EHB Implementation Roadmap: Public support as catalyst for hydrogen infrastructure

European Hydrogen Backbone

APRIL 2024

Guidehouse

Connective hydrogen infrastructure is central to the energy transition

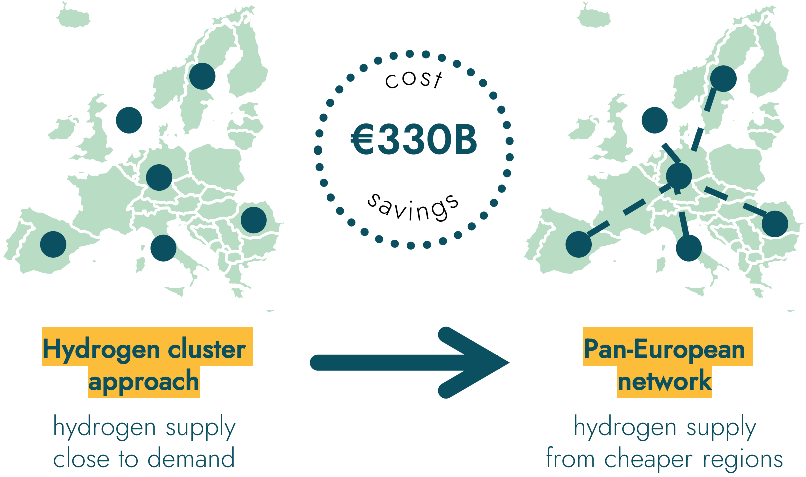
European Hydrogen Backbone
Executive summary (1/2)

www.ehb.eu

Hydrogen and the EHB are crucial enablers of the European energy transition.

— A successful early rollout of hydrogen infrastructure will be key to achieving Europe's decarbonisation targets by 2030 and beyond.

— Pan-European hydrogen infrastructure supports the scale-up of renewable energy and bolsters security of supply, with connectivity between supply and demand regions directly contributing hundreds of billions of euros in savings.[1]



Early market dynamics during the scale-up of hydrogen result in misaligned incentives for EHB buildout, hindering proactive early-stage investments.

Investors are willing to invest in bankable projects but require guarantees.

— Investors seek projects with firm end-user commitments, which are difficult to obtain in the early stages of market ramp-up.

Pipelines sensibly built to accommodate future demand come with early-stage financial risks.

— The EHB is most cost-effective when sized to serve mature-market volumes, preventing expensive expansion projects and infrastructure-related bottlenecks as the hydrogen market develops.

— Consequently, generating sufficient revenue in the first five-to-ten years of operation poses challenges for forward-looking pipeline developers, with low initial revenues discouraging private investment despite the decades-long durability of decarbonisation benefits.

TSOs are pushing forward with build-out but should not be required to bear all financial risk.

— Public risk sharing is needed to enable investment in the construction and operation of pipeline projects, rather than disincentivising proactive TSOs by requiring them to bear the risk alone.

— Example: A €5 billion cross-border pipeline project requires an initial investment of €125-250M for developmental studies[a] to help mature the project and make it bankable for investors.

1) Gas for Climate, 'Assessing the benefits of a pan-European hydrogen transmission network'
a) DEVEX assumed to be a percentage of CAPEX, with variability on a project-to-project basis

Early-market public support for hydrogen infrastructure is the most cost-effective way to spur the build-out of hydrogen value chains

European Hydrogen Backbone
Executive summary (2/2)

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The EHB recommends two forms of public support: developmental support and construction/operating support.

Benefits of developmental support:

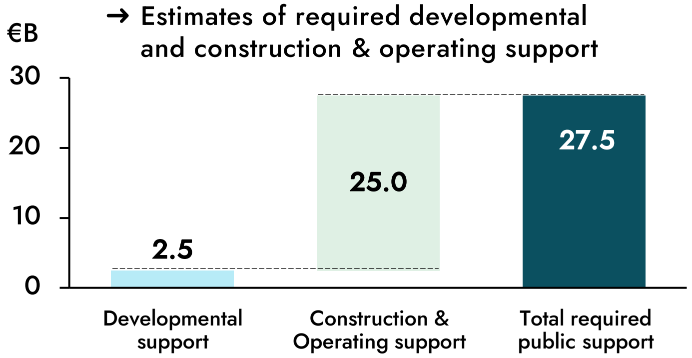
Broad allocation of early-stage ***developmental support*** provides policymakers with key insights on network build-out and enables developing hydrogen pipeline projects to unlock greater access to market capital by creating **bankable projects**. It can also provide **cost efficiencies** by spurring collaborative development of technology.

Benefits of construction & operating support:

Construction and operating support helps to align incentives and overcome the temporary early-market imbalance that occurs during the first five-to-ten years of network operation. Policymakers must avoid penalising early hydrogen network adopters with high early tariffs and pioneering network developers with the full burden of market development risk.

Total external support required

- An estimated €27.5B of public support enables 14MT (490 TWh) of hydrogen to be delivered by ~31.000 km of hydrogen pipelines by 2030, reducing annual emissions by up to 312 MT CO_2e per year by 2050.[b]
- Beyond what is currently-available in EU funding, additional public support is needed.



Realising 2030 decarbonisation goals requires near-term public action.

The use of public funding can be reduced using emerging support mechanisms.

