Breakthrough Energy

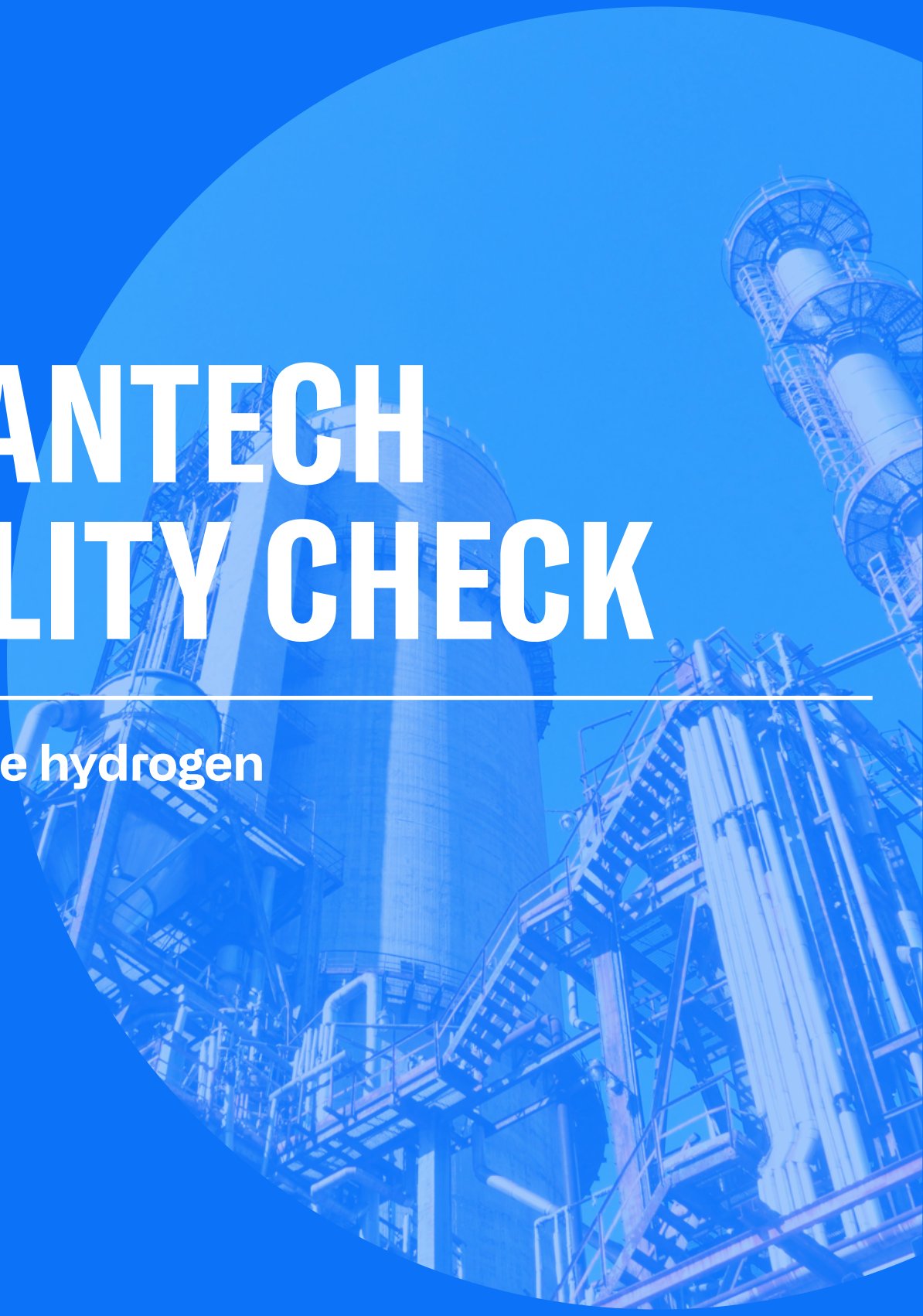
Cleantech for Europe

With analyses led by

SYSTEMIQ

CLEANTECH REALITY CHECK

Renewable hydrogen



CLEANTECH REALITY CHECK

SCALING RENEWABLE HYDROGEN AND ITS DERIVATIVES IN EUROPE

EUROPE'S SCALE OR FAIL MOMENT

By **Ann Mettler,** Vice President - Europe and **Julia Reinaud**, Senior Director - Europe, **Breakthrough Energy**

- **When it comes to cleantech, European policymaking needs to shift gears. In a world of increasing global competition and geopolitical challenges, in which industrial policy is making a ferocious comeback, targets – even the most ambitious – are nothing to celebrate until they are achieved.** In Europe, too often strategies don't result in progress and laudable goals aren't reached. Nowhere is this more apparent than in Europe's goal to reach net zero, which while admirably ambitious is on the whole far from being achievable at the current rate of progress. Consider: by 2030, meeting Europe's climate targets will require 500-900 gigawatts of extra solar and wind capacity, 11-20 million tonnes of renewable hydrogen use, and 0.6 million tonnes of Sustainable Aviation Fuels, among other clean technologies. It's a tall order.

- **With the European Commission slated to come out with a Clean Industrial Deal in the first 100 days of its new mandate, it is more urgent than ever that policymakers strive harder to use real-time metrics that shed light on actual performance – and not bask in the warm glow of far-off targets.** That's why at the start of a new political cycle in the European Union, when Europe is facing a 'scale or fail moment', we're kicking off this *Cleantech Reality Check* series.

- **We purposefully kick off the series on renewable hydrogen,** an emerging clean technology that dominated EU political discourse and attention for several years, and where European ambition is epitomised by some of the world's boldest targets. In an effort to not only offer the latest critical data points pertaining to Europe's overall performance on hydrogen but also shed light on its end use in key markets, we include deep dives on shipping, aviation and refineries.

- **Since it was launched, Breakthrough Energy Europe has set out to share what we know about clean tech innovation: from discovery and development all the way to deployment.** Success and impact will always be predicated on the actual use of clean technologies and it's here where Europe too often falls short, both in manufacturing and deployment. This is why it is imperative to have a 'reality check' from time to time. Despite the ambition of the 2020 Green Deal, today's realities point to serious challenges: whether in electric vehicles or batteries, renewable hydrogen or electrolysers, wind and solar, heat pumps, sustainable fuels, there is not a single unequivocal success story.

- **Over the coming months we will provide a snapshot of the enablers, barriers, and action agenda for select technologies and sectors that are of strategic importance to Europe's industrial future.** What will this entail? For a start, looking at whether final investment decisions are reached on clean energy projects – not just at announcements made. It is also necessary to measure not only supply but actual demand: is anyone buying the clean technologies we are trying to nurture? Is investment flowing into the technologies and industries we've prioritised, and what share is coming from the private sector? These metrics provide valuable insight into the state of the clean energy transition in Europe and important cues as to where private investors see opportunity and future markets. **But only if we make the effort to look.**

- It is our hope that such a timely reality check can help policymakers, industry leaders, startups and investors to assess the progress made to date, and if necessary, rejig strategies or pivot to entirely new approaches. After all, innovation rarely presents itself as a linear pathway and is more akin to a multidimensional game of chess. And if we want to win this game, it is time to sharpen up, speed up and scale up.

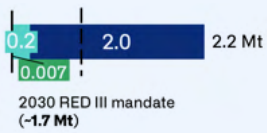
The Cleantech Reality Check is published jointly by Breakthrough Energy and Cleantech for Europe, with analytical support provided by Systemiq.

CLEANTECH REALITY CHECK

SCALING RENEWABLE HYDROGEN AND ITS DERIVATIVES IN EUROPE

- The European Union has one of the most ambitious green hydrogen targets globally. Under the REPowerEU plan, the EU aims to produce 10 million tons (Mt) of renewable hydrogen domestically. This Cleantech Reality Check assesses the renewable hydrogen project pipeline, final investment decisions (FIDs), cost-competitiveness, demand generation and market dynamics focusing on transportation use.
- The future of sustainable transportation hinges on the successful adoption of renewable fuels. Renewable hydrogen, e-SAF, e-ammonia, and e-methanol are vying for a place in the energy mix, each offering distinct pathways to decarbonisation in sectors of strategic importance to Europe. This reality check delves into the comparative progress and challenges in three key sectors.

OFF-TRACK — ON-TRACK

	E-FUELS FOR SHIPPING	E-SAF FOR AVIATION	HYDROGEN FOR REFINERIES
	e-fuels in shipping are well off-track for mid-term scaling with current policy flexibility promoting non-breakthrough technologies such as LNG, limited public funding for OPEX over CAPEX, and uncertainty in the accounting of emissions reductions for the voluntary market all stifling demand signals, leaving vessel owners/operators unable to make the business case for long-term offtake.	e-SAF projects are not getting to FIDs due to a lack of adequate public support for the first wave of e-SAF projects, a lack of bankable offtake agreements and adequate mitigation mechanisms for first-of-a-kind project risk, and perceived regulatory uncertainty (despite the legally binding nature of ReFuelEU Aviation)	The use case for renewable hydrogen in refineries is clear, but stronger and clearer policy targets are required for business certainty, more accessible and higher project funding support to bridge cost premiums is needed to overcome economic failures and coordinated infrastructure support to leverage EU's cheapest hydrogen production.
Green premium gap Grey price (€/t) Approx, range of e-fuel costs	~2x - 4x ~€750 (price) ~€1600-2700 (costs)	~5x – 8x ~€950 (price) ~€5000-8000 (costs)	~1.5x – 3x ~€3400 (price) ~€4500-9000 (costs)
Projects having reached FID	4 PROJECTS REACHED FID 2 for Methanol | 2 for Ammonia	0 PROJECTS REACHED FID	23 PROJECTS REACHED FID
Project pipeline Announced Operational Reached FID / Construction	• e-Methanol  • e-Ammonia 	• e-SAF 	• Renewable H2 
What is working well	• EU industrial leadership • Maturing technology and market mechanisms • Ambitious project development	• Long-term demand signal • EU industrial leadership • High long-term interest from banks and equity	• First mover offtaker enabling early scaling • Comprehensive policy framework established • Incumbents absorbing project risk
What is not working well	• Near term LNG fuel uptake permitted • Insufficient offtake incentives • Unclear pooling additionality guidance under Fuel EU maritime	• Regulatory uncertainty • Lack of bankable offtake contracts (10+ year) • Inadequate public funding	• Targets failing to mobilise required demand • Complex and misdirected funding • Lack of infrastructure investment and pan-EU coordination

CLEANTECH REALITY CHECK

SCALING RENEWABLE HYDROGEN AND ITS DERIVATIVES IN EUROPE

The transition to a sustainable and clean mobility future in Europe and investments into renewable hydrogen based production factories demands more than just technological innovation. Successful scaling of clean technologies hinges on a delicate interplay of factors. Let's explore the critical elements that will pave the way for the widespread adoption of renewable fuels.

ARE THE ENABLING CONDITIONS FOR RAPID SCALE UP IN PLACE?

In place and sufficient
In place and insufficient
Missing

DEMAND ENVIRONMENT ENCOURAGES EARLY OFFTAKE

- Legislated GHG reduction targets set an ambitious horizon
- Sector is included in the EU Emissions Trading System (EU ETS) with appropriate exceptions for financial signal
- Subsidies and incentives effectively reduce green premium

SUPPLY ENVIRONMENT ENABLES ECONOMIES OF SCALE

- Technology specific mandates ensure timely volumes for targets
- Infrastructure funding is targeted and deployed
- Technology and enabling infrastructure are mature

MARKET IS FACILITATED AND COORDINATED

- Product Standards & Certification Schemes include green product
- Accounting & Reporting Frameworks on national and value chain level
- Voluntary market mechanisms are in place

ACTION AGENDA

Key actions and intervention areas to develop the EU project pipeline

	MARITIME	AVIATION	REFINERIES
1	• Create markets by providing short-term demand certainty	• Build a business case for e-SAF by establishing an adequate mix of incentives and penalties while ensuring that European first-movers remain competitive	• Establish long-term regulatory certainty around set-out policy targets
2	• Enable the downstream business case through OPEX orientated support	• Increase targeted public funding in the short-term and long-term to support the first wave of projects	• Strengthen public funding to support longer term scale-up and enable more private sector investments
3	• Support supply chain demand signals with regulatory clarity for insets (within value chain emissions reductions)	• Stimulate accessible and affordable loans	• Guide pan-EU coordination to streamline ongoing H2 infrastructure development

Breakthrough Energy Cleantech for Europe

Based on the analysis of SYSTEMIQ

CLEANTECH REALITY CHECK

AVIATION

E-SAF in Europe: Waiting for take-off

What is e-SAF ?

Electro-fuel Sustainable Aviation Fuel (e-SAF) is a type of synthetic aviation fuel produced from clean hydrogen and captured CO2 that reduces emissions by at least 90% compared to fossil jet fuel. By 2050, the ReFuelEU Aviation regulation mandates a 35% e-SAF share on the total EU aviation fuel demand. The scale-up of e-SAF is imperative to the decarbonisation of aviation, as the only alternative for low-carbon, long-haul flight is bio-SAF which is constrained by the limited availability of sustainable biomass.

Key take-aways

- e-SAF projects are struggling to reach Final Investment Decision (FID), with none having achieved FID globally to date, and only two projects in post/engineering design stage.
- By 2030/31, the ReFuelEU Aviation regulation mandates ~600 kilotonnes per annum (ktpa) of e-SAF in Europe, but only a capacity of ~300 ktpa is currently on track to be operational by 2030.
- The primary barriers to deployment include investor concerns over regulatory uncertainty, along with insufficient public funding support and limited bankable offtake agreements and adequate mitigation mechanisms of first-of-a-kind project risk.

AVIATION

E-SAF: WAITING FOR TAKE-OFF

STRATEGIC IMPORTANCE FOR EUROPE

- European e-SAF production offers a **once-in-a-century opportunity to reduce the EU's dependence on** aviation fuel imports, increase energy security (e.g. in cases of future conflicts), and accelerate the growth of an emerging domestic industry, as many e-SAF startups currently originate in Europe.
- It also offers the opportunity to **restructure value chains**, by exporting key equipment and IP to regions with **cheaper and more abundant renewable electricity** that will produce **e-SAF at larger scales** and by importing those fuels back to the EU.
- If Europe scales e-SAF now, it could access a global e-SAF market of EUR 350+ billion per annum by 2050.

CURRENT PROGRESS OF LARGE-SCALE E-SAF PROJECTS (25+ KTPA E-SAF CAPACITY) IN THE EU

OFF-TRACK — **ON-TRACK**

Status : OFF-TRACK e-SAF projects are not getting to FIDs due to **perceived regulatory uncertainty from investors** (despite the legally binding nature of ReFuelEU Aviation), a **lack of adequate public support for first-of-a-kind plants**, **bankable offtake agreements**, and **adequate mitigation mechanisms of first-of-a-kind project risk**.

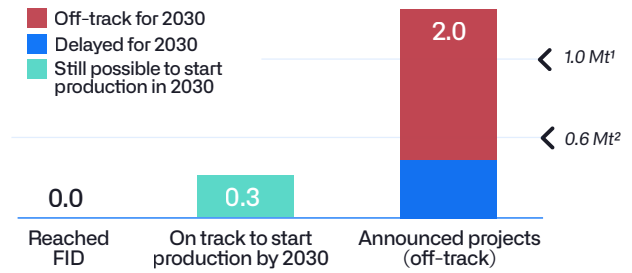
0 large-scale projects have **reached Final Investment Decision** (FID) anywhere in the world

2 projects are current in or post Front-End Engineering Design (FEED) stage, preparing for FID

TWO-THIRDS OF GLOBAL E-SAF PIPELINE IS IN EUROPE, BUT PLANTS NOT ON TRACK TO MEET 2030 EU MANDATE

- **Europe** is **home to two-thirds** of the global e-SAF pipeline (~2.3 out of 3 million tonnes (Mt)).
- Projects need to **enter FEED phase within the next few months** to be able to start production in 2030.
- From the 30+ announced projects, **only a handful of projects could still meet that timeline**[1].

Announced e-SAF production capacity in the EU by 2030, in Mt
– excl. pilot projects <25ktpa



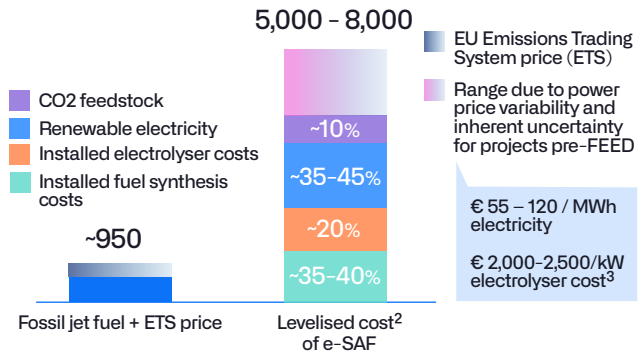
[1]: 2032-34 ReFuelEU Aviation mandate

[2]: 2030/31 ReFuelEU Aviation mandate

E-SAF'S >5-8X GREEN PREMIUM MAKES IT UNCOMPETITIVE AGAINST CONVENTIONAL JET FUEL TODAY

- e-SAF production is electricity-intensive and involves high project-on-project risks for a first-of-a-kind plant.
- By maturing the technology (and thereby reducing the risks) and through innovation across the e-SAF production process, e-SAF costs could **come down by 40-50%** in the long run.
- However, e-SAF will not enter the market without the penalties foreseen within ReFuelEU Aviation.

Levelised cost[2] of e-fuel compared to price of fossil jet fuel + ETS
in EUR per tonne



[1] FEED (Front-End Engineering Design): 12+ months, getting to offtake contracts and financial close: 6+ months, Construction: 36 months, commissioning: 2-3 months, start-up phase:15+ months.
[2] Only includes CAPEX and OPEX of the project itself and does not include e.g. pre-development costs, taxes, etc. hence the actual price of e-SAF required is expected to be higher than the stated costs.
[3] Includes all expenses to start producing hydrogen e.g. installation (EPC, labour), site preparation (civil works, construction), auxiliary systems (e.g balance of plant equipment like water purification systems, compressors, cooling systems), etc.

Sources: Project SkyPower (2024): Accelerating the take-off for e-SAF in Europe – Insights Report; Analysis by Systemiq undertaken for Breakthrough Energy and Cleantech for Europe.

AVIATION

E-SAF: WAITING FOR TAKE-OFF

ENABLERS – WHAT IS GOING WELL

LONG-TERM DEMAND SIGNAL

ReFuelEU Aviation promotes the use of e-SAF, with an average 1.2% mandate in 2030-31, increasing to 35% by 2050. The regulation includes high penalties (at least 2x the green premium) and no buy-out option due to make-up obligation. SAF allowances[1] could provide revenue certainty in the long run: the number of allowances dedicated to e-SAF increases and is provided on a 10-year basis.

EU INDUSTRIAL LEADERSHIP

Two-thirds of the global e-SAF project pipeline is in Europe (2.3 Mtpa - equivalent to 5% of the expected 48 Mt of aviation fuel demand in the EU by 2030). For 10+ years, R&D support and the prospect of a strong demand signal with ReFuelEU Aviation has made the EU a tech leader, with pilot plants in operation or under construction.

HIGH LONG-TERM INTEREST FROM BANKS AND EQUITY

Banks and equity express high long-term interest to provide finance of EUR 1-2 billion for a ~50 ktpa e-SAF plant, due to long-term offtake security provided by ReFuelEU Aviation. Hence, enough capital is ready to be deployed to cover the total CAPEX need of EUR 15-25 billion to fulfil the 2030 e-SAF mandate, once e-SAF projects are sufficiently de-risked.

BARRIERS – WHAT IS NOT GOING WELL

REGULATORY UNCERTAINTY

ReFuelEU Aviation provides a solid regulatory framework. While the EU's e-SAF mandates are clear and legally binding since 2024, perceived regulatory uncertainty forms a barrier to FID, e.g. because Member States have not yet provided clarity on penalty systems. Reducing ambition levels would be incompatible with the EU's 2040 climate targets.

LACK OF BANKABLE OFFTAKE CONTRACTS (10+ YEAR, E.G. TAKE-OR-PAY)

from fuel suppliers (Oil & Gas companies) and airlines. So far, O&G majors have not yet contracted e-SAF from producers, despite being the obligated party as suppliers – nor have they invested into e-SAF projects themselves.
Due to the technological performance and supply risks of first-of-a-kind e-SAF projects, airlines are hesitant to enter long-term offtake contracts – in particular if their competitors are not taking the same step, as production costs of future e-SAF plants could decrease and expose them to a first mover disadvantage.

INADEQUATE PUBLIC FUNDING

Many EU funding instruments (e.g. EU Innovation Fund, EU Hydrogen Bank, SAF Allowances) are currently inaccessible to e-SAF projects (in the light of competition with lower-hanging fruit-sectors, or bio-SAF) and are not capitalised adequately.

ACTION AGENDA – WHAT NEEDS TO BE DONE

1 Build a business case for e-SAF:

Establish an adequate mix of incentives and penalties to create a business case for e-SAF by implementing EU policies at member state levels and ensure that European companies using e-SAF benefit from a global level playing field and are not punished for being first movers.

2 Provide sufficient and adequate public funding for the first wave of e-SAF projects:

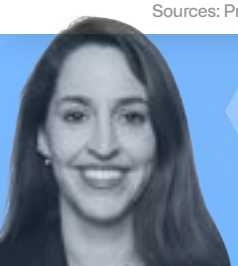
Provide sufficient public funding in the short-term, e.g. in form of a dedicated e-SAF call within the EU Innovation Fund or the EU Hydrogen Bank (ticket sizes of EUR 400-600 million to close competitiveness gap with the US) – and in form of development expenditure support (ticket size of EUR 10-15 million per project for FEED studies).
In the long-term, increase number of SAF Allowances dedicated to e-SAF and change to 10-year allocations.

3 Stimulate accessible and affordable loans:

from the European/national investment banks, and loan guarantees from InvestEU and export credit agencies (backing commercial debt.)

[1] ETS allowances for uptake of SAF - herein referred to as SAF Allowances

Sources: Project SkyPower (2024): Accelerating the take-off for e-SAF in Europe – Insights Report; Analysis by Systemiq undertaken for Breakthrough Energy and Cleantech for Europe.

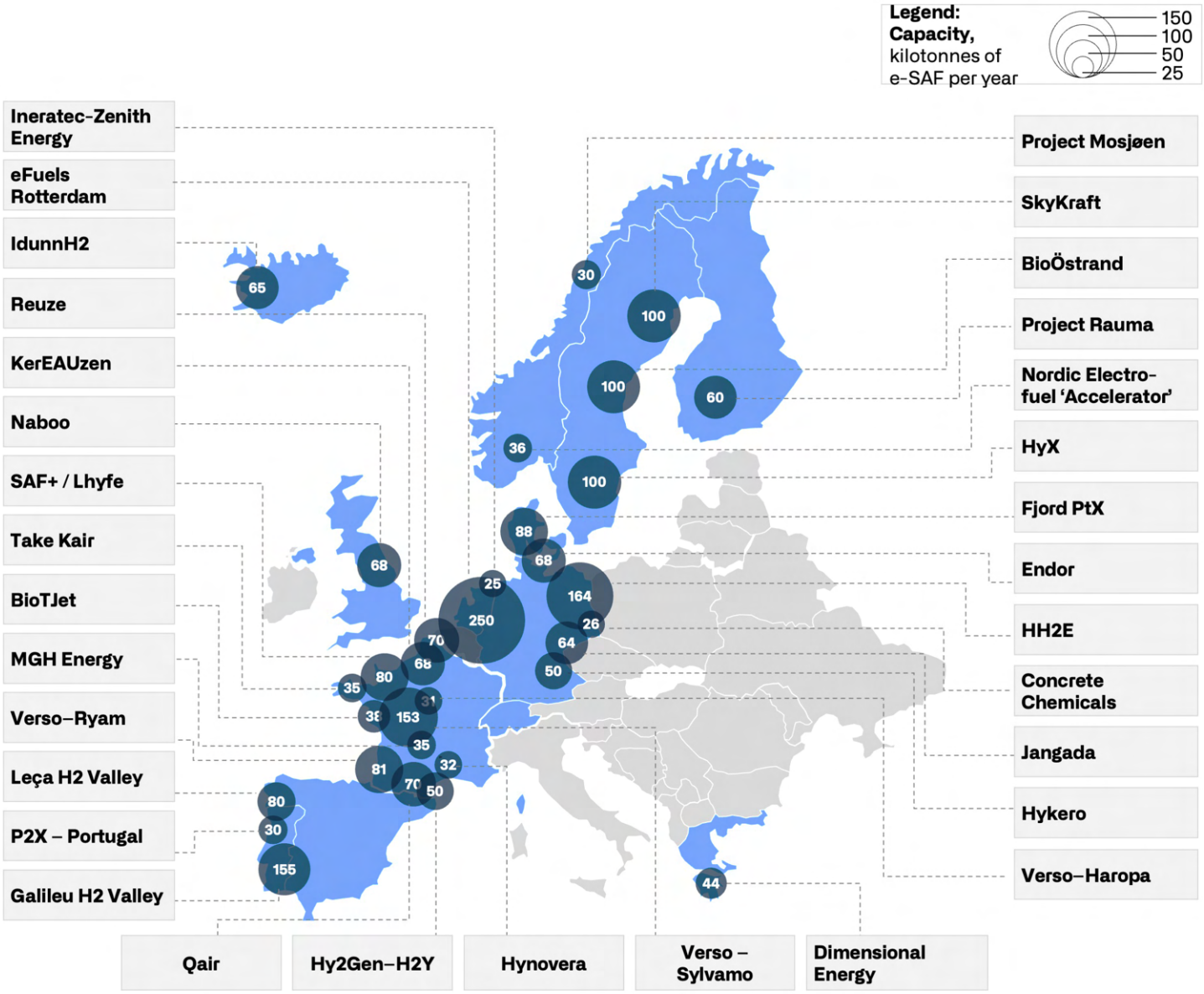


"The scale-up of e-SAF production in Europe presents a pivotal opportunity to achieve energy independence in Europe. The EU must harness its experience from past clean energy breakthroughs and seize this moment to become a leader in e-SAF.

Amy Hebert, CEO **Arcadia e-Fuels**

AROUND 30 ANNOUNCED LARGE-SCALE E-SAF PLANTS (~2.3 MTPA) IN EUROPE

(as of October 2024)



Notes: All projects plan to use biogenic CO2. Some projects also plan to use point source CO2 from cement or steel production. Map excludes projects <25 ktpa e-SAF capacity
Source: Systemiq, T&E, MPP (2024), based on public announcements and press search.

Breakthrough Energy Cleantech for Europe

Based on the analysis of SYSTEMIQ

CLEANTECH REALITY CHECK

MARITIME

E-fuels for shipping: Sinking before we sail?

What are e-ammonia and e-methanol?

E-ammonia and e-methanol are two essential near-zero emission fuels for shipping's decarbonisation.[1]
While energy efficiency and the uptake of bio-based fuels will lead initial decarbonisation, these e-fuels offer significant Greenhouse gas (GHG) reductions compared to fossil fuels but require new engine technology and infrastructure.[2] E-ammonia is promising for long-term decarbonisation due to its carbon-free nature, but faces challenges with toxicity and NOx emissions. E-methanol has gained traction due to available dual-fuel engines and infrastructure, but its long-term scalability is constrained by limited availability of suitable carbon sources (required for methanol production), competition from sectors without carbon free alternatives i.e., aviation, and the slow development and high costs of direct air capture.

Key take-aways

- Only two e-ammonia and two e-methanol projects with shipping explicitly targeted as an offtaker have reached final investment decision (FID). Rapid scale-up of demand for these scaleable zero-emission fuels (SZEF) is critical to realise sufficient mid-term volumes.
- Fuel EU Maritime (FEUM) sets a conditional target for 2% uptake of Renewable liquid and gaseous Fuels of Non-Biological Origin (RFNBO) by 2034, and the International Maritime Organisation (IMO) has set 5% by 2030 as the goal, yet less than 0.1 million tonnes (Mt), ~6% of the required volumes to meet just the 2% target, has reached FID.
- Strengthening the Fuel EU Maritime RFNBO uptake targets and financial support to fuel offtakers to reduce the OPEX hurdle are key to drive upstream investment and ensure that the maritime industry remains competitive while leading in decarbonisation.

MARITIME

E-FUELS FOR SHIPPING: SINKING BEFORE WE SAIL?

STRATEGIC IMPORTANCE FOR EUROPE

- Large-scale decarbonisation: EU maritime transport represents 3-4% of EU total emissions and ~20% of global shipping emissions.
- EU is a Maritime leader: Four of the five largest container shipping companies are European.
- Short term: Demonstrate first production volumes of e-ammonia and e-methanol and prepare to scale the technology and infrastructure.
- Long-run: Become a leading exporter of key technology / IP (with e-ammonia production cheaper in geographies with abundant, low-cost renewable electricity / clean hydrogen), unlocking a global market of up to €140bn p.a.

CURRENT PROGRESS OF MARITIME E-FUELS (E-AMMONIA & E-METHANOL) IN THE EU

OFF-TRACK — ON-TRACK

Status: WELL OFF TRACK e-fuels in shipping are well off track for mid-term scaling with current policy flexibility promoting non-break-through technologies such as LNG, limited public funding for OPEX over CAPEX, and uncertainty in the accounting of emissions reductions for the voluntary market all stifling demand signals, leaving vessel owners and operators unable to make the business case for long-term offtake.

<2% of projects identified with shipping as potential end use sector have funding[3]

4 Only **two e-methanol and two e-ammonia projects** with explicit mention of shipping as an offtaker have **reached Final Investment Decision** (**FID**) as of Q3 2024[4]

SIGNIFICANT EFFORT REQUIRED TO REACH 2030 MARITIME TARGETS, WHILE DIVERSIFIED OFFTAKE CAN SUPPORT FIDS ONLY 20 OF 37 E-METHANOL AND 21 OF 62 E-AMMONIA PROJECTS MENTION SHIPPING OR THE TRANSPORT SECTOR AS TARGET OFFTAKE[5]

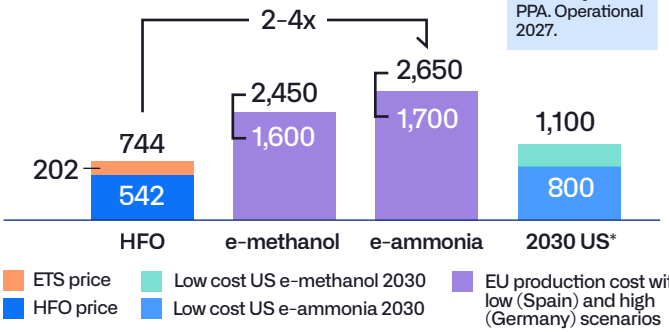
- The e-methanol pipeline is more mature with larger projects at FID than e-ammonia.
- However, the e-ammonia pipeline of announced projects holds significant promise, far exceeding an ambitious 5% SZEF target and is nearly 2.5x the size of the e-methanol project pipeline.
- Suggested 2030 global volumes available to shipping are estimated to be 3.5Mt e-methanol and 32Mt e-ammonia based on project announcements.[7]

* 5% target an illustrative threshold based on the Zero-Emission Shipping Mission for 5-10% SZEF by 2030, target volumes shown are cumulative so together they achieve the minimum 5% threshold.[6]

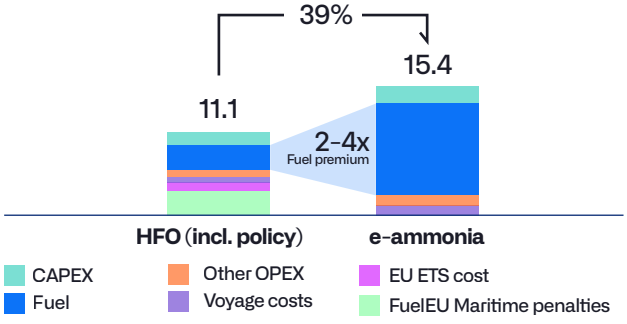
EUROPEAN PRODUCTION FACES HIGH PREMIUMS OF >2-4X EXISTING MARINE FUEL, EVEN WITH PRODUCTION IN FAVOURABLE LOCATIONS SUCH AS SOUTHERN SPAIN. LCOX IS UNCOMPETITIVE WITH U.S. PRODUCTION BENEFITTING FROM TAX CREDITS

- **LCOX[9] e-methanol and e-ammonia,** € / tonne HFO eq

LCOX for new build plant. Electricity via PPA. Operational 2027.



- **Total Cost of Ownership (new build vessel)** USD million / year



Industry perspectives emphasise the potential for costs to exceed these modelled estimates

9) LCOX stands for levelized cost of fuel.

MARITIME

E-FUELS FOR SHIPPING: SINKING BEFORE WE SAIL?

ENABLERS – WHAT IS GOING WELL

EU INDUSTRIAL LEADERSHIP

The EU comprehensive policy framework includes shipping within the EU ETS (a world first). Fuel EU Maritime (FEUM) sets progressive targets for reducing the GHG intensity of on-board energy use (complementing efficiency measures). It includes a 2% RFNBO mandate from 2034. The EU Hydrogen Bank has reserved EUR 200 million for maritime offtakers and penalties collected under FEUM in Member States' budgets must support deployment of renewable and low carbon fuels e.g., bunkering infrastructure for fueling.

MATURING TECHNOLOGY AND MARKET MECHANISMS

Global order book is growing for dual-fuel vessels capable of using e-fuels and European operators are leading the charge, the global order book stands at +25 ammonia and +250 methanol vessels. Full scale methanol bunkering is now enabled in ports of Antwerp and Rotterdam, and voluntary market coordination efforts to mobilise early volumes are underway e.g. Buyer's Alliances such as Zero Emission Maritime Buyers Alliance, alongside the piloting of emerging book & claim systems.

AMBITIOUS PROJECT DEVELOPMENT

The announced projects for ammonia production in EU with potential to supply maritime is on paper sufficient[8] to exceed current FEUM and the higher ambition 5% SZEF targets. However, maturing the pipeline depends on long-term offtake commitments, enabled by regulatory certainty and financial support to downstream operators. Sufficient capital is in the marketplace to finance new projects if the business case can be made with creditworthy offtake agreements.

BARRIERS – WHAT IS NOT GOING WELL

NEAR TERM LNG FUEL UPTAKE PERMITTED UNDER FEUM

Fuel EU Maritime not IPCC 1.5 aligned and emphasis on annual avg. GHG intensity enables uptake of more competitive LNG fuel and biofuels well into the 2030s. As such, LNG dominates new vessel order book over e-fuels, with dual-fuel vessels used as a hedge. Upstream methane leakage from near-term LNG uptake presents significant climate risk. FEUM targets for e-fuels are not currently driving the necessary upstream investments.

INSUFFICIENT OFFTAKE INCENTIVES

Producers unable to secure long term (+10yr) bankable offtake contracts due to inability of vessel operators to commit. Limited public support for OPEX vs CAPEX currently stifles the downstream business case. EU ETS missing regulatory clarity on the penalties for varying fuels and the future allocation /availability of ETS revenues to support e-fuels.

UNCLEAR FEUM POOLING ADDITIONALITY GUIDANCE

The lack of guidance under the FEUM pooling mechanism for dealing with surplus compliance and how to account for the potential allocation to the voluntary market risks the double-counting of emissions reductions. This uncertainty stifles integrity and limits the downstream demand signals for emissions reductions within the supply chain, eroding shipping companies' ability to harness willingness-to-pay and recover fuel switching costs.

ACTION AGENDA – WHAT NEEDS TO BE DONE

1 Create markets by providing short-term demand certainty

Make agreed FuelEU Maritime e-fuels sub targets binding to create stronger near-term demand. Ensure adequate mechanisms are in place to mobilise demand to a point of 10-15-year offtake commitment. RFNBO multiplier to be energy-based versus GHG-intensity to achieve earlier cost advantages for e-fuels and a greater incentive.

2 Enable the downstream business case through OPEX orientated support

Direct funding for vessel operators and guarantees for OEMs adopting e-fuels is necessary to stimulate demand signals and reduce the risks taken by first movers leading e-fuel adoption. Mobilise the revenues from the maritime ETS with targeted allocation to e-fuels via competitive subsidy mechanisms e.g., EU Hydrogen Bank and Green Market Makers such as H2Global Foundation required to remove funding uncertainty.

3 Support supply chain demand signals with regulatory clarity for insets

FEUM must provide a clear reporting system for surrendering over compliance and selling insets (within value chain emissions reductions) on the voluntary market. Enabling companies to credibly sell insets and comply with additionality principles is essential to market integrity and harnessing demand from ambitious cargo owners. EU regulators should engage the shipping value chain and seek to add an option during the FEUM 'Verification Period' for companies to 'retire' surplus compliance.

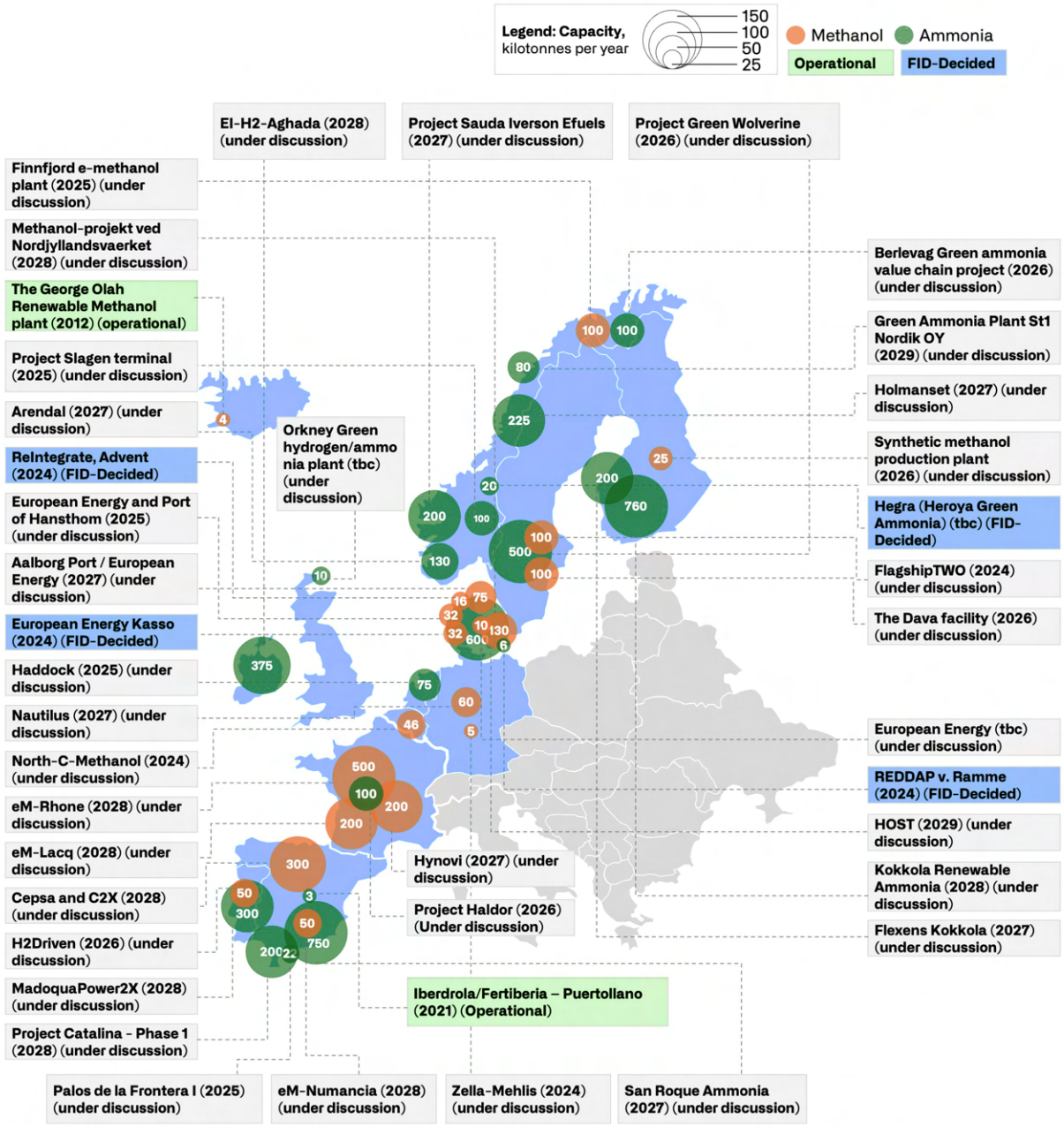
Shipping is off track to meet its breakthrough goal of 5-10% use of scalable, zero-emission fuels. This is a global challenge, but European industry and policymakers have a key role to play as first movers in the transition and by providing a truly ambitious voice at the IMO. While first steps have been taken, greater ambition and more urgent action is both justified and necessary.

Johannah Christensen, CEO of **Global Maritime Forum**

MARITIME

E-FUELS FOR SHIPPING: SINKING BEFORE WE SAIL?

40+ ANNOUNCED SHIPPING E-FUELS PROJECTS (~6.8 MTPA) IN EUROPE



Notes: Map is not exhaustive of all e-fuels projects in Europe, projects are placed in respective countries but not always on their respective location.
Source: T&E e-fuels Observatory for Shipping

Abbreviations: LCOX- Levilised Cost Of X (fuel) | SZEF – Scalable Zero Emission Fuel | FEUM - Fuel EU Maritime | ETS – Emissions Trading System | HFO – Heavy Fuel Oil | BAU – Business as usual | ZEMBA – Zero Emissions Maritime Buyers Alliance | MS – Member States | OEMs – Original Equipment Manufacturers | RFNBO - Renewable Fuels of Non-Biological Origin | GMM - Green Market Makers

Notes & Sources: Analysis by Systemiq undertaken for Breakthrough Energy and Cleantech for Europe. Analysis based on prior completed analysis by Systemiq for MPP relating to EU PtX LOCX, Transport & Environment E-fuels for Shipping Observatory, MPP Global Project Tracker, RMI (2024),Oceans of Opportunity, Getting to Zero Coalition (2024): Climate action in shipping: Progress towards Shipping's 2030 Breakthrough.

1) e-ammonia and e-methanol have been the focus of this assessment as they are both derivatives of hydrogen, other scaleable zero emission fuels (SZEF) will play a role in near term decarbonisation e.g., bio-methane and e-methane. This document's emphasis on e-methanol and e-ammonia does not exclude or imply that they are the sole solutions for decarbonizing the maritime industry.
2) Ammonia Fuel & Methanol Fuel - Alternative Shipping Fuels, Fuel for Thought Knowledge Hub, Lloyds Register.
3) <2% of projects identified in the Transport & Environment e-fuels for shipping European observatory includes renewable hydrogen, e-ammonia and e-methanol.
4) Recent survey by Lloyd's Register Maritime Decarbonisation Hub and ZEMBA found 69% of respondents globally ranked the maritime sector as their number one focus for the deployment of e-fuels indicating significant appetite from producers to facilitate maritime offtake Lloyd's Register, ZEMBA (2024) Availability of E-fuels and E-fuel-capable Vessels from 2027–2030
5) project pipeline reflects only projects identified with explicit mention to supply maritime sector or transport more broadly. Projects are identified by T&E e-Fuels observatory which surveys the state of e-fuel production in Europe for use in shipping and identifies projects with potential supply the maritime sector based on minimum commitment to supply the transport sector in general. These projects are compared to the overall European project pipeline provided by MPP Global Projects Tracker
6) The demand split is modelled at a ratio of two-to one methanol to ammonia based on an extrapolation of demand for the two fuels in 2030 from existing methanol and ammonia vessel orders, following approach by RMI in RMI (2024) Oceans of Opportunity drawing from DNV Alternative Fuels Insights (AFI) platform.
7) RMI (2024) Oceans of Opportunity.
8) Total cost of ownership modelling completed on basis of new build ammonia vessel entering operation in 2027 and using 100% ammonia only. 8) Unlikely projects will reach operational by 2030 due to project maturation and construction timelines and while there is enough e-ammonia in the pipeline to meet the targets, the problem is there aren't sufficient vessels that can take this volume

Breakthrough Energy Cleantech for Europe

Based on the analysis of SYSTEMIQ

CLEANTECH REALITY CHECK

REFINERIES

Renewable H2 for refineries: Getting pumped

What is renewable hydrogen (H2)?

Renewable hydrogen (RFNBO-aligned: renewable fuel of non-biological origin) is produced through electrolysis using renewable electricity and water. Hydrogen in oil refining is largely used to hydrocrack and treat heavy crude oil into transport fuels and industrial feedstock. Most hydrogen today is produced on-site from natural gas or as a byproduct from refinery processes. Refinery emissions, with a notable contribution from on-site H2 production, currently represent ~46% of scope 1 and 2 CO2 emissions from oil and gas production.

Key take-aways

- Renewable hydrogen use by refineries could prove to be one of the catalysers of the European Hydrogen Economy, with more than 60 projects announced (accounting for ~2.2 Mt) with potential refinery off-take, and more than 20 projects (~0.2 Mt) beyond FID (Final Investment Decision).
- Faster scale-up is needed when comparing to the current 4.5 Mt of hydrogen used by the refinery sector (mainly fossil-based), or the EU's overall target of 10 million tonnes (Mt) renewable hydrogen.
- The main barriers include insufficient demand mobilisation from policy targets, complicated and suboptimal public funding mechanisms, and fragmented infrastructure development.

REFINERIES

RENEWABLE H2 FOR REFINERIES: GETTING PUMPED

STRATEGIC IMPORTANCE FOR EUROPE

- The refining sector, while undergoing deep transformation to meet Europe's net zero goals, could prove to be one of the catalysers of the European Hydrogen economy, as it currently is a significant driver of the EU's renewable H2 demand.
- Europe is leading significantly in the globally announced project pipeline when it comes to renewable hydrogen intended for refining. Maintaining competitiveness on cost and technology is key, especially with Chinese H2 development subsidies creating an uneven playing field.
- The EU recognises renewable energy's importance in transport and industry through targets in the Renewable Energy Directive III and RePowerEU, however these targets are less constraining than the regulations in other sectors like aviation (REFuelEU).

CURRENT PROGRESS OF RENEWABLE H2 WITH REFINERY END-USE IN THE EU

OFF-TRACK — H_2 — ON-TRACK

Status: SIGNS OF PROGRESS Although the use case for renewable H2 in refineries is clear, and recent renewable H2 projects FIDs show signs of progress, sustained impetus of renewable H2 development is slowed as policy targets are yet to mobilise refinery demand, funding is complicated to access for H2 projects, and lowest-cost renewable power is yet to be leveraged across the EU H2 economy.

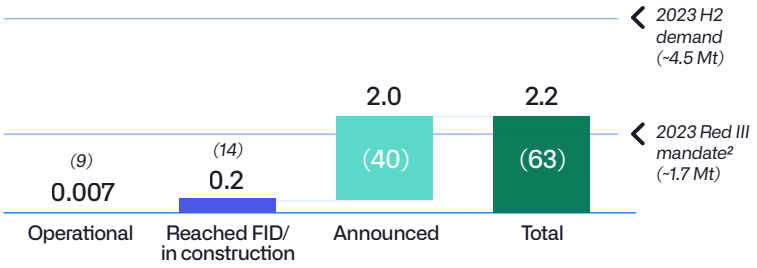
63 projects announced to be operational by 2030

23 projects having reached FID or operational in EU as of Q3 2024

RENEWABLE H2 PRODUCTION CAPACITY BEYOND FID ONLY ACCOUNTS FOR 5% OF REFINERIES' H2 DEMAND

- The EU's announced and operational production capacity for renewable hydrogen earmarked for refinery end-use represents 66% of the globally announced and operational capacity for refinery end-use, but only 22% of the targeted overall 10 Mt H2 domestic production under Fit For 55.

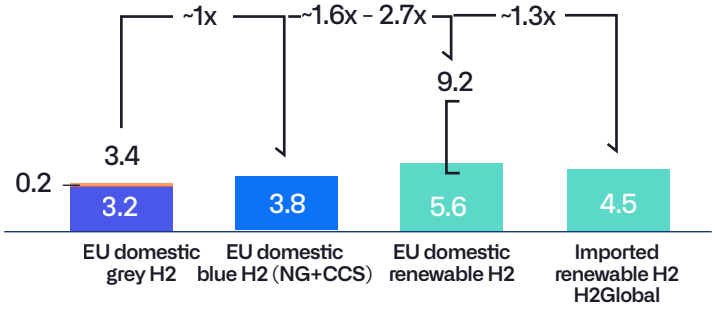
- **Announced renewable H2 production capacity for refineries** commissioned by 2030 (Mt)[1] (# projects)



EU RENEWABLE H2 CANNOT YET COMPETE WITH GREY, BLUE, OR IMPORTED H2

- More than 40% of Europe's refining capacity falls in countries with high renewable hydrogen production costs.
- Roughly 70% of refinery emissions in 2023 were covered by free allowances in the EU Emissions Trading System (EU ETS).

- **Levelised Cost of H2 2024[3]** (€ / kg H2)



[1] Does not include concept or demonstration projects
[2] Estimated Renewable H² use target for refineries based on the 2030 RED III mandate which states that 42% of H² for industry must be renewable and 1% of all energy supplied to the transport sector must be fuels of RNFBO origin, assuming here that all RFNBO fuels supplied to transport market will originate from refineries. This target could also be met by other e-fuels.
[3] Grey and blue LCOH2 averaged over 4 EU countries with largest refinery capacity (Germany, Spain, France, Netherlands), domestic renewable H2 low-end represents Spain, high-end represents Germany, imported renewable H2 based on H2Global and FertiGlobe's e-ammonia landing price at €1000/ton.
Sources: Analysis by Systemiq undertaken for Breakthrough Energy and Cleantech for Europe. Analysis based on prior completed analysis by Systemiq for MPP relating to EU PtX LOCX, IEA H2 project database, Clean Hydrogen Observatory 2023, ETC 2023 Fossil Fuels in Transition; EU ETS emissions viewer.

REFINERIES

RENEWABLE H2 FOR REFINERIES: GETTING PUMPED

ENABLERS – WHAT IS GOING WELL

FIRSTMOVER OFFTAKER ENABLING EARLY SCALING

Europe leads renewable H2 project pipeline for refineries, leveraging their willingness to pay, and existing grey demand (57% of Europe's H2 use today) to reach FID. Co-locating with refinery projects (~25% of refinery H2 demand) and low-tech integration costs both reduce barriers to entry for refineries and thus refineries play key role to scale first volumes.

COMPREHENSIVE POLICY FRAMEWORK ESTABLISHED

The Renewable Energy Directive (RED) has set the overarching framework through mandated renewable H2 use targets for industrial feedstock products (42%) and national shares of RFNBO's supplied to the transport sector (1%) by 2030. EU has led high integrity RFNBO definition giving industry clarity, and EU Hydrogen Bank critically provides a framework for supporting both OPEX and CAPEX support (first auction enabled bankability with ~85M for refinery renewable H2).

OIL & GAS COMPANIES ABSORBING PROJECT RISK

Whereas other e-fuel segments such as e-SAF for aviation struggle to finance capital-intensive projects, renewable H2 plants benefit from the presence and interest from O&G companies, thereby being able to leverage their existing infrastructure and sizeable balance sheets for favourable capital costs and risk-taking ability.

BARRIERS – WHAT IS NOT GOING WELL

POLICY TARGETS YET TO MOBILISE DEMAND

Uncertainty exists around various topics surrounding Member State implementation of RED III (e.g. on target compliance schemes, RFNBO multipliers), halting clarity on the business case for using renewable H2 in refineries. The absence of RED targets beyond 2030 disincentives high ambition and/or long-term investment.

COMPLEX AND SUB-OPTIMAL FUNDING

The multitude of EU H2 funding pools increases complexity, delays funding and cannot be stacked, whereby funding granted 2-3 yrs ago proves insufficient in new macro-economic environment without indexing. Much EU funding goes to first-of-a-kind demonstration projects, and requires wider embedded guidelines on sourcing EU-made equipment.

DISPARATE DEVELOPMENT OF INFRASTRUCTURE

Pan-EU coordination is essential to leverage competitive renewable power across the EU H2 economy. However, ongoing H2 infrastructure developments so far are driven mainly by national gas network operators, with too little institutionalized EU coordination required to ensure the optimal build-out of renewable power and H2 infrastructure.

ACTION AGENDA – WHAT NEEDS TO BE DONE

1 Establish long-term regulatory certainty around set-out policy targets

Set effective measures for Member States to implement REDIII into national legislation before the set-out deadline, providing regulatory certainty for various topics surrounding national compliance schemes on both RFNBO's supplied to the transport sector and refineries' use of renewable H2 for industrial products. RED targets could also be extended beyond 2030.

2 Strengthen public funding to support longer term scale-up of the EU H2 economy

This could take the form of increased funding to the EU Hydrogen Bank for auctions specific to end-uses, and financial guarantees through the EIB. To further bridge the green cost gap, enable funding flexibility to allow funding stacking by projects recognised by Member States or Important Projects of Common European Interest (IPCEI), align state aid rules with the EU's next Multiannual Financial Framework budget and existing funding, and index funding to the macro-economic environment. Set the policy framework to ensure EU-funded projects source EU-made H2 equipment, and for the EU Hydrogen Bank to operate as green market maker like Hintco and H2Global.

3 Guide pan-EU coordination to streamline ongoing H2 infrastructure development

Guide the development of the European Network of Network Operators of Hydrogen (ENNOH), aiming at regulatory clarity on implementation of intertemporal and cross-border tariff allocation, H2 purity standards, equitable market entry for all H2 developers, and a development plan for H2 infrastructure planning aligned with the renewable electricity sector, energy industry, renewable H2 developers, and overall EU targets.

Solving the climate change challenge while maintaining competitiveness on a global scale will require partnerships between governments and industries. The European Union could support this effort by reducing complexity around incentives, providing additional regulatory certainty and also ensuring a level playing field to bolster the European clean fuels economy.

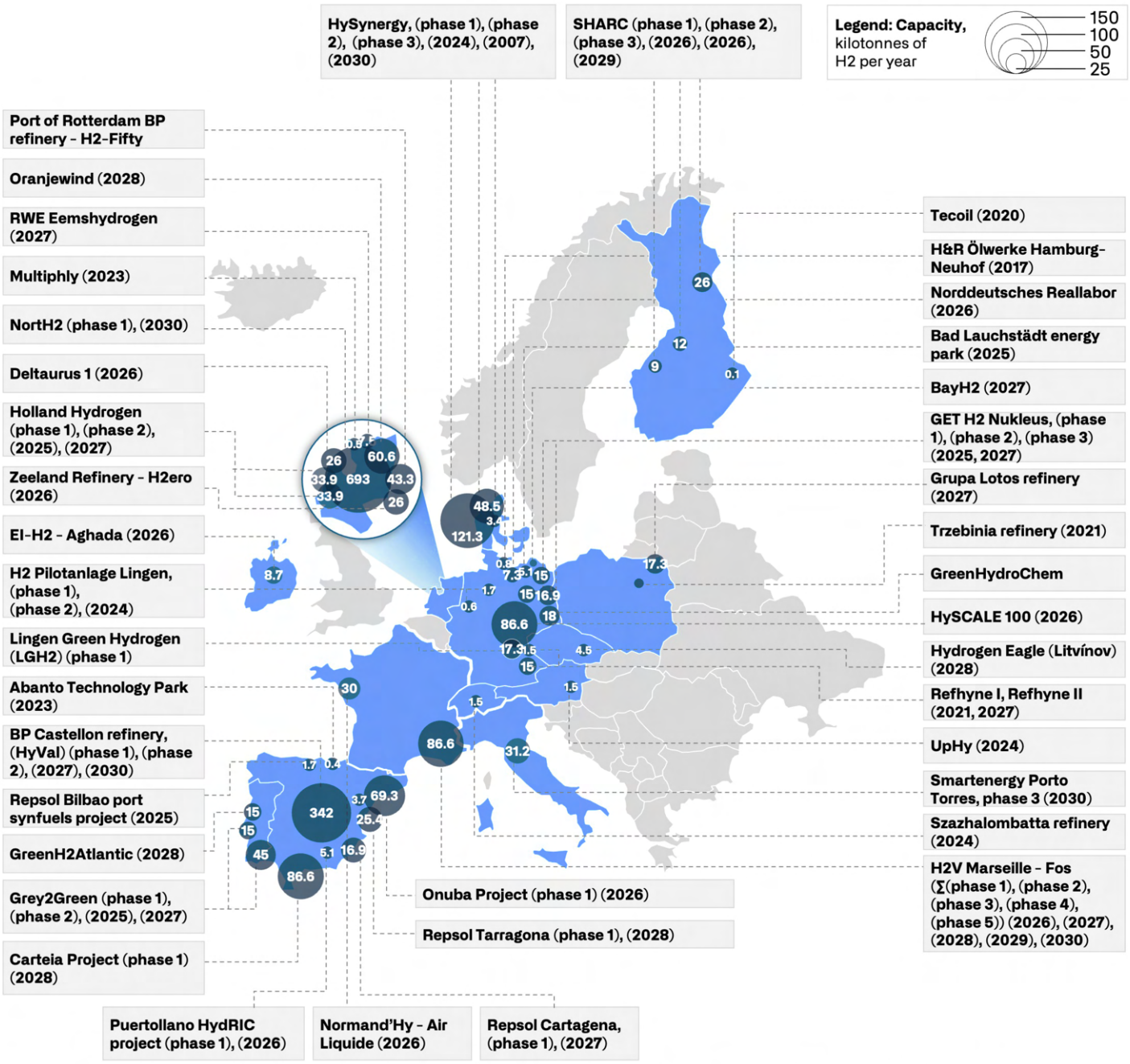
Amy Chiang, Chief Sustainability and External Affairs Officer, **Topsoe**

REFINERIES

RENEWABLE H2 FOR REFINERIES: GETTING PUMPED

60+ ANNOUNCED RENEWABLE H2 PLANTS (~2.2 MTPA) IN EUROPE

(as of October 2024)



Notes: Map excludes projects in feasibility stage smaller than 5kt H2 output, projects are placed in respective countries but not always on their respective location.
Source: IEA H2 projects database

In order to make the European Hydrogen Economy thrive, we must implement offtake incentives, improve funding, financing and guarantees for first movers, and introduce resilience criteria in auctions to safeguard European competitiveness.

Anne-Laure de Chammard, Executive Board Member & Group Executive Vice President, **Siemens Energy**