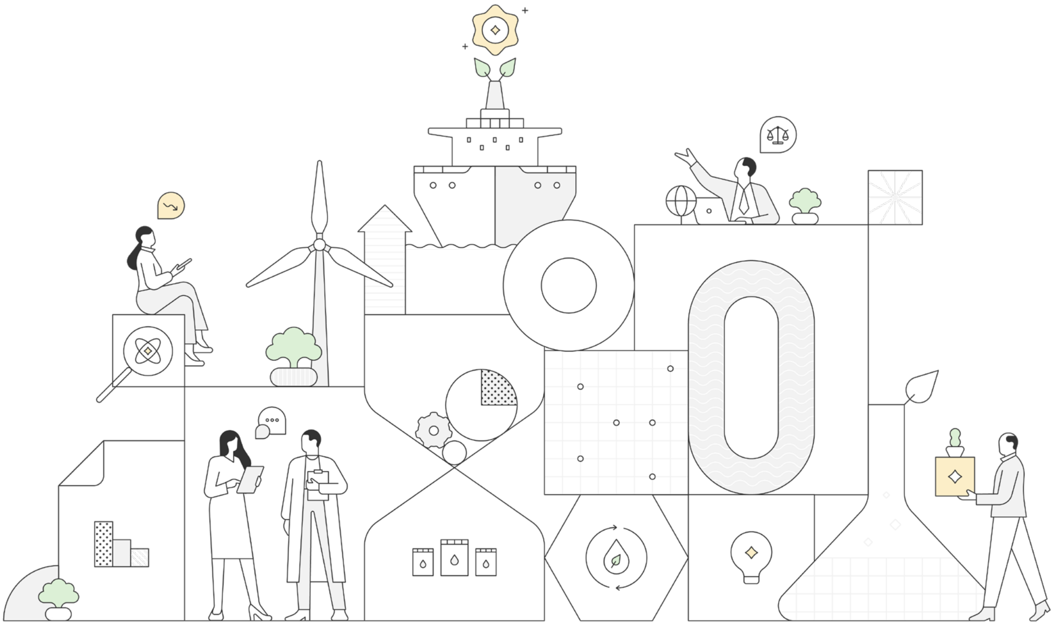

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Executive summary

Decarbonizing international shipping ultimately requires switching to low- and zero-emissions fuels. However, these fuels remain substantially more expensive than the fossil energy they would replace, partly because the climate damage from fossil fuels is not reflected in their market price. Targeted financial support can help close this gap, but its design determines whether subsidies buy cheap near-term emissions cuts or build a future low-emissions fuel system.

To ground our discussion of subsidy programming for low-emissions fuels, we focus on an active policy debate: how to incentivize "zero or near-zero" (ZNZ) fuel use in the context of the International Maritime Organization's (IMO) Net-Zero Framework (NZF). If implemented, this framework currently under negotiation would be a globally binding climate regulation for shipping.

Underlying any ZNZ reward scheme is an overarching choice: whether subsidies are used to lower the cost of abatement using fuels already close to being competitive, or to accelerate the deployment of higher-cost but scalable next-generation fuel pathways. Pursuing both aims with a single undifferentiated instrument risks achieving neither well.

Taking this trade-off as the starting point, we distil the design of a ZNZ reward program into five interlocking "variables": eligibility, abatement benchmark, multipliers, differentiation, and reward instruments. In this paper, we set out the options under each variable and examine the trade-offs across incentive strength, fiscal durability, and environmental integrity. We recommend an approach where the analysis supports a clear preference.

Section 1 of the paper explains the need for incentives. Section 2 introduces the NZF and the methodology for calculating ZNZ rewards. Section 3 lays out our main analysis of each of the five variables, while the conclusion consolidates this analysis in a decision table. Two appendices cover the multiplier mechanism and further differentiation criteria.

We argue that eligibility should rest on a clear abatement benchmark (in the IMO context, the NZF's well-to-wake greenhouse gas (GHG) intensity threshold and associated IMO Life Cycle Assessment (LCA) Guidelines), rather than on a parallel sustainability framework. Of the remaining decision variables, multipliers are a second-best lever where monetary rewards are unavailable, since they sever the link between credited and physical abatement. Reward rate differentiation can be useful to bring forward scalable next-generation fuels. Finally, the choice of reward instrument is important: fixed rates favor investor predictability at the cost of quantity rationing, flexible rates protect the budget at the cost of reward certainty, and auctions combine fiscal discipline with price discovery at higher administrative cost.

Policymakers prioritizing lower abatement costs should generally favor harmonized rates; those prioritizing scaling of low-emissions energy carriers should differentiate reward rates, with multipliers as a fallback where funds are insufficient. With other regional and national regimes falling into place, the need for thoughtful design of subsidy regimes for low-emissions energy in the NZF and more broadly will only become more relevant.

01 Introduction

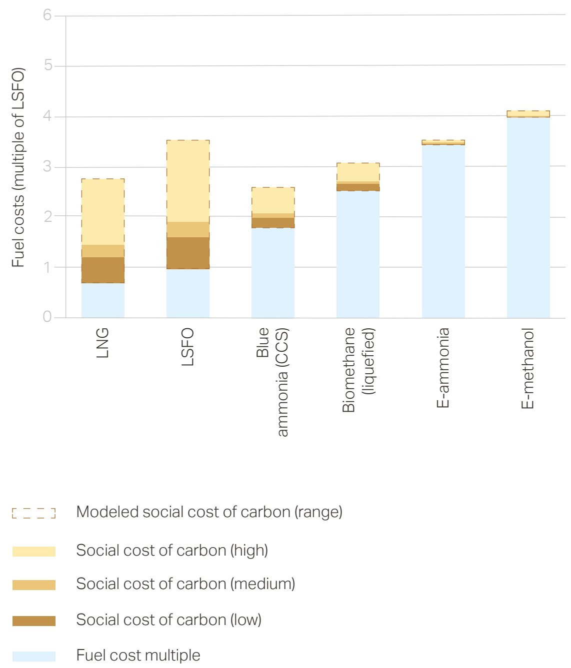
Developing an effective reward program for low-emissions fuels requires careful design and informed trade-offs. This options paper seeks to bring clarity to the decisions facing policymakers by setting out key design choices for an effective subsidy regime for low-emissions fuels.[a] We apply our analysis to the active policy debate of how to incentivize the use of low-emissions fuels in the context of globally binding climate regulation: the IMO NZF.

1.1 Motivation for rewarding low-emissions fuels?

Low-emissions fuels are technically feasible, but more expensive than traditional fossil energy sources. This cost (or price) gap reflects several factors, including technical maturity and market scale. But an important driver for the cost gap is that fossil energy generally does not reflect the cost of the externality of climate damage from emissions associated with its production or combustion.

Figure 1 shows the effect of adding the cost of climate damage estimated in the literature to the cost of energy. These social costs of carbon (SCCs) are the estimated net present value of future costs of anthropogenic climate change. If this negative climate externality were priced in, a range of low-emissions fuels could be cost-competitive.

Figure 1: Integrating a social cost of carbon would impact relative fuel costs.



Notes: Data: MMMCZCS modeled production costs or market proxies. Fuel costs are shown as multiples of LSFO, a benchmark fossil fuel. Data assumes 2030 estimated fuel costs for the median case. Fuel-specific SCC add-ons are derived by applying the relevant well-to-wake carbon intensity values to the low, median, and high SCC used in the analysis, set at 75, 100, and 300 USD/tCO$_2$eq) respectively. SCC estimates from climate modeling literature summarized by Tol (2023).[1] Fuel costs are strictly indicative. Own analysis. LSFO = low-sulfur fuel oil, LNG = liquefied natural gas, CCS = carbon capture and storage.

[a] Throughout the paper, we refer to low-emissions energy for combustion as 'fuels', referring to both liquids and gases.

Against this backdrop, financial support from policymakers can make low-emissions energy competitive, incentivizing uptake over time and accelerating a shift to a broad-based market for these fuels. In general, achieving this scale-up requires policy support to address cost gaps and revenue risk.

For example, data from structured interviews show that fuel project developers regard bankable offtake contracts as the most binding constraint on their ability to achieve financial close on alternative fuel production projects.[2] Policy support can help overcome this constraint by reducing offtaker risk and improving revenue certainty, for example through demand-side subsidies, credit guarantees, or contracts for difference that make long-term purchase agreements more commercially viable for buyers.[3,4]

This brings us to the question of how policymakers can structure subsidy programs for low-emissions energy to best support the desired policy outcomes.

1.2 Lowering abatement costs today or building future energy supply for tomorrow?

When considering how to structure rewards for units of emissions abatement, the core design decision for policymakers is whether subsidies should primarily:

– "Maximize abatement today": lower the cost of abatement for consumers by rewarding low-emissions energy that is relatively cheap today, or;

– "Incentivize scaling for tomorrow": accelerate the deployment of low-emissions fuels that have not yet scaled and so remain relatively expensive today, while offering larger future emissions reductions.

For the purposes of this paper, we focus on emissions abatement using low-emissions fuels rather than technologies like wind-assisted propulsion.

Lowering the cost of abatement for consumers favors readily deployable, lower-cost fuel pathways and can deliver near-term volumes efficiently. This "maximize abatement today" approach prioritizes energy types that are already relatively competitive because they can deliver immediate volumes at low subsidy levels.

On the other hand, accelerating the deployment of low-emissions energy that remains expensive today requires incentivizing production. Under this "incentivize scaling for tomorrow" approach, the reward scheme would deliberately provide stronger and more predictable support for higher-cost but scalable pathways (e.g., fuels requiring new assets and long lead times). This support helps to bring projects to a final investment decision, stimulate learning-by-doing, and build the infrastructure needed to scale up next-generation fuels.[b]

This is a trade-off. The "maximize abatement today" approach can secure more emissions abatement because scaled energy is cheaper. However, with fixed total funds, this approach can crowd out more expensive pathways that may be strategically important for long-term decarbonization.

1.3 Decision variables

In general, designing an effective reward methodology for low-emissions fuels depends on a set of design choices ("decision variables"). In this paper, we discuss five key decision variables: eligibility, abatement benchmark, multipliers, differentiation, and reward instruments. Collectively, these variables determine whether subsidies "maximize abatement today" or "incentivize scaling for tomorrow" — the main policy tradeoff at hand. The NZF as currently under negotiation (Section 2) is the starting point of our analysis.

[b] Here, we define 'next-generation fuels' as a family of fuels that includes both e-fuels (such as e-ammonia and e-methanol) and advanced biofuels such as hydrothermal liquefaction (HTL) and pyrolysis bio-oils. These options are still costly and immature, but they offer the scalability and climate performance needed for a net-zero pathway by 2050.

02 Reward design in practice: the IMO NZF

The IMO NZF is a set of regulatory measures that seek to reduce GHG emissions from international shipping, in line with the IMO's 2023 GHG Strategy.[5,6] At the core of the IMO NZF is the Global Fuel Standard (GFS). The GFS sets a limit on the greenhouse gas fuel intensity (GFI) of energy used by ships, with the limit becoming increasingly stringent over time.

Building on the GFS, the NZF creates a compliance market with two main instruments. Firstly, ships that do not meet the applicable GFI target must purchase remedial units (RUs). Secondly, ships that perform better than the target can generate surplus units (SUs), which can be sold at a market-determined price to other ships so that the buyers can compensate for non-compliance. Buying SUs is therefore an alternative compliance option under the NZF. Together, these levers raise the cost of operating with higher-emissions fuels and monetize the value of outperforming the GFS.

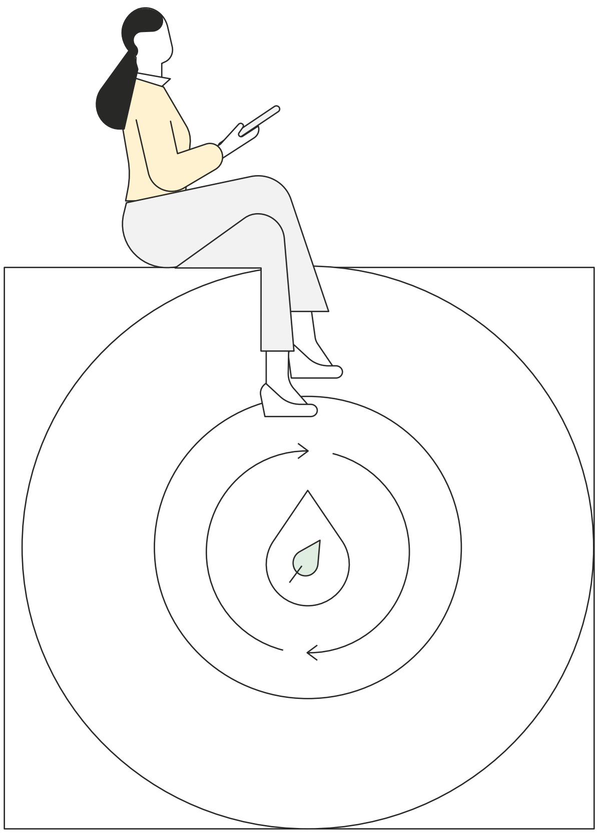
In addition, the NZF introduces a reward mechanism to further reduce the cost, and thereby accelerate the uptake, of very low-emissions fuels. In the draft framework, ZNZ fuels and technologies are currently defined as those with a GFI below 19 grams of carbon dioxide equivalent per megajoule (gCO_2eq/MJ) through 2034 and below 14 gCO_2eq/MJ from 2035.[7] These fuels and technologies are eligible for ZNZ rewards, which are funded through RU revenues.

The ZNZ reward is intended to support the 2023 IMO GHG Strategy's objective that ZNZ technologies, fuels, and/or energy sources represent at least 5%, striving for 10%, of the energy used by international shipping by 2030. IMO Member States are now actively considering the design of these rewards.

Because the NZF is under negotiation, it may not ultimately include ZNZ rewards. The design choices discussed here remain relevant to any scheme to incentivize production and consumption of low-emissions fuels.

2.1 Calibrating subsidies

In all reward schemes, policymakers choose a unit of analysis (e.g., units produced) to receive rewards. In the NZF, a ship's ZNZ reward for a given calendar year is calculated by linking (i) the quantity of well-to-wake GHG emissions avoided (compared to a threshold) using eligible ZNZ fuels to (ii) the applicable reward rate. If applicable, an eligible energy source might benefit from a so-called multiplier.



How ZNZ rewards are calculated in the NZF

1. Calculate GHG emissions avoided

For a calendar year *y*, total avoided emissions are the sum across all ZNZ fuels *i* used by the ship:

$$GHG_{avoided,y} = \sum_{i=1}^{I} GHG_{avoided,i,y}$$

where: $GHG_{avoided,i,y}$ is the GHG emissions avoided from using ZNZ fuel *i* in year *y*, expressed in tonnes of well-to-wake carbon dioxide-equivalent GHGs (tCO_2eq)

I is the number of distinct ZNZ fuels used by the ship in year *y*

Total avoided emissions can also be expressed as:

$$GHG_{avoided,y} = \sum_{i} (e_f - e_i)\, q_i \cdot 10^{-6}$$

where: q_i is eligible ZNZ energy (MJ)

e_i and e_f are the well-to-wake GFI values (in gCO_2eq/MJ) of the eligible fuel (*i*) and the benchmark against which its abatement is measured (*f*) respectively, and a scaling factor given the units used here

A ship's average emissions intensity ("attained GFI") is then defined as:

$$e = \frac{\sum_i e_i\, q_i}{\sum_i q_i}$$

2. Apply the reward rate:

A ship that has used eligible ZNZ fuels during year *y* may apply for a reward. The total reward is calculated by applying the relevant reward rate to each fuel's avoided emissions and summing:

$$Reward_y = \sum_{i=1}^{I} (GHG_{avoided,i,y} \times Rate_{i,y}) * I\{0,1\}$$

where: $Reward_y$ is the total reward claimed for year *y* (USD)

$Rate_{i,y}$ is the reward rate applicable to fuel *i* in year *y* (USD/tCO_2eq)—this rate may be common across fuels (harmonized) or differentiated based on certain principles

$I\{0,1\}$ signifies reward eligibility—if a fuel is ruled out from the ZNZ definition (either on a GFI basis or additional criteria), it does not generate ZNZ rewards

3. Optionally apply a multiplier

A potential additional policy feature is the introduction of a multiplier for selected ZNZ energy. The multiplier increases these pathways' compliance weight in the attained GFI calculation without changing physical emissions.

Unlike ZNZ rewards, multipliers are not monetary payments; they increase incentives by granting additional SUs (compliance credits) that can be sold and therefore have monetary value. A multiplier (m_i) can be represented as an adjustment to the denominator of the attained GFI:

$$\tilde{e} \equiv \frac{\sum_i e_i\, q_i}{\sum_{i \in M} m_i q_i + \sum_{j \notin M} q_j}$$

where: *M* is the set of multiplied pathways

j denotes an eligible fuel without a multiplier applied

If $m_i \geq 1$, then the "effective energy" in the denominator increases, so $\tilde{e} < e$ for the same physical energy (ZNZ) use. We discuss multipliers further in Section 3.3 and Appendix 1 of this paper.

03 Decision variables and considerations

In this section, we describe each of our five selected decision variables in the context of the IMO NZF and share either a recommended approach or a discussion of the trade-offs for policymakers. We consider how the reward schedule shapes incentives, the fiscal sustainability of the funding allocated to support low-emissions energy, and the environmental integrity of the resulting rule set.

3.1 Eligibility

Eligibility simply refers to which types of energy can access rewards. There are generally two approaches:

Option A: Purely intensity-based cut-off

For the IMO NZF, a single GFI-based cut-off provides a technology-neutral, transparent, and low-complexity eligibility rule that can be implemented quickly and consistently across fuels. It limits discretion, reduces administrative burden, and keeps the reward mechanism focused on the core climate metric already embedded in the NZF: the well-to-wake GFI.

On the other hand, a GFI cut-off alone can advantage pathways that have low GHG intensity but are linked to other material harms (e.g., land-use change, biodiversity impacts, water stress, local pollution, weak traceability). If this effect is not mitigated, Option A can allow these pathways to capture a disproportionate share of policy support, potentially undermining the regulation's credibility.[8]

Option B: Intensity-based cut-off and additional considerations

Adding criteria for sustainability or certification helps ensure that rewards target fuels that are both low-emissions and environmentally credible. These criteria should consider the material and geographic heterogeneity of relevant sustainability risks. For example, land-use impacts may vary substantially by feedstock origin and supply chain.[9]

Considerations:

Eligibility is central to both the effectiveness and legitimacy of the ZNZ reward mechanism: it determines which pathways can access support and whether rewarded uptake is environmentally credible. In the current IMO NZF draft text, ZNZ eligibility is simply defined through a well-to-wake GFI threshold, initially set at 19 gCO_2eq/MJ.[7]

Therefore, the effectiveness and legitimacy of the reward mechanism depend heavily on rules governing sustainability criteria—in this case, the IMO LCA Guidelines and associated sustainability provisions. The IMO's 2024 LCA Guidelines, which allow us to estimate the well-to-wake GHG emission factors for marine fuels, also include ten sustainability themes or aspects, each with its own objective and metric.[10] These themes are broadly described and are pending further guidance to be developed by the IMO.

A useful guide here is the Tinbergen Rule: distinct objectives are best served by distinct instruments.[11] As it stands, the NZF incentivizes lower carbon intensity through the GFI and addresses broader sustainability performance through the LCA Guidelines.

The reward, then, should focus on what these existing NZF mechanisms do not fully address—"incentivizing scaling for tomorrow" (e.g., financing constraints, scalability limits, and learning/experience effects) or "maximizing abatement today"—while avoiding duplication of carbon-intensity incentives (GFI) or re-litigating sustainability rulemaking (LCA Guidelines). Therefore, the ZNZ reward methodology should operationalize the IMO LCA Guidelines as an entry condition for eligibility, rather than creating a parallel sustainability framework within the reward rules.

In a second-best scenario where sustainability elements are not sufficiently addressed or implementable, it would be appropriate for the reward eligibility rules to include sustainability criteria (e.g., certification/traceability requirements or exclusions for clearly high-risk pathways). This would preserve the technology-neutral intent of the GFI threshold while preventing the reward from inadvertently incentivizing unsustainable pathways.[c]

3.2 Abatement benchmark

The abatement benchmark is the reference GHG intensity value used to calculate "GHG avoided." This benchmark is a core design lever because it affects the incentive strength of the ZNZ reward and the rate at which the funding source is drawn down.[12]

In the NZF, "GHG avoided" for fuel pathway *i* increases with the difference between the benchmark and the fuel's GHG intensity per unit of energy, e_i:

$$GHG_{avoided,y} = \sum_{i} (e_f - e_i)\, q_i \cdot 10^{-6}$$

A higher abatement benchmark (for example, the GHG intensity of LSFO rather than LNG) mechanically increases the "GHG avoided" per MJ, which—holding reward rates constant—raises payout claims and makes the funding source easier to deplete. Choosing a lower benchmark therefore allows for a higher reward per tonne of emissions avoided.

The GFI of a given fuel pathway might evolve over time: e_i will typically decline as upstream supply chains and electricity systems decarbonize and production processes improve. Early in the transition, relatively few producers may be able to meet the ZNZ threshold, limiting eligible volumes. Later, more pathways may qualify and the same pathway may deliver more avoided emissions per MJ as its life-cycle intensity falls. This means that abatement benchmark design interacts with the expected evolution of e_i and therefore affects both the strength of incentives and the funding source exposure as eligibility expands.

Option A: Static benchmark

A static benchmark is simple and predictable. The main downside is fiscal: if ZNZ uptake grows substantially over time, a fixed benchmark (e_f) keeps "GHG avoided per MJ" constant. This implies that total credited avoided emissions (and therefore payout claims at a given reward rate) can rise rapidly as the number of eligible units grows. Without additional guardrails (rationing on volume or reducing reward rates), this increases the risk that the source of subsidy funds is depleted quickly as uptake scales.

Option B: Time-varying benchmark

A declining benchmark (a reduction in e_f over time) can act as an automatic fiscal stabilizer as uptake of eligible fuels grows. By reducing credited "GHG avoided per MJ" over time, this option dampens the growth in total credited avoided emissions and therefore slows the expansion of payout obligations for a given volume of eligible fuels. This can reduce the likelihood of exhausting the budget if there is high ZNZ uptake.

A declining benchmark should not be viewed as a substitute for fiscal guardrails, as the hard budget constraint for the funding source still applies. But this is a parameter choice that reduces the likelihood and severity of binding guardrails as volumes consumed grow.

Considerations:

A fixed benchmark results in more eligible abatement as the use of ZNZs scales up, while a declining benchmark blunts this effect (generating relatively fewer abatement claims over time). With a capped amount of funding available, this reduces to a choice between higher total rewards for using an eligible fuel (but a greater likelihood that some eligible abatement will not receive a reward) and a lower total reward for using an eligible fuel (but a lower likelihood that some eligible abatement will not be rewarded).

[c] Further, policymakers should be aware that eligibility for reward is not sufficient to enable fuel pathways that require significant new infrastructure (e.g., for production, storage, and bunkering). For these fuels, translating rewards into real supply expansion also depends on bankability and allocation design. This does not mean that such 'infrastructure-dependent' fuels are inherently "ineffective" candidates for rewards. Rather, they require more careful instrument design (e.g., predictable support or contracting) to convert eligibility into investable signals. On a related note, judging support needs based on unit fuel costs alone can be misleading. This is because the relevant barrier for some pathways is not just the cost of the fuel molecule, but the combined cost of the molecule plus enabling infrastructure. The implications for targeting and differentiation are discussed in Section 3.4.

As such, this variable presents a decision between higher average rewards and more rationing, and lower average rewards but less rationing.

In the IMO context, fiscal sustainability is probably a hard constraint. ZNZ uptake is expected to scale significantly over time,[13] and ensuring broad-based access to rewards for using ZNZs is an important design feature. By dampening the growth in credited "GHG avoided" per MJ as volumes rise, Option B reduces the likelihood of abrupt budget corrections and can make the reward mechanism more durable as the market matures. Therefore, a declining, time-varying benchmark is likely the preferred option. In the NZF, a practical way to implement a time-varying benchmark is to link e_f to the IMO GFI reference values. There are two important caveats. First, reference values beyond 2035 are not yet defined in the current framework. This is a source of policy uncertainty for industry participants and complicates long-term investment planning. Second, the advantage of reducing fiscal pressure on funding for rewards is achieved by mechanically reducing (the discounted present value of) future rewards. This can reduce the incentive to procure low-emissions energy over time, undermining the goal of the incentive program. This declining support may be offset if green premiums fall with scale and learning, meaning that later volumes can clear with lower rewards.

3.3 Multipliers

Multipliers are regulatory mechanisms that increase the compliance value of specific fuels, typically by multiplying their contribution in GHG intensity or energy accounting. The rationale for applying a multiplier is to accelerate early uptake of scalable, sustainable technologies (e.g., e-fuels), especially when these face high initial costs or supply barriers.

A multiplier (represented as m_i) increases the amount of abatement calculated for the same physical emissions.

$$\tilde{e} \equiv \frac{\sum_{i} e_i q_i}{\sum_{i \in M} m_i q_i + \sum_{j \notin M} q_j}$$

Including a multiplier has two implications:

– Budgetary slack: Multipliers require no spending by the regulator or a central Fund at the point of award. They increase the amount of tradable compliance (SUs, in the case of the NZF) created per unit of eligible fuel (ZNZ). In that narrow sense, multipliers are "free" to the policymaker.

– Potential price impacts: Multipliers create credited abatement that is larger than physical abatement. This increases the supply of SUs relative to what would be generated under physical accounting. All else being equal, this increased supply puts downward pressure on the SU price (the overall effect depends on market design and demand for SUs).[14]

In Appendix 1, we share technical derivations showing how multipliers affect measured GHG intensity, SU generation, and marginal incentives.

Multipliers can appear complicated but are not novel. They feature in many regulatory regimes, such as the Low Carbon Fuel Standard in California and the European Union's (EU) Renewable Energy Directive and FuelEU Maritime.[15, 16, 17] In the context of the IMO NZF, several Member State submissions (notably from the Clean Shipping Coalition, Korea, and the World Shipping Council) have proposed multipliers as a tool to accelerate uptake of ZNZs.[18, 19, 20] Therefore, while multipliers are not part of the ZNZ reward design per se, we include them in our discussion here as a policy option that can interact with this reward design.

Option A: No multiplier

This option assumes that the policy design includes revenue generation (e.g., from RU payments, levies, or another mechanism) and an operational channel to disburse financial rewards for uptake of ZNZ fuels.

Under Option A, incentives for ZNZ fuels are delivered through explicit payouts. In the NZF context, ships that use eligible ZNZ fuels receive a financial reward per unit of verified physical uptake (or per unit of verified emissions reduction). This approach preserves a clear link between physical abatement and incentives: the measured intensity reflects real fuel shares and real well-to-wake intensities, while additional support is provided transparently through payments. Because the policy can directly mitigate the cost gaps of ZNZ fuels using revenue, there is little need to inflate compliance performance using multipliers.

Option B: Multiplier applied to a specific subset of fuels

This option assumes the policy design does not generate revenue (or enough revenue) so there are no or insufficient financial rewards available to incentivize alternative fuel uptake. Under Option B, policymakers want to accelerate uptake of specific alternative fuels but cannot rely on payouts.

A multiplier is a non-budgetary incentive: eligible fuels receive a compliance “boost” by counting more in the accounting of energy and/or GHG intensity. This lowers the measured compliance intensity for a given physical blend and increases the ability to generate (or avoid) compliance units under the NZF—see also Appendix 1.

Considerations:

Multipliers can be understood as a policy substitute for subsidy: they increase the private payoff for adopting eligible fuels by granting additional credited compliance units (SUs in the NZF context) rather than transferring funds.

In the absence of any funds to pay ZNZ rewards, a multiplier can be the only available lever to strengthen incentives for more expensive fuels. The multiplier effectively monetizes uptake of these fuels by generating greater potential for surplus compliance.

Option B can therefore deliver stronger near-term adoption signals without a funding pipeline, but it does so at a cost. This option increases credited compliance relative to physical abatement and affects the supply, and potentially the price, of SUs. The net effect on total abatement (and ZNZ uptake) is therefore ambiguous.

Accordingly, Option A is the preferred design where feasible. This option supports early uptake and avoids distortions to markets and price dynamics for SUs. Multipliers should be treated as a second-best lever: most relevant when the NZF does not mobilize (sufficient) revenue. Longer-term scale-up of new system fuels is better supported through monetary instruments once available.

If they are applied, multipliers should be calibrated so that added ZNZ abatement outweighs any reduction in other SU-driven abatement from lower SU prices. This trade-off is also time-dependent: multipliers are most plausibly a transitional tool in early years (when ZNZ supply is scarce and funding may be limited). To avoid persistent dilution of compliance signals, multipliers can then be phased down as markets mature.

3.4 Differentiation

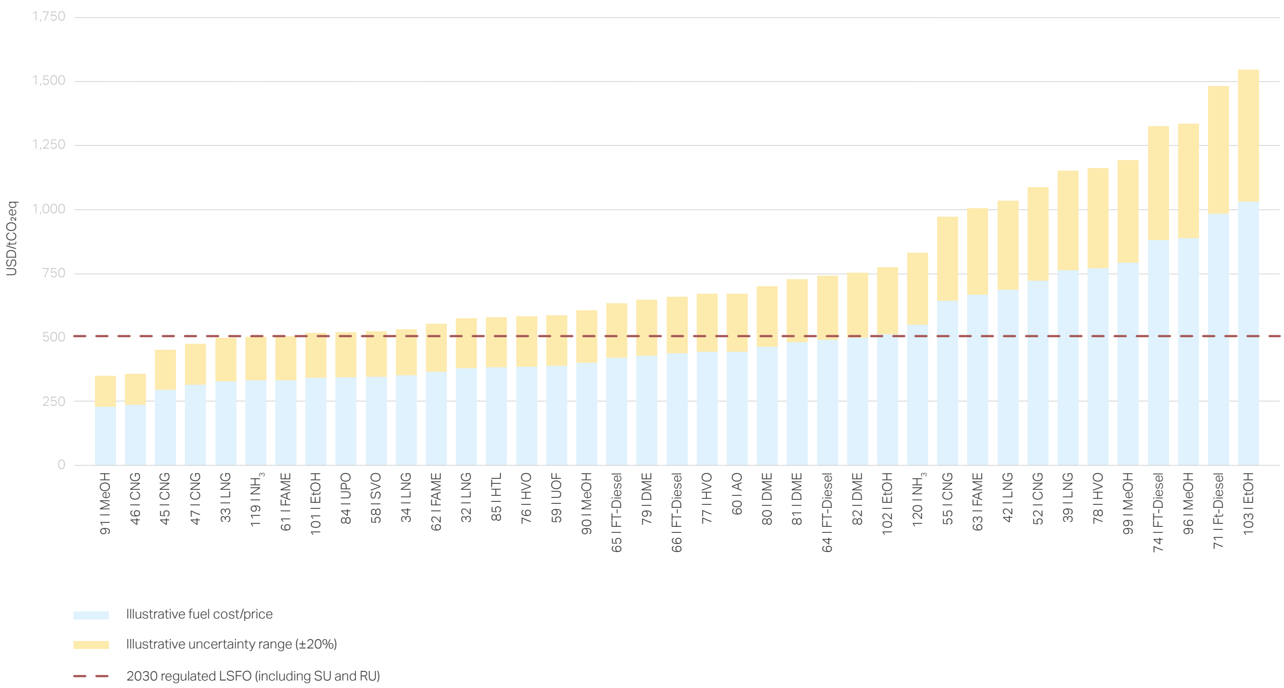
Differentiation means setting different reward levels for different (eligible) fuel pathways. It differs from eligibility in that the former is binary, while differentiation is a matter of degree. Differentiation could be based on one or several principles, which we discuss further in Appendix 2.

To illustrate the challenge that differentiation can address, Figure 2 shows a range of illustrative costs for selected fuels that may be eligible for rewards in the context of the NZF. These are a subset of the fuel pathways listed by the IMO LCA Guidelines as “bio-” or “e-”, referring to either biologically derived energy (e.g., biodiesel) or energy based on electrolytic hydrogen (e.g., some low-emissions ammonia pathways). Illustrative values in Figure 2 use a combination of market data and publicly accessible sources and do not represent any individual company’s position. They are illustrative and reference points for the purpose of the analysis, not benchmarks—readers must apply their own assumptions.

Subsidies help to address the cost difference between low-emissions energy and fossil energy, indicated in Figure 2 with a horizontal line at a representative price point for fossil energy and adding the total penalties (RUs) and compliance benefits (SUs). We use illustrative LSFO model prices for 2030 (per the MMMCZCS NZF compliance cost calculator) as the indicative cost comparison point.

As Figure 2 shows, the estimated cost gap with respect to LSFO can vary substantially depending on the fuel pathway. A single (undifferentiated) reward rate therefore creates a trade-off: a high reward rate can be inefficient because it over-subsidizes abatement generated by fuels with smaller cost gaps, while a low reward rate may be ineffective because it will incentivize some low-emissions energy, but risks excluding higher-cost energy sources that could be scalable. In the face of this trade-off, differentiated reward rates can offer a policy mechanism for fine-tuning the range of fuel pathways supported by the reward scheme.

Figure 2: Modeled illustrative cost gaps for fuel pathways vary significantly.



Notes: Fuels shown here are a subset of fuels categorized as 'bio' or 'e' in the IMO LCA pathways. Fuel labels represent an IMO fuel code (e.g., 91) and combine this with a fuel pathway mapping (e.g., MeOH for methanol). Fuel pathways are assumed to have a well-to-wake emissions intensity of 18 gCO_2eq/MJ (where IMO LCA estimates are not available). The 2030 LSFO reference includes an unregulated LSFO price plus SU and RU (USD 1,586/t LSFOeq, equivalent to USD 509/tCO_2eq). The difference between each bar and the LSFO reference line shows the remaining support needed for that fuel to reach parity with LSFO (the cost gap), which can be negative for some fuels. We add an illustrative uncertainty range to factor in price/cost variability. Fuel costs are strictly illustrative. Own analysis. LSFO = low-sulfur fuel oil, SU = surplus unit, RU = remedial unit.
Sources: Argus Alternative Marine Fuels; Argus Biofuels; Davis et al. (2011); Dossow et al. (2025); Dziva et al. (2024); EU Horizon (2021); European Biogas Association (2023); IEA (2025); IRENA (2021); Landälv & Waldheim (2017); Liu & Hamel (2023); MMMCZCS (2024); Oxford Institute for Energy Studies (2024); Pedersen et al. (2018); Platts Global Bunker Fuel Cost Calculator; Rystad Energy.

Option A: No differentiation (harmonized reward rate)

A single reward rate applies to all eligible ZNZ pathways. This is administratively simple and transparent. However, a rate high enough to support higher cost fuels risks overpaying fuels that are already nearcompetitive (inefficient), while a rate set to avoid overpayment may fail to unlock "scaling for tomorrow"—investment in fuel pathways that are more expensive yet scalable (ineffective).

Option B: Differentiation based on cost gaps

Reward rates vary across fuel groups according to the size of the remaining cost barrier (e.g., cost gap versus a fossil benchmark or carbon abatement cost in USD/tCO_2eq). Compared with Option A, this approach improves both effectiveness and cost discipline: lower rates can be applied to fuels where compliance incentives (SUs) already close most of the gap, and higher rates where the gap remains large.

Cost-gap estimates should be treated as time-sensitive and updated regularly, because externally-assessed subsidy needs can quickly become miscalibrated as industries innovate and costs fall. Experience with early solar PV feed-in tariffs in parts of Europe, for example, suggests that static, government-assessed cost gaps can overestimate required support.[21]

A weakness of this option is that cost-gap differentiation alone does not distinguish between pathways that are expensive but scalable and pathways that are expensive because they are fundamentally constrained (e.g., due to limited feedstock).

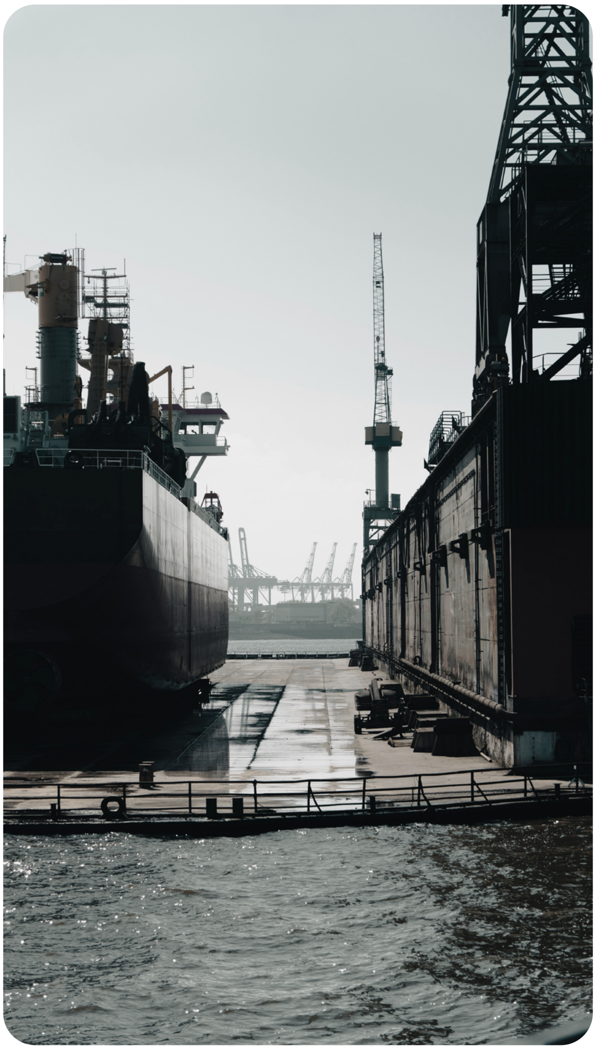
Option C: Differentiation based on cost gaps and other features that policymakers wish to incentivize

Reward rates vary across fuel groups and are set using cost barriers and a further assessment. For example, policymakers could consider a pathway's scalability or cost-down potential as criteria for differentiation.

Cost-down potential indicates whether early support is likely to generate dynamic benefits (learning-by-doing, scale economies, infrastructure spillovers), but it does not indicate the level of support needed to trigger uptake today. Appendix 2 further explores how these additional criteria could be operationalized.

Option C can reduce the risk that scarce or constrained pathways receive high rewards simply because they are costly today, while protecting scalable next-generation pathways from crowd-out by readily deployable fuels with smaller near-term cost gaps.

The main friction for this option is operational. For example, differentiation based on scalability requires policymakers to agree on transparent measurements to assess this criterion (feedstock potential, conversion yields, infrastructure readiness) and periodic updating. This complexity increases governance and data requirements.



Considerations:

If policymakers primarily want to maximize near-term low-cost abatement with minimal complexity ("maximize abatement today"), a harmonized rate (Option A) may be sufficient. Policymakers considering this option should recognize that it will favor readily deployable, high-elasticity fuel pathways.

Option B introduces targeting and can therefore support a broader set of fuels than Option A. However, a targeting mechanism based on cost gaps alone may not fully prevent crowd-out of scalable next-generation pathways.

Therefore, if the policy objective is to also bring forward scalable next-generation fuel pathways (the "incentivize scaling for tomorrow" approach), differentiation must incorporate a scalability lens (Option C) and/or segmentation. In short, Option C is preferable when long-run scale-up is part of the goal; Options A and B are consistent with a strategy focused mainly on cheaper near-term volumes.

If the goal of the ZNZ reward mechanism is to subsidize both current and next-generation fuels, differentiation should be embedded as a core element. Without differentiation, limited budgets and high supply responsiveness can concentrate support in a narrow set of fuel options, even if those options face scalability constraints. Differentiation is therefore also justified to keep open pathways that are scalable at the system level while the evidence on costs, supply constraints, and infrastructure matures.

3.5 Reward instruments

A central design choice for the ZNZ reward is the instrument used to allocate support under a fiscal constraint. In the case of the NZF, the funding source cannot commit to spending more in ZNZ rewards than it collects in revenue from RUs. In practice, therefore, the reward mechanism must translate a finite annual budget into actual payments, while maintaining incentives that are credible enough to drive additional ZNZ uptake and investment. For a given year (*y*), we can illustrate this budget constraint by summing the per-ship reward (which is itself a sum over ZNZ fuel *i*) across all *N* ships in the fleet.

$$\text{Expected payouts}_{Fund} = \sum_{n=1}^{N} \sum_{i=1}^{I} \text{Reward rate}_{i,y} * (e_f - e_i) * q_{i,n} * 10^{-6} \leq \text{(Expected) Fund revenues}$$

Where: *n* indexes ships, *i* indexes ZNZ fuels used by ship *n*, and $q_{i,n}$ is the eligible ZNZ energy (MJ) of ZNZ fuel *i* used by ship *n*.

Three options are considered below. Each resolves the same tensions differently: who bears the risk of uncertain uptake (the funding source or market participants), and how budget discipline is achieved (rationing volumes, varying rates, or competitive allocation of funds). Comparing the options set out below, this allocation of risk cannot be avoided: policymakers must instead be clear-eyed about how their choice of rate methodology affects the allocation of risk.

Option A: Fixed reward rate (ex-ante fixed rate; rationing on quantities if oversubscribed)

The Fund announces an ex-ante reward rate (potentially differentiated by fuel type), paid per unit of GHG avoided. If total claims exceed the annual budget available, the Fund stays within budget through explicit rationing (caps) rather than by changing the reward rate ex-post.

Option B: Flexible reward rate (ex-post adjusted reward rate; all eligible quantities receive something)

Total annual spending is capped, and the realized reward rate is determined after total eligible ZNZ uptake is known. In oversubscribed years, the reward rate automatically adjusts downward so that all eligible ZNZ quantities (q_i) still receive a payment.

Option C: Auctions (competitive allocation within a fixed budget)

The funding source allocates a fixed annual (or multi-year) budget through competitive bidding. Eligible participants bid for the reward level they require (e.g., USD/tCO_2eq avoided), and contracts are awarded until the budget is exhausted. Auctions can be segmented (separate pots by fuel class) to support differentiation and reduce crowd-out.

Considerations:

All three instruments can respect a hard fiscal limit, but they allocate risk and uncertainty differently. Choosing among these options depends on the policymaker's objective.

Fixed reward rates (Option A) offer strong predictability of the unit reward and can be more supportive of investment planning, especially for pathways requiring long lead times and high upfront capital. It is also relatively straightforward to communicate, as participants know the reward rate schedule in advance.

For this option, fiscal protection comes via quantity rationing: in years of high ZNZ uptake, some eligible volumes may not receive the reward, depending on the rationing rule. If rationing is poorly specified (e.g., ad hoc, first-come-first-served without clarity), predictability can erode and administrative disputes can increase. In addition, a fixed rate can lead to over- or under-compensation if fuel costs evolve quickly, unless rates are periodically reviewed or differentiated within pots.

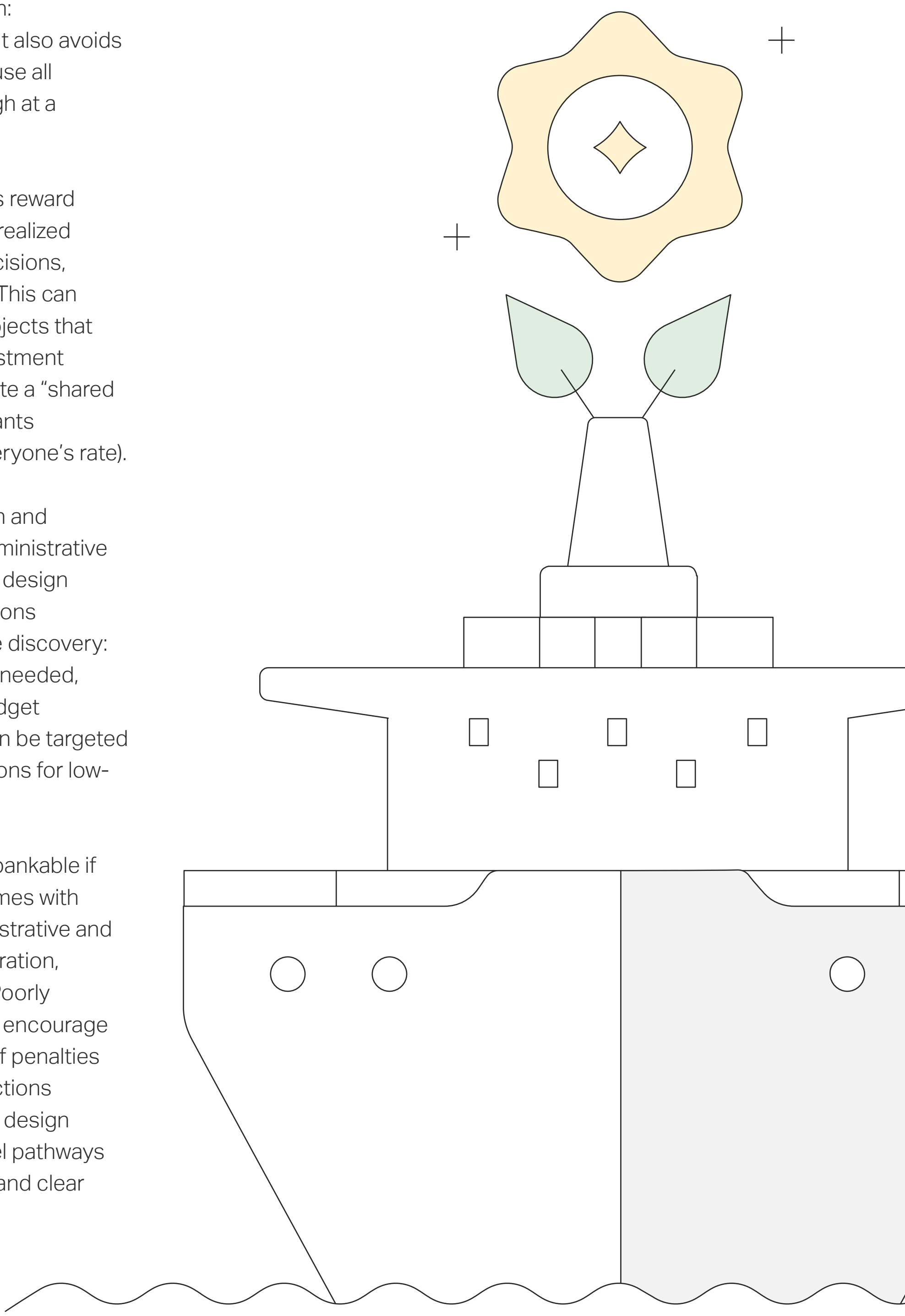
Flexible rewards (Option B) protect the budget automatically but shift uncertainty to the unit reward, which can weaken bankability. This option provides a strong form of automatic fiscal protection: overspending risk is eliminated by design. It also avoids hard "winners/losers" from rationing, because all eligible claimants receive a payout (although at a variable rate).

The primary downside of flexible rewards is reward uncertainty: participants cannot know the realized unit payment when making investment decisions, because it depends on aggregate uptake. This can weaken incentives for capital-intensive projects that require revenue visibility before a final investment decision. Further, this uncertainty can create a "shared budget" dynamic where individual participants face dilution risk (others' uptake lowers everyone's rate).

Auctions (Option C) avoid both rate dilution and overspending. However, they introduce administrative and participation costs and require careful design to avoid crowd-out and non-delivery. Auctions combine strong fiscal protection with price discovery: competition reveals the minimum support needed, reducing systematic overpayment risk. Budget discipline is built in, and the mechanism can be targeted through segmentation (e.g., separate auctions for low- versus high-elasticity fuels).

For winning projects, auctions can still be bankable if they award clear multi-year terms. This comes with a trade-off: auctions impose higher administrative and participation costs (qualification, bid preparation, verification, non-delivery enforcement).[22] Poorly designed auctions can deter participation, encourage strategic bidding, or result in non-delivery if penalties and qualification rules are weak. Finally, auctions may not be technology-neutral in practice: design features can implicitly advantage some fuel pathways over others,[23] which makes differentiation and clear objectives important.

If the policy objective is to support the deployment of low-emissions energy, providing reward rates that are signaled in advance is likely the critical enabling factor. Under fiscal constraints, auctions can provide this certainty. Fixed reward rates can provide certainty on pricing, but not for all units produced or consumed, while flexible reward rates assure all units of some uplift at the cost of uncertainty on pricing.



04 Conclusions

This paper summarizes a small set of variables that policymakers may consider when designing reward programs to incentivize the uptake of low-emissions fuels (Table 1).

Our discussion, grounded in the context of the IMO NZF, highlights the trade-offs in each design decision and can help policymakers select a coherent package of design choices consistent with their intended transition pathway.

Table 1: Summary of decision variables and high-level policy options.

Decision variable	Definition	Rationale	Options		
Eligibility	Which fuels/ pathways qualify for rewards (binary: in/ out).	Protect environmental integrity and credibility by ensuring rewards go only to fuel pathways that meet GHG and sustainability requirements.	Intensity-based cut-off.	Intensity-based cut-off and additional sustainability considerations.	
Abatement benchmark	The reference GFI value used to calculate "GHG avoided" by using the eligible fuel.	Influences "GHG avoided" and manages incentive strength and fiscal exposure of the subsidy. Because lower-emissions energy is more expensive, a lower benchmark (i.e., smaller 'GHG avoided') generally means that eligible fuels face a higher abatement cost.	A static benchmark that does not change over time.	Changing benchmark (time-varying).	
Multipliers	Regulatory mechanisms that increase the compliance value of specific fuels, typically by multiplying their measured energy content or abatement.	In scenarios where there is no central financing source or budget, multipliers may be one of the few viable levers to steer uptake toward targeted fuel pathways.	No multiplier (assuming revenue generation).	Multiplier for a specific subset of fuels (in the absence of revenue generation).	
Differentiation of reward rates	Setting different reward levels for different eligible fuel pathways.	A high uniform reward rate will be inefficient because it over-subsidizes abatement generated from fuels with smaller cost gaps. A low uniform reward rate will incentivize some low-emissions energy, but can be ineffective as it risks excluding energy sources that are higher-cost.	No differentiation (harmonized reward rate across all eligible fuels).	Differentiation based only on cost gaps compared to a benchmark fuel.	Differentiation based on cost gaps and other features that policymakers wish to incentivize (e.g., scalability, cost-down potential).
Reward instruments	The mechanism for allocating rewards.	Translate a budget constraint into payments while balancing bankability, cost discipline, and administrative complexity (i.e., who bears uptake/ price uncertainty).	Reward fixed by the policymaker before the "market" clears (i.e., before total abatement generated is known).	Reward fixed by the policymaker after the "market" clears (i.e., after total abatement generated is known).	Reward determined through competitive bidding (auction) and fixed once awarded.

GFI = GHG Fuel Intensity, GHG = greenhouse gas

There are three important takeaways from our analysis:

First, each decision carries trade-offs. Some choices have clear recommendations (e.g., the need for credible eligibility/LCA linkage and for fiscal guardrails under a hard budget constraint). Others have no single "best" answer (e.g., the degree of differentiation and the choice of allocation instrument). For the latter cases, this paper aims to help negotiators and policymakers remain clear about the trade-offs that arise from the choices they make.

Second, the core decision is whether subsidies should mainly enable the consumption of near-term and lower-cost energy ("maximize abatement today") or help scale next-generation fuels that require new investment ("incentivize scaling for tomorrow").

Third, the cost and calibration of rewards should follow from the outcome of this core decision. Policymakers must be clear on what they aim to achieve when choosing among these design variables. Policymakers aiming to "maximize abatement today" should emphasize harmonized reward rates tied to credible revenue streams and do not need to carefully consider differentiation. At the same time, they must accept that these choices do not create incentives to make or use low-emissions fuels that are not yet available at scale (and hence more expensive today).

By contrast, policymakers aiming to ensure the use and availability of these newer, scalable low-emissions fuels—"incentivize scaling for tomorrow"—are well-served by differentiating reward rates and considering the use of multipliers if funds are insufficient. They should carefully consider criteria beyond cost gaps that should inform reward rate calculations.

The IMO NZF is a near-term and fast-moving opportunity to embed global, binding regulation. With other regional and national regimes falling into place, the need for thoughtful design of subsidy regimes for low-emissions energy will only become more relevant.

05 Acknowledgements

This paper was prepared by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS). The paper does not represent the views of external reviewers or their organizations.

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Thanks to Nina Sophia Maeder (formerly MMMCZCS) for her input and feedback on the work.

Abbreviations

CCS	Carbon capture and storage
CO_2	Carbon dioxide
gCO_2eq/MJ	Grams CO_2-equivalent per megajoule
GFI	Greenhouse gas (GHG) fuel intensity
GFS	Global Fuel Standard
GHG	Greenhouse gas
IMO	International Maritime Organization
LCA	Life cycle assessment
LNG	Liquefied natural gas
LSFO	Low-sulfur fuel oil
MMMCZCS	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
NZF	Net-Zero Framework
RU	Remedial unit
SCC	Social cost of carbon
SU	Surplus unit
tCO_2eq	Tonnes CO_2-equivalent
TRL	Technology readiness level
USD	United States dollar
ZNZ	Zero- or near zero

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Appendix 1: Multipliers

In the NZF, compliance is determined by average GHG intensity (GFI) of the fuel mix, while investment/operational decisions are driven by marginal costs of switching fuels. This tension between an average metric and marginal choices produces "kinks" in the regulatory incentives. These "kink points" mark the emissions-intensity thresholds where the NZF switches from one compliance treatment to another.

Around these points, a small change in emissions intensity has a different marginal regulatory effect because the fuel mix moves into a different reward or penalty zone.

Figure 3 illustrates how the marginal regulatory value of abatement under the NZF changes discretely across different ranges of emissions intensity. This can also be expressed in the following equation, where *P(e)* denotes the regulatory costs and incentives:[24]

$$P(e) = \begin{cases} -s \cdot (e_D - e) \cdot E, & \text{if } e < e_D \quad \text{(SUs)} \\ r_D \cdot (e - e_D) \cdot E, & \text{if } e_D \leq e < e_B \quad \text{(Tier 1 RUs)} \\ r_B \cdot (e - e_B) \cdot E + r_D (e_B - e_D) \cdot E, & \text{if } e \geq e_B \quad \text{(Tier 2 + Tier 1 RUs)} \end{cases}$$

Definitions

We consider a ship that meets one unit of energy demand using a mix of:

- q_A: share of alternative/ZNZ fuel, $q_F = 1 - q_A$: share of fossil fuel
- E_m: the multiplier-adjusted accounted energy of the fuel total mix

Fuel GHG intensities:

- e_A: well-to-wake GHG intensity of the alternative fuel, e_F: well-to-wake GHG intensity of fossil fuel Typically $e_A < e_F$ for a genuinely low-emissions alternative
- e_m: the GHG intensity (emissions per unit of accounted energy); the subscript *m* denotes the multiplier-adjusted version

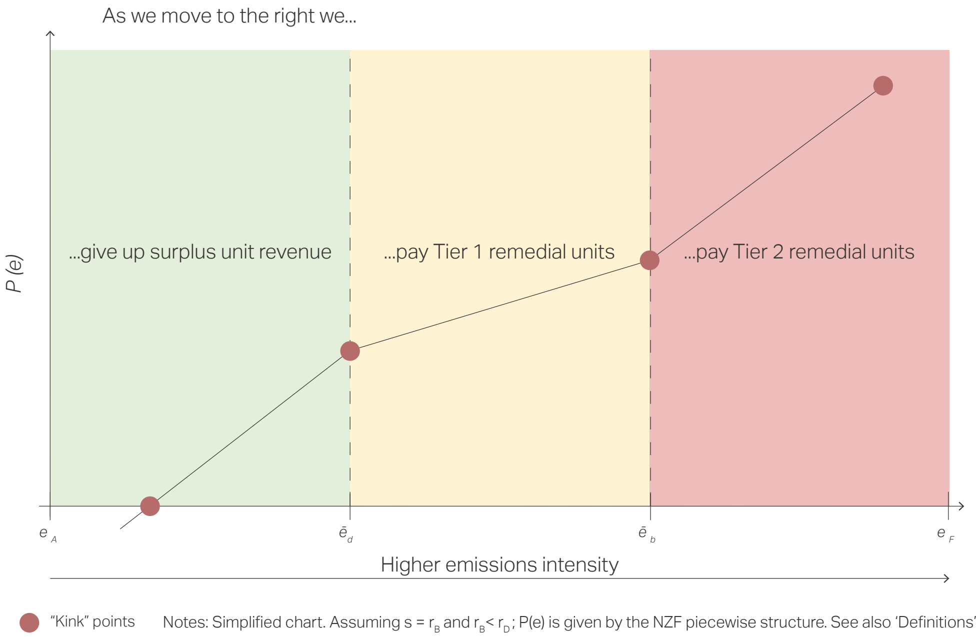
NZF GHG intensity targets:

- e_D: direct (Tier 1) target, e_B: base (Tier 2) target, with $e_D < e_B$

NZF unit values (slopes of the piecewise regulatory function):

- s: value (price) of SUs when a ship lowers its emissions further than is required by e_D
- r_D: Tier 1 RU rate in the band e_D to e_B
- r_B: Tier 2 RU rate above e_B
- c_A, c_F: unit energy costs of alternative and fossil fuels

Figure 3: Regulatory cost under the NZF depends on emissions intensity.



Notes: Simplified chart. Assuming $s = r_B$ and $r_B < r_D$; P(e) is given by the NZF piecewise structure. See also 'Definitions' box.

Introduction of a multiplier for the IMO NZF

A multiplier changes how the average emissions intensity is calculated for compliance purposes, without changing the ship's physical energy use. Multipliers make a given physical uptake of low-emissions fuels look "bigger" in the compliance metric, thereby changing the strength and location of the marginal incentive to switch (i.e., shifting the curve shown in Figure 3 downwards).

The regulation introduces a multiplier $m > 1$ for ZNZ fuels that affects compliance accounting (and thus only q_A in the NZF context):

$$E_m \equiv q_F + m\, q_A = 1 + (m - 1)\, q_A$$

The multiplier-adjusted average intensity used for compliance calculations then becomes:

$$e_m(q_A) = \frac{e_A q_A + e_F q_F}{E_m}$$

$$e_m(q_A) = \frac{e_A q_A + e_F q_F}{1 + (m - 1)\, q_A} = \frac{e_F + (e_A - e_F)\, q_A}{1 + (m - 1)\, q_A}$$

With the multiplier, each unit of alternative fuel counts more in the denominator, so the intensity e_m is lower than without multipliers (when $m > 1$) for the same physical fuel mix. Because E_m rises with q_A when $m > 1$, each physical unit of alternative fuel has a larger effect on the compliance denominator.

This makes the compliance intensity e_m lower than it would be without multipliers for the same physical blend. By amplifying the compliance impact of q_A, multipliers can move ships earlier into more favorable regions of the NZF schedule: for example, out of Tier 2 penalties (red in Figure 3) or into SU generation (green in Figure 3).

Multipliers monetize abatement through SU generation

Consider the ship's average intensity relative to the direct target e_D. When the ship's (accounted) intensity is below e_D, the ship generates SUs proportional to the accounted intensity's distance from the target, multiplied by accounted energy. In our notation (and within the SU region),

$$SUs(q_A, m) = (e_D - e_m(q_A, m))E_m(q_A, m)$$

where:

$$E_m = q_F + m\,q_A$$

$$e_m = \frac{e_A q_A + e_F q_F}{E_m}$$

If SUs can be sold at price *s*, then the ship's SU revenue is:

$$R_{SU}(q_A, m) = s \cdot SUs(q_A, m) = s\,(e_D - e_m)\,E_m$$

In this way, the NZF "monetizes" abatement: cleaner fuel choices lower the compliance intensity and generate tradable SUs that can be sold.

Now introduce the multiplier $m > 1$. Holding the physical fuel blend fixed, the multiplier increases accounted energy E_m and reduces accounted intensity e_m, mechanically increasing SU generation:

$$(e_D - e_m)\,E_m = e_D\,E_m - (e_A q_A + e_F q_F) = e_D\,(q_F + m\,q_A) - (e_A\,q_A + e_F\,q_F)$$

so relative to the no-multiplier case (***m = 1***), SU generation increases by:

$$\Delta SUs = e_D\,(m - 1)\,q_A$$

The multiplier therefore creates additional monetization of a given physical uptake q_A by expanding the "credited" compliance margin against e_D.

The marginal cost of increasing physical uptake of low-emissions fuel (q_A)

The ship minimizes fuel costs + regulatory costs − regulatory benefits, i.e., the total cost *C*:

$$C(q_A) = c_A\,q_A + c_F\,(1 - q_A) + P(e_m(q_A))$$

The central object for ZNZ uptake is the marginal total cost of increasing q_A.

Hence, we calculate the partial derivative for three cases (the three colored regions in Figure 3):

(1) SU generation region (green in Figure 3): $e_m < e_D$

$$\frac{dC}{dq_A} = (c_A - c_F) + s[(e_A - e_F) - (m - 1)e_D]$$

(2) Base compliance region (yellow in Figure 3): $e_D \leq e_m < e_B$

$$\frac{dC}{dq_A} = (c_A - c_F) + r_D\,[(e_A - e_F) - (m - 1)e_D]$$

(3) Non-compliance region (red in Figure 3): $e_m \geq e_B$

$$\frac{dC}{dq_A} = (c_A - c_F) + r_B\,[(e_A - e_F) - (m - 1)e_B] + r_D\,(m - 1)(e_B - e_D)$$

Intuition:

(1) and **(2)** can be rewritten as:

$dC / dq_A = \Delta c + \kappa(\Delta e - (m - 1)e_D),\ \kappa \in \{s, r_D\},$

where κ is the marginal regulatory cost rate or 'price' per unit of emissions intensity that the ship faces under the regulation

- $(m - 1)e_D - \Delta e$ is positive (because $(m - 1)e_D > 0$ and $-\Delta e > 0$)
- Accordingly, the right-hand side is positive, meaning that even if an alternative fuel (including ZNZ fuels) is more expensive than the fossil baseline ($\Delta c > 0$), the derivative can still be negative (implying that total costs decrease while increasing q_A at the margin) if the regulatory benefit is strong enough (large κ, large m, large e_D, or very negative Δe).
- However, if Δc is large and κ is small, the derivative can be positive.

For case **(3)** to have the condition $dC / dq_A < 0$, the following must apply:

$$\Delta c < -[r_B (\Delta e - (m - 1)e_B) + r_D (m - 1)(e_B - e_D)]$$

Rearranging the bracket into the following form:

$$r_B \Delta e + (m - 1)((r_D - r_B)e_B - r_D e_D)$$

$$\frac{dC}{dq_A} = \Delta c + r_B \Delta e + (m - 1)((r_D - r_B)e_B - r_D e_D)$$

The multiplier's impact on marginal incentives depends on the relative steepness of Tier 2 and Tier 1 RU rates. In general, if $r_B \geq r_D$ (the standard design with higher marginal penalties above e_B), the multiplier term is negative and increasing the multiplier lowers dC / dq_A, strengthening incentives to increase q_A.

In the IMO NZF parameterization, $r_B > r_D$ (380 vs 100), so the direction is unambiguous: higher multipliers strengthen the marginal incentive to increase q_A when $e_m \geq e_B$. Whether dC / dq_A becomes negative still depends on the fuel cost premium and the intensity gap.

What multipliers change in the NZF

The uptake of alternative fuel is governed by the question: does a marginal increase in the alternative fuel share lower or raise total cost once NZF incentives are included? Put differently, the sign of the marginal effect of increasing q_A depends on whether the regulatory benefit from lowering compliance intensity outweighs the fuel cost premium of the alternative fuel.

Fuel-cost channel

If the alternative fuel is more expensive than fossil ($c_A > c_F$), shifting the mix toward the alternative mechanically raises fuel expenditure. This pushes the marginal incentive against uptake of alternative fuel.

With a multiplier $m > 1$, each incremental unit of alternative fuel has a larger effect on the accounted compliance metric. Therefore, the marginal NZF benefit (avoided RUs or earned SUs) is larger. The effect is most pronounced where the schedule is steep (high r_B or r_D).

Regulatory cost channel

The NZF places a value on lowering GHG intensity, but that value depends on which compliance region the ship sits (see Figure 3). Because the NZF regulatory cost function is kinked, the marginal regulatory value of an intensity reduction changes discretely across regions:

- In the SU region (green in Figure 3), abatement earns credits valued at the SU price s
- In the Tier 1 RU band (yellow in Figure 3), more abatement avoids penalties valued at r_D
- In the Tier 2 RU region (red in Figure 3), abatement avoids higher penalties at r_B (plus the Tier 1 component between e_D and e_B)

This is why the 'value' of same physical switch toward alternative fuels can be very different depending on whether it helps the ship avoid Tier 2 penalties, avoid Tier 1 penalties, or generate SUs. In other words, NZF incentives are not smooth; they are shaped by where the fuel mix places you relative to e_D and e_B. By lowering the <u>accounted</u> intensity for a given physical blend, multipliers can move a ship across the thresholds between regions.

Overall, multipliers tilt incentives toward higher q_A by increasing the regulatory payoff for fuel switching. However, the net effect on actual uptake of alternative fuels is not mechanically guaranteed: if the alternative fuel remains sufficiently expensive, the fuel-cost channel can still dominate. Put differently, multipliers relax the adoption threshold, allowing the NZF to justify a larger alternative-fuel premium, but do not eliminate the underlying cost trade-off.

SU price dynamics

In a setting where the SU price s is determined endogenously in a compliance market (as is the case for the NZF), a multiplier also affects the supply and demand for compliance, which alters s.

Under particular market assumptions, multipliers can reduce SU scarcity and therefore reduce SU prices. The sign and magnitude of the SU price response depend on market design and equilibrium conditions that are outside our partial-equilibrium treatment (where s is taken as given). Nevertheless, our analysis shows that multipliers increase the compliance effectiveness of physical alternative-fuel uptake and can therefore strengthen incentives for q_A, while the ultimate effect on actual physical uptake of alternative fuel remains ambiguous.

Why an accounting multiplier creates blend-ratio-dependent incentives and can favor low blends

Policymakers should be cautious in designing how multipliers are applied in blended-fuel accounting. If a multiplier enters the denominator of an attained-GFI calculation, the implied reward per unit of low-emissions fuel can vary with blend share. Importantly, this implied reward may perversely increase when using low emissions fuels at small mixing ratios (which we refer to here as ‘low blends’).

If the multiplier increases the “counted” energy of the low-emissions component in the denominator, then the attained GFI becomes:

$$\tilde{e}(q_A, m) = \frac{e_A q_A + e_F (1 - q_A)}{m q_A + (1 - q_A)}$$

If the abatement benchmark is the fossil intensity e_F, the blend’s credited reduction per MJ of total energy is:

$$\Delta e(q_A, m) = e_F - \tilde{e}(q_A, m)$$

Substituting the expression for $\tilde{e}$ and simplifying gives:

$$\Delta e(q_A, m) = \frac{q_A [e_F (m-1) + (e_F - e_A)]}{1 + (m-1) q_A}$$

To see the “per-unit incentive” for the low-emissions component, consider credited reduction per unit of low-emissions fuel (per MJ of A):

$$\frac{\Delta e(q_A, m)}{q_A} = \frac{e_F (m-1) + (e_F - e_A)}{1 + (m-1) q_A}$$

This expression is decreasing in q_A whenever $m > 1$, because the denominator $1 + (m - 1)q_A$ rises with the blend share.

- As $q_A \to 0$ (very low blends), the per-unit reward value is highest.

$$\frac{\Delta e}{q_A} \rightarrow e_F (m-1) + (e_F - e_A)$$

- As q_A increases, the per-unit reward value falls:

$$\frac{\partial}{\partial q_A}\left(\frac{\Delta e}{q_A}\right) = -\frac{(m-1)[e_F (m-1) + (e_F - e_A)]}{(1 + (m-1) q_A)^2} < 0$$

Interpretation

With a multiplier entering the denominator of the calculated emissions intensity, the rewarded value per MJ of low-emissions fuel is not constant. Instead, it depends on the blend share and is largest for low blends. This can unintentionally favor low-blend “drop-in” use cases and penalize pathways using higher shares of alternative fuel.

Design implications

The motivation for considering multipliers in this paper is primarily as a second-best substitute when no reward funding is available. In this context, a multiplier would be an accounting lever that strengthens incentives without reward disbursements.

An alternative is to apply the multiplier directly to the reward for the low-emissions component, rather than embedding it in the attained-GFI denominator. This keeps the reward per unit of low-emissions fuel constant (scaled by m), independent of whether it is blended at 5% or 100%. However, this approach presupposes that a reward mechanism and funding exist. In other words, such reward multipliers are only meaningful in a funded reward regime. If no funding source is available, the only available multiplier channel is via compliance crediting, which comes with the trade-offs discussed above.

Appendix 2: Differentiation beyond cost gaps

A cost gap can reflect different underlying realities: it may signal a scalable pathway that is early-stage and needs support to reach commercial scale, or a pathway that is structurally constrained (e.g., limited sustainable feedstock or bottlenecks), where higher rewards mainly bid up scarce inputs rather than expanding supply. For that reason, if policymakers wish to incentivize uptake of low-emissions fuels, they may wish to supplement cost-based differentiation criteria with an additional indicator (see also Section 3.4).

Differentiated reward rates can be determined based on one or several underlying criteria. Building on the wider innovation and technology policy literature,[25, 26] we suggest some potential criteria in Table 2.

In practice, cost gaps are typically inferred from observable prices (e.g., contracted/offtake prices or published benchmarks) rather than true production costs. In illiquid markets, relying on bespoke bilateral contract prices can create gaming risk;[27] therefore, any cost-gap approach should be anchored to standardized reference prices and transparent methodologies. The choice of reference method may also differ according to market maturity: established "drop-in" markets can often be benchmarked using market indices, while emerging "new energy system" fuels may require administratively set references or auctions until liquidity improves.

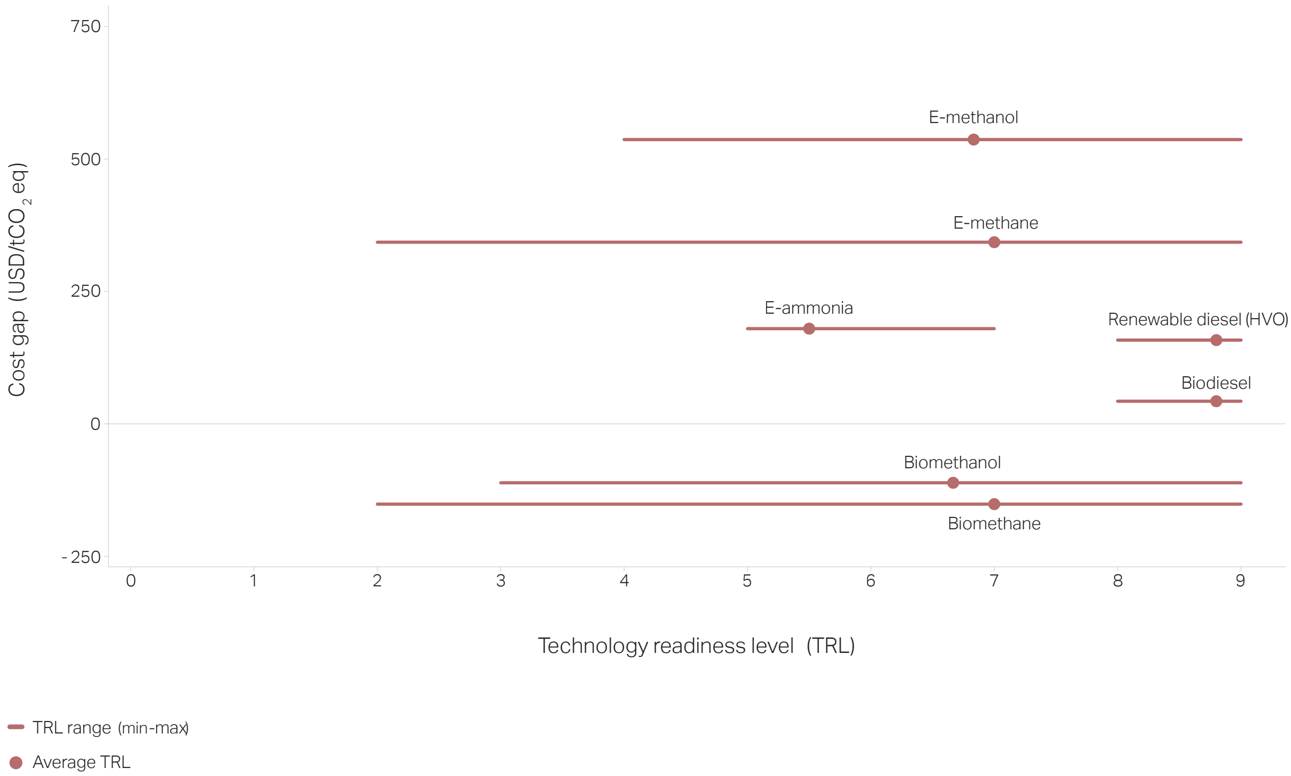
Figure 4 plots the cost gap and technology readiness level (TRL) for a sample of fuel pathways. As the figure shows, cost and technological maturity do not align in a simple way.

Table 2: Potential approaches to differentiating reward rates.

	Cost gaps	Other potential targeting criteria	
		Scalability	Technological maturity
Definition	The remaining cost premium of using fuel pathway *i* relative to a fossil benchmark, after accounting for NZF compliance (RU1, RU2, SU).	Targets fuels with relatively more abundant feedstock.	Targets fuels where there is evidence that unit costs will fall most with increased production (for example, due to learning, breaking through clear technical barriers, economies of scale).
Rationale	Directing subsidies towards fuels that are already 'in the money' only further lowers the cost of energy for pathways that are already cost-competitive.	If a pathway is constrained by limited sustainable feedstock, subsidizing higher deployment can raise marginal costs over time. Hence, directing subsidies toward such pathways risks increasing long-run system costs.	Subsidies should be relatively more focused on fuels/pathways that are less mature because they have a larger potential for cost reductions over time.

Notes: Policymakers may also consider a pathway's "cost-down potential" (learning-by-doing, scale economies, and supply-chain improvements) as a qualitative complement. With that said, this criterion can be difficult to quantify robustly.

Figure 4: Indicative fuel pathway differentiation by cost gap and technology readiness.



Notes: Cost gaps are calculated as average cost gaps (USD/tCO_2eq) as shown in Figure 2. Each gap is the vertical difference between illustrative fuel costs/prices and the regulated LSFO fossil benchmark. Fuel codes from Figure 2 are aggregated into common fuel pathways over which average cost gaps are calculated. TRL data is based on the Zero Carbon Fuel Monitor from Lloyds Register, which covers only some of the pathways shown in Figure 2. The readiness levels rate technology on a scale from 1 (lowest) to 9 (highest), across six dimensions. The figure shows the minimum and maximum TRL value, combined with the average TRL value across these dimensions, for each respective fuel pathway.

Both cost gaps and technological maturity come with some pitfalls as differentiation criteria. As discussed in Section 3.4, an undifferentiated reward rate can be ineffective if it directs support disproportionately toward lower-cost pathways that are already near-competitive. Differentiating reward rates based on cost gaps could select for higher-cost energy but could also favor the more mature technology pathways among this higher-cost group, thereby hindering the ability of less mature technologies to progress down the cost curve over time. In short, without further differentiation, avoiding one type of crowding-out creates the risk of another.

Meanwhile, maturity indicators like the TRL can be imperfect proxies for whether a pathway can scale to meaningful volumes, because a technology can be "mature" yet constrained by feedstock or infrastructure.

Scalability, by contrast, focuses directly on the transition objective to identify which pathways can credibly expand supply without rapidly escalating marginal costs. This criterion therefore provides a clearer basis for preventing crowd-out while prioritizing fuels that can deliver durable scale. If policymakers wish to incentivize low-emissions fuel uptake, they may wish to supplement cost-based criteria with scalability.

Whatever the differentiating factor, the design choice ultimately requires regulators to operationalize the concept by agreeing on a transparent approach to measurement. One possible approach to scalability, for example, would be to draw on estimates of total feedstock availability and map these against the component inputs for a range of eligible pathways. Previous work shows, for example, that it could be hard to scale the supply of biogenic CO_2 required for some low-emissions methanol pathways.[28]

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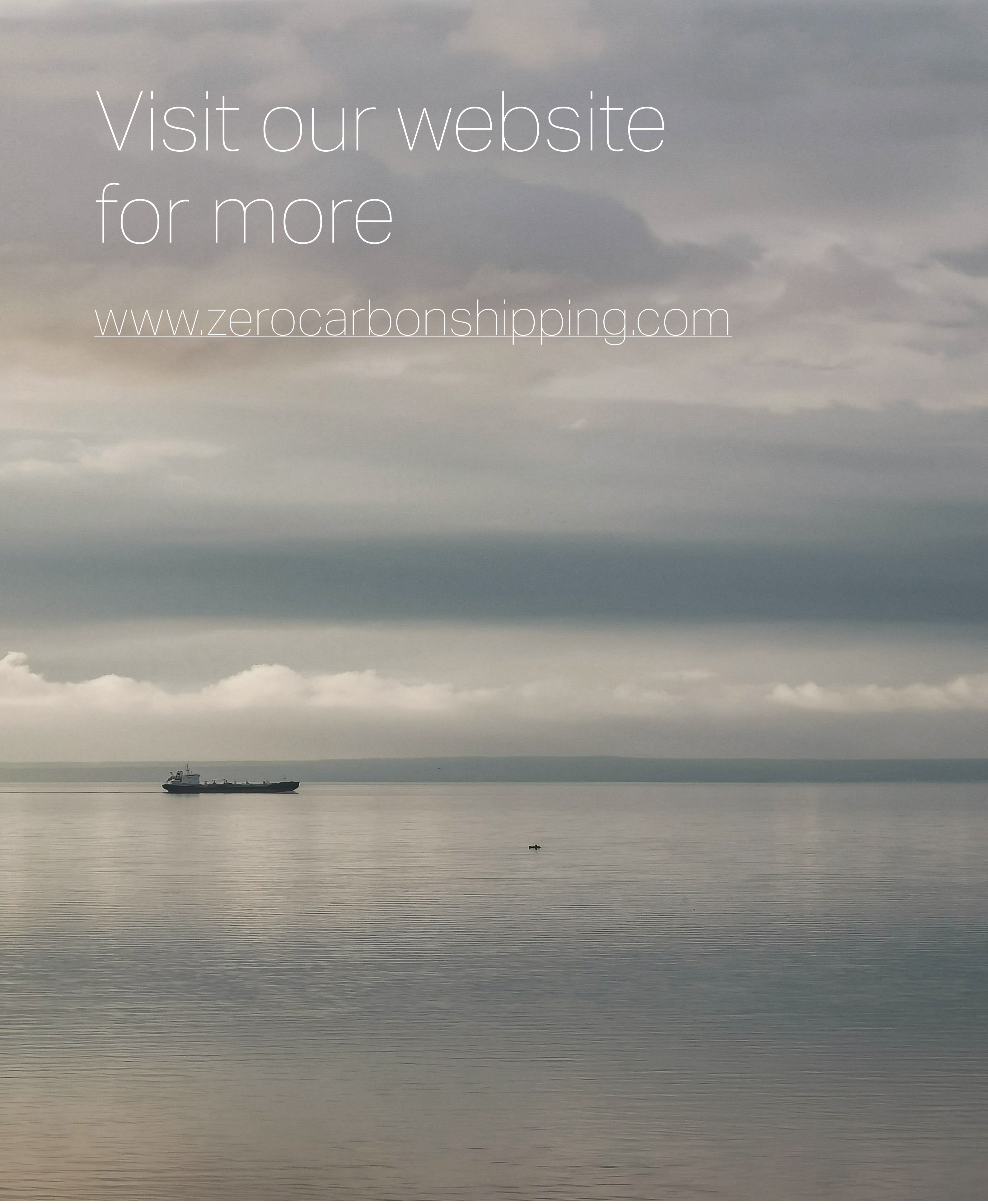

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