Emerging mechanisms and regulatory proposals such as an *intertemporal cost allocation framework* can significantly reduce the amount of direct public funding required.

Support should be allocated now.

Given the typical seven-year project development timeline and the urgency of 2030 EU climate goals, support should be committed as soon as possible.

Further efficiency can be gained through better coordination.

Significant cost savings can be realised through network planning and development in conjunction with other energy vectors.

b) Metric tonnes of CO_2 equivalent emissions reductions. Guidehouse, Inc analysis based on projected hydrogen demand in 2050, by sector, using green hydrogen as a substitute for fossil energy

The European energy transition necessitates committed, near-term action

The EHB is a key component of cross-sector decarbonisation, keeping Europe on a trajectory towards 2030 and 2050 climate targets

The scale and urgency of the challenge:

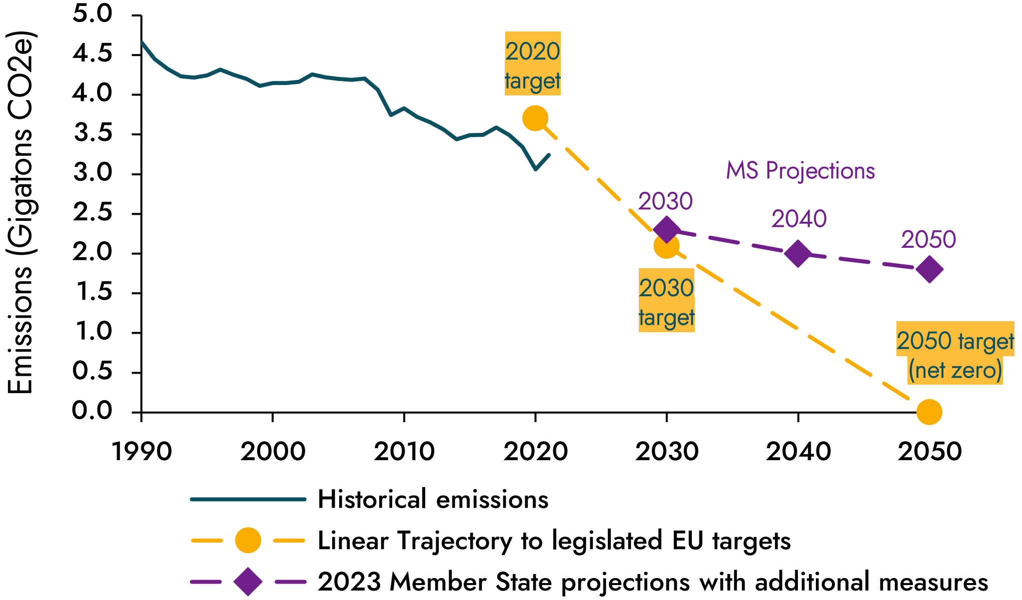
The EU has set ambitious emissions reduction targets for 2030 and 2050, outlining a key role for **hydrogen** in its REPowerEU strategy.

According to the IPCC's 2023 report, effective and currently feasible options for reducing GHG emissions are available but are not being deployed quickly enough.[2] Similarly, as of early 2024, the IEA projected that only 7% of announced 2030 renewable hydrogen production capacity is currently on track, *specifically citing a lack of transport infrastructure as a limiting factor.*[3]

As a result, many governments and multinational corporations are scaling down near-term emissions targets, citing supply concerns and high energy costs.[4]

Hydrogen offers a multi-sectoral solution that complements other decarbonisation pathways like electrification and carbon management. *It is of crucial importance to provide near-term public financial support to hydrogen infrastructure projects to enable it to build on existing momentum and bolster further decarbonisation efforts.*

→ European decarbonisation progress towards goals[5,c]



*"In the next decade we must **redraw the map of infrastructure** across the continent. We will need electricity super-grids. **The gas network must be repurposed to transport hydrogen** or CO_2"*

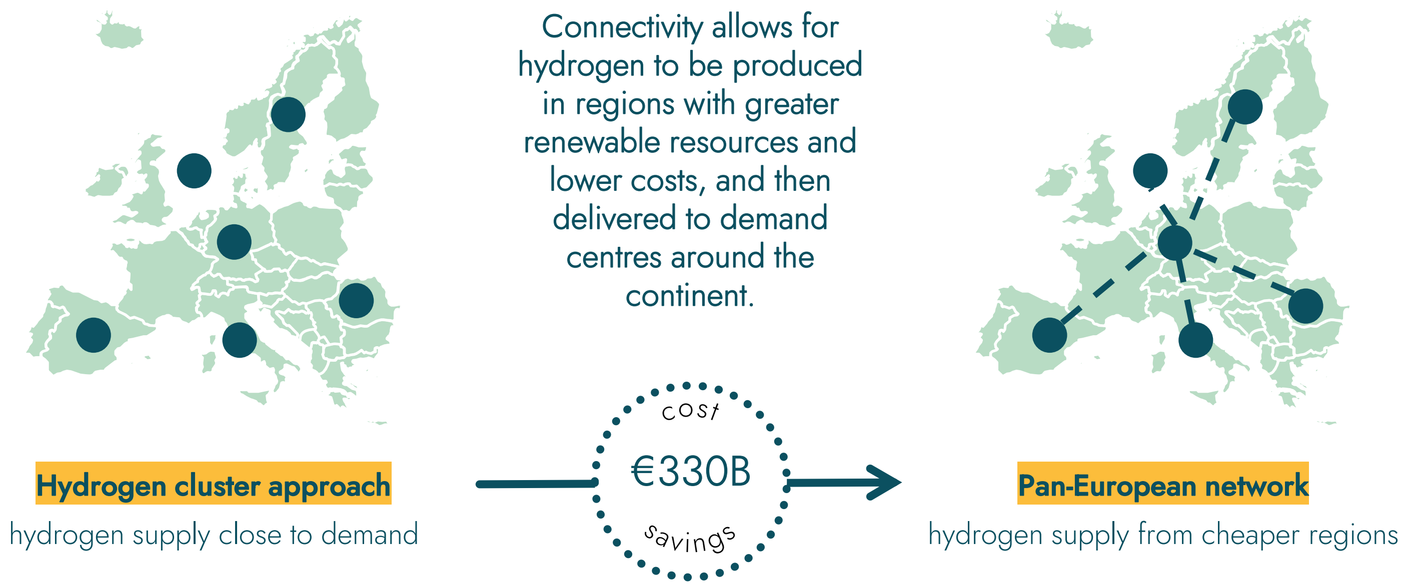
—Šefčovič, Simpson, and Hoekstra, 6 February 2024.

Sources: A complete reference list is provided at the end of the report on slide 22.
Footnotes: c) Includes offset LULUCF emissions

Hydrogen infrastructure supports renewable energy build-out, connecting cost-effective supply and demand across the continent

A well-connected hydrogen network builds upon the strengths of European energy system to facilitate decarbonisation, renewable energy integration, and network resilience

Connective hydrogen infrastructure provides the most cost-effective solution for supplying the hydrogen economy, with a pan-European network projected to save €330B as compared to a clustered approach. [1,3,6,7]



The EHB can play a major role in overall European decarbonisation efforts, reducing annual emissions by up to 312 MT CO_2e per year by 2050.[b] **Hydrogen delivered by the EHB will:**

- Directly mitigate emissions from hard-to-decarbonise sectors of the economy
- Enable increased build-out and integration of variable renewable energies across the continent
- Improve energy system stability by stockpiling excess supply from different regions and across varying timeframes, particularly when the network is coupled with storage facilities
- Provide access to hydrogen storage for countries that do not possess suitable geological characteristics themselves, increasing system flexibility and reducing risks associated with geopolitical disruptions
- Bolster network resilience and security of supply via the integration of multiple energy sources, locations, and pathways

Sources: A complete reference list is provided at the end of the report on slide 22.

Footnotes: b) Metric tonnes of CO_2 equivalent emissions reductions. Guidehouse, Inc analysis based on projected hydrogen demand in 2050, by sector, using green hydrogen as a substitute for fossil energy

TSOs are driving development of the EHB, leading both large-scale coordination efforts and the delivery of real projects on the ground

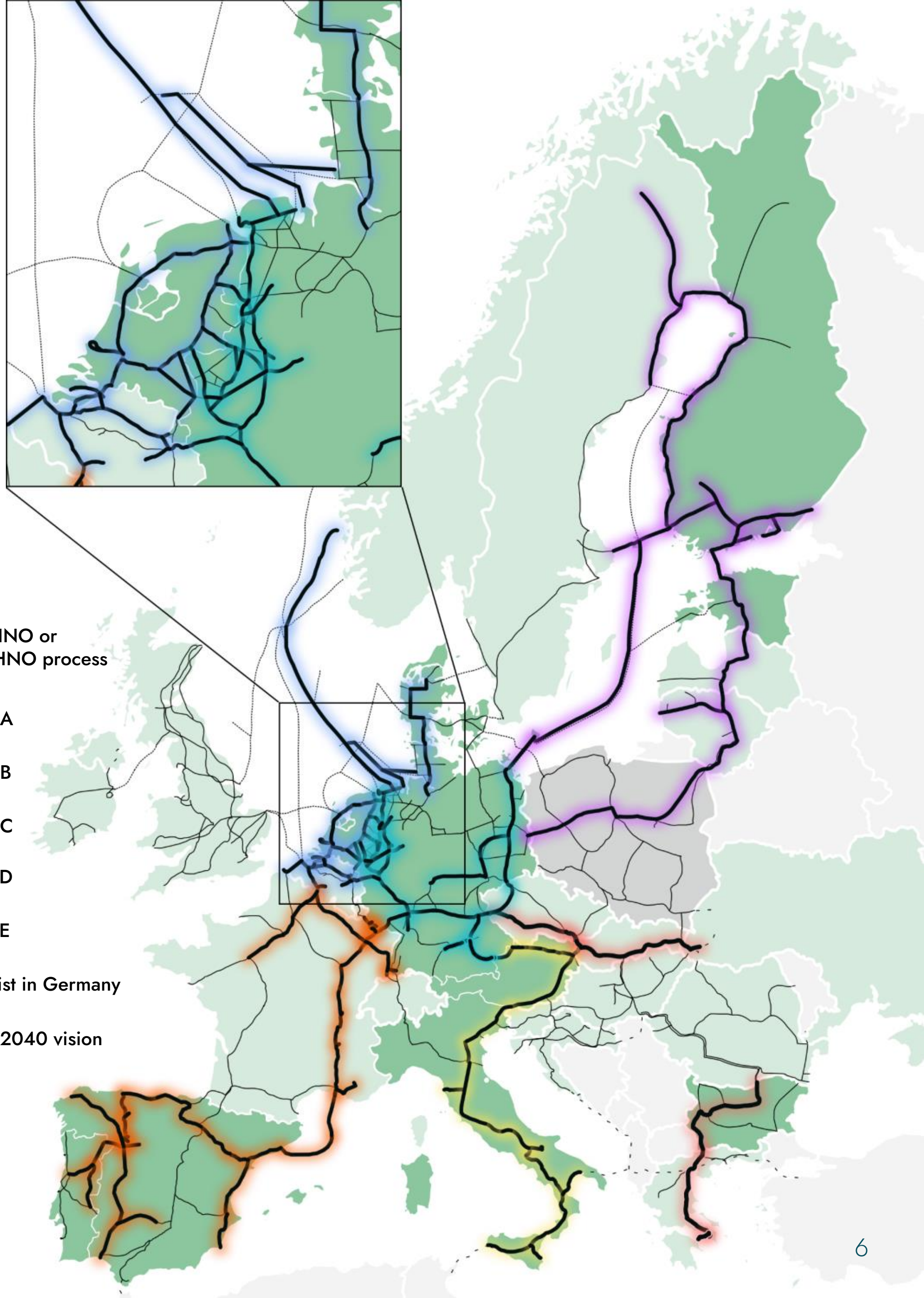
EHB members have continued to push forward with PCI and HNO nominations, market studies, and concrete project implementation

EHB members are developing concrete projects:[6]

- 41 EHB projects have received PCI status.[d]
- EHB infrastructure projects have been included in ENTSOG's 2024 Ten-Year Network Development Plan (TYNDP).[6,e]
- Development studies in Spain, Denmark, France, Germany, Lithuania, and Norway have identified ample supply and demand resources that support a strong business case.[6-11]

EHB members are actively leading national and international hydrogen development activities:

- The first Hydrogen Network Operator (HNO) nominations have taken place, with three EHB member TSOs awarded HNO status, two close to securing the role in their countries, and more expected to follow, as a further five are in the nomination process.[6]
- EHB members will also be active stakeholders in the developing European Network of Network Operators for Hydrogen (ENNOH).



Sources: A complete reference list is provided at the end of the report on slide 22.
Footnotes: d) The definitive selection of PCIs was published in April 2024.
e) the projects in this map only highlight H2 infrastructure part of the assumed 6th PCI list; for an overview of all projects please see Figure 6 in this report

Implementation timelines: Access to phased financial support is key to hydrogen infrastructure development

Hydrogen pipeline projects typically require initial developmental expenditures (DEVEX) to enable Final Investment Decisions (FID), as well as funding for construction and operations

Today | ~2027 | ~2030 | ~2070

Development Phase

Individual Project FIDs and start of construction

Construction & Operations Phase

Developmental Activities:

- Developmental and feasibility studies
- Permitting and regulatory approvals
- Gauging and securing end-user commitments
- Technical analyses

Construction Activities:

- Construction
- Workforce contracting
- Procurement of materials and equipment

Operational Activities:

- Operational costs
- Maintenance costs

DEVEX support (pre-FID) enables:

- **Developmental support** enables TSOs to conduct feasibility and other studies to increase a project's maturity and bankability, prior to FID.
- **Example:** a typical DEVEX investment of 125-250M€[f] is required for a 5B€ hydrogen project, which is a burdensome cost for TSOs to bear alone in light of the broader societal decarbonisation benefits.

Construction & operating support (post-FID) enables:

- The construction and operations phases occur after successful FID, requiring capital expenditures (CAPEX) to build the network and operational expenditures (OPEX) to operate and maintain the pipeline.
- A *commitment* of **construction & operating support** is necessary *before FID* to allow TSOs to de-risk investment and attract additional private capital.

Footnotes: f) DEVEX assumed to be a percentage of CAPEX, with variability on a project-to-project basis

For new markets, coordinated public support is most effectively used to mitigate investment risk, acting as a catalyst for broader network buildout

De-risking enables a strategic view of network development and increases the EHB's ability to attract market capital

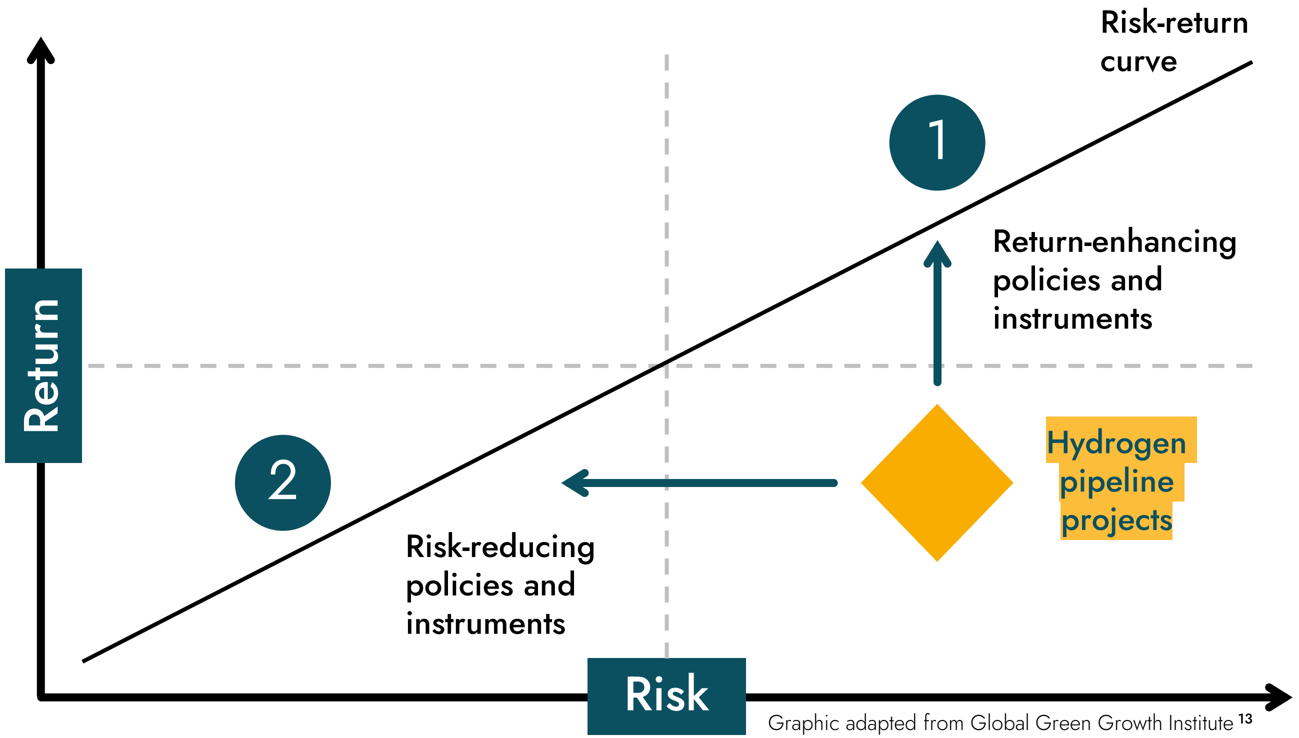
Mitigating risk is an essential step to build out a new market, especially for interconnected markets like hydrogen.

In the still-developing hydrogen market, 'due diligence' activities can provide a roadmap to coordinate efficient whole-network build-out. Given the societal benefits of a productive hydrogen value chain, TSOs cannot be solely responsible to bear the risks involved with infrastructure development.

De-risking activities increase the ability to attract external funding.

Commercial investors' willingness to finance hydrogen projects is limited by perceived development risks and low early-stage returns. Public support mechanisms can provide two alternatives for assistance, either by: **enhancing potential returns** or **reducing risks.**[13] De-risking is the more effective option to improve the risk-return curve and stimulate external investments, given the constraints of operating in a regulated market that limits potential returns.[14]

→ Risk-return curve for hydrogen projects



Graphic adapted from Global Green Growth Institute [13]

Sources: A complete reference list is provided at the end of the report on slide 22.

Both developmental and implementation support are needed to enable successful network development

Investment in DEVEX helps clarify network coordination and build-out, while construction and operating support can help to overcome inherent early-market dynamics

1 Development Phase (pre-FID)

Public support for developmental activities can enable efficient deployment of capital across the full network, increasing the likelihood of success.

For those projects in the earlier stages of development, pre-FID support can help to resolve technical and financial challenges, increasing the confidence of external investors.

A whole-network view of deployment allows for strategic planning that enables optimal phasing of build-out, with increased reliability and energy security.

A coordinated approach to technology advancement—with simultaneous collaboration among multiple market players—can reduce CAPEX requirements, resulting in greater speed to market, better access to technology, and a reduction in overall costs.

2 Construction & Operations Phase (post-FID)

Public support also works to de-risk construction and operational activities during the initial years of market ramp-up.

The first five-to-ten years of network operation—a period with increasing but less than full market adoption—present a challenge for pipelines to generate the total revenues allowed by regulators.

The gap between required CAPEX and early projected revenues is considered an investment risk by investors, who lack the appetite to be first movers in this space. Therefore, clarity around public construction and operating support is critical to sufficiently de-risk these investments, prior to FID.

Such support also allows successful pioneering projects to provide early lessons learned and serve as a roadmap for broader network buildout.

Recommendation: Policymakers can provide clarity and bolster progress toward 2030 climate goals by allocating phased public support

Near-term allocation of both developmental support (2.5B€) and construction & operating support (25B€) provides the clarity required to catalyse cost-efficient network build-out

2.5B€ in development support is needed now to advance ~31.000 km (~44 projects) towards FID and put the network on the optimal build-out path.

— DEVEX support is required as soon as possible to enable EHB projects to reach FID, with a quarter of the projected 2030 EHB network planned to be operational before 2029, and a further three-quarters of EHB projects planned to be running by 2030.

25B€ in construction and operating support is needed before 2027 to overcome inherent early-market dynamics, increase the confidence of outside investors, and enable successful early-stage projects to serve as blueprints for future progress.

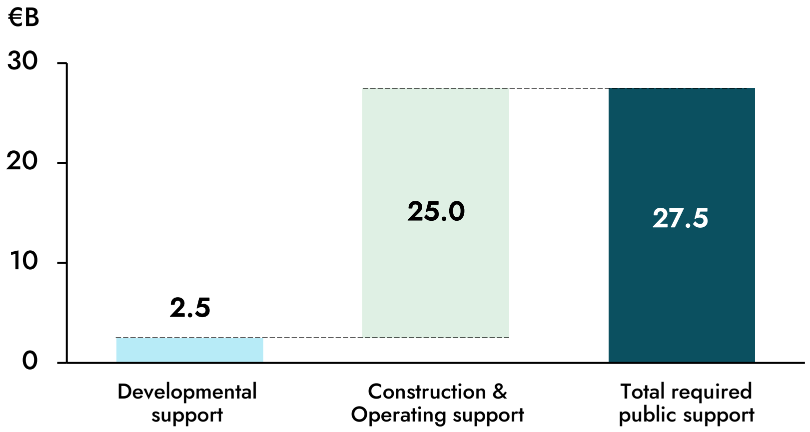
— The EHB provides a durable foundation for long-term European decarbonisation efforts, but early-market dynamics necessitate coordinated support during its initial phase.

— It is not necessary that the entirety of the 25B€ be funded via direct financial allocations from public bodies—a variety of support schemes and external actions can help to reduce the ask, including:

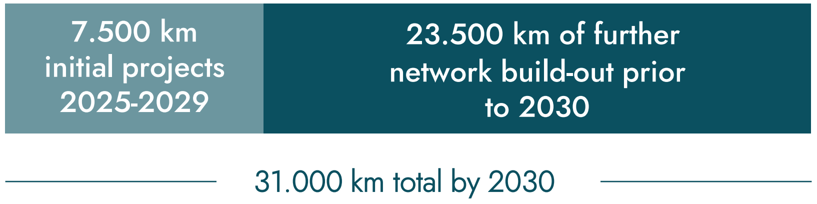
  — Emerging support mechanisms that enable efficient accounting of the long-term project economics

  — Regulatory actions that accommodate the varied timelines and wide-ranging societal benefit derived from the EHB

→ Estimate of required developmental and construction & operating support



→ Projected EHB Build-out



Recommendation: European policymakers can efficiently deploy public financial support by funding DEVEX studies for early-stage projects

Investing in DEVEX is the most cost-effective way to leverage limited near-term funding, providing information to de-risk projects and unlock larger pools of market capital

2022 · 2023 · 2024 · 2025 · 2026 · 2027 · 2028 · 2029 · 2030

1 Development Phase (pre-FID)

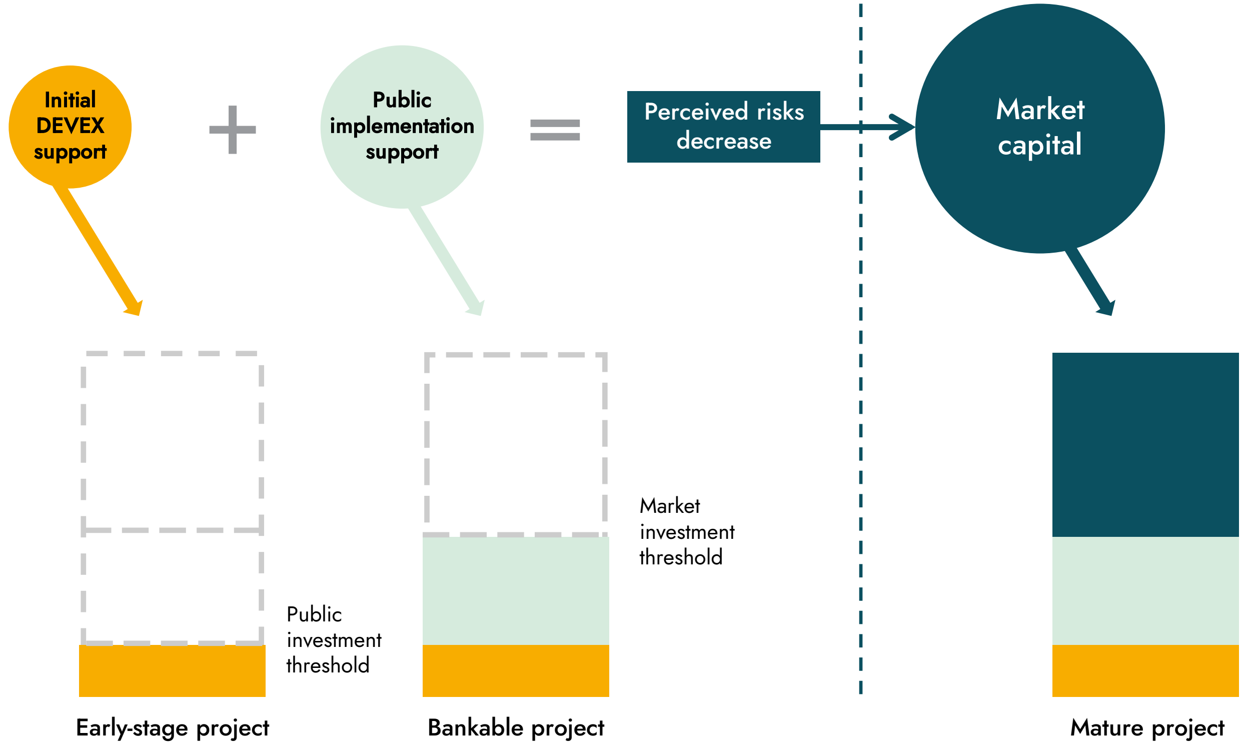
Private market capital is available, but it must be unlocked by early-stage DEVEX investments that de-risk and clarify the EHB's business case.

Public capital is limited; it is crucial to leverage such support for the greatest possible impact. For the EHB, development studies help to put build-out on the optimal path by clarifying the long-term business case and boosting the network's attractiveness to external investors.

Global investments in infrastructure are expected to double in 2024 (relative to 2023), with continued growth expected in the next 2-3 years.[15] Large institutional investors are making significant infrastructure acquisitions and reaching infrastructure fundraising targets faster than expected,[16] indicating that more market capital could become available soon.

With a relatively small amount of initial public support, DEVEX activities could be leveraged to stimulate greater decarbonisation benefits by providing better access to providers of market-rate capital.

→ Stages and levers of project development and investment



Graphic adapted from Global Green Growth Institute[13]

Sources: A complete reference list is provided at the end of the report on slide 22.

Support of DEVEX also illuminates the path to efficient network-wide development

Early developmental insights can improve the phasing of network build-out, enable efficient coordination between market actors, and promote cost reductions

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1 Development Phase (pre-FID)

The insights gained from developmental studies pave the way for efficient network-wide development.

Developmental studies provide insights into the initial key connectors of the grid, highlighting the most effective investments to target. Although the final form of a pan-European grid provides continent-scale connectivity, progress will not occur all at once, and policy-makers can most quickly and cost-effectively spur build-out by providing insights into optimal project phasing.

The information provided by developmental studies will lead to system-wide cost reductions through incentivised collaboration.

Developmental support across Europe will allow projects to simultaneously mature, with shared progress enabling project developers to share learnings, accelerate development, and reduce costs.

Collaborative efforts can help to reduce bottlenecks by addressing common needs like hydrogen supply chain development or the advancing the development of latest-generation compressor technologies. This collaborative approach can foster greater efficiency and productivity within the entire network.

Developmental support is a compelling investment for policymakers.

Allocating funds to DEVEX studies has limited downsides; apart from any individual project's FID outcome, DEVEX funding will create insights that help to identify the most attractive EHB investments. Highlighting projects with a strong business case and high likelihood of success increases the overall probability of Europe reaching its decarbonisation targets.

€2.5 billion in developmental support will prepare ~31,000 km of projects for FID, bolstering progress towards Europe's decarbonisation goals

Reducing the financial burden of the DEVEX phase creates alignment of incentives for pioneering first-movers, making efficient use of limited EC resources

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1 Development Phase (pre-FID)

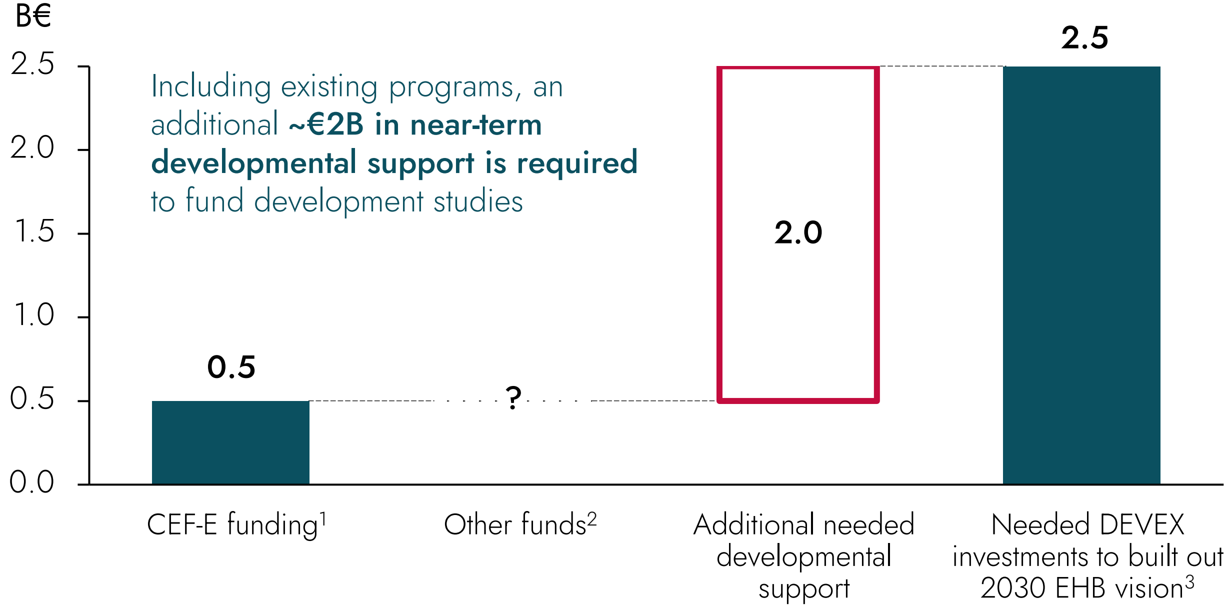
EHB Recommendation: Fund development studies for as many hydrogen infrastructure projects as possible, across the entirety of Europe

Grant support to a large set of projects to fund development studies. Each study will be used to quantify risks and assess the opportunities to most effectively accelerate implementation.

This funding helps mitigate initial development and investment risks, aligning incentives towards expedient full-network build-out and spurring further development of Europe's renewable energy and hydrogen industries.

TSOs cannot start developmental studies without sufficient public support, leading directly to delayed pipeline completion dates and putting climate goals at risk.

→ Developmental funding: needed vs available



1: An estimated €3.5 billion remains from the Connecting Europe Facility – Energy (CEF-E) €5.9 billion total program budget. 15% of the CEF-E spending is dedicated to cross-border projects, with a potential increase up to 20% subject to market uptake. This means that €2.8 billion (€3.5 billion x 0.8) is left for PCI projects. Through 2027, the CEF-E program will support 5 categories of PCI: electricity, smart gas grids, hydrogen, electrolyser facilities, and CO_2 networks. Therefore, it is estimated here that only approximately €0.5 billion (€2.85 billion / 5) of the remaining budget (available for the next 4 years) will be allocated to support hydrogen transport infrastructure.

2: It is unclear how much support network operators can expect from other funds, such as the European Regional Development Fund, Modernisation Fund, Cohesion Fund, InvestEU, and Horizon Europe.

3: We assume the total DEVEX needs of the 2030 EHB network are a percentage of CAPEX, based on an internal EHB member survey.

Construction and operating support is also crucial for strengthening the early-market business case

To overcome the uncertainties inherent in any new market, policymakers should allocate funding to ensure that both pioneering and longer-term hydrogen infrastructure projects are successful

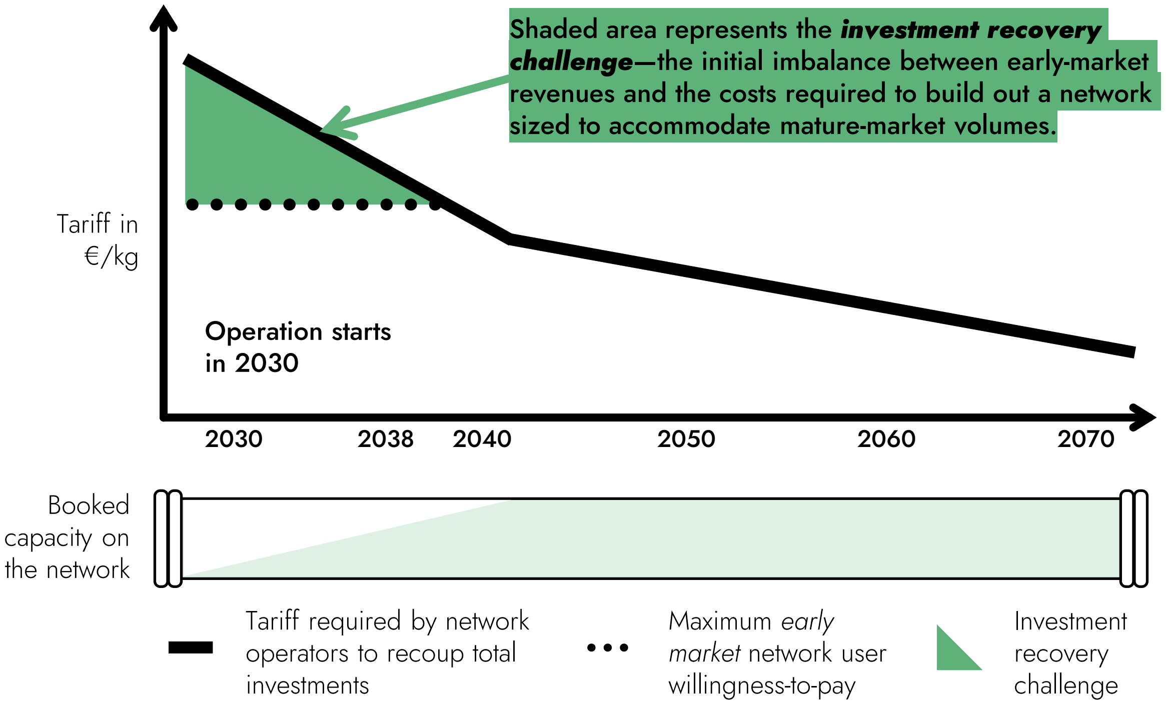
2022 · 2023 · 2024 · 2025 · 2026 · 2027 · 2028 · 2029 · 2030

2 Construction & Operations Phase (post-FID)

Revisiting the Investment Recovery Challenge

- The EHB is most cost-effective when sized to accommodate mature-market volumes, preventing expensive expansion projects and infrastructure-related bottlenecks as the hydrogen market develops.
- During the early years of network operation and while the user base is still increasing, the imbalance between upfront CAPEX costs and early market revenues makes it difficult for a typical pipeline project operating in this new environment to generate the full revenues allowed by a regulator.[g]
- The EHB is projected to deliver large-scale societal benefits for decades, but this initial imbalance—occurring during the first five-to-ten years of network operation—is considered an investment risk by outside investors.
- Public support is critical to overcome this risk, helping a large group of developmental projects proceed from the development phase into the construction phase. **Public support should be designed to align incentives such that early adopter hydrogen network users are not disincentivised by high early tariffs, and such that proactive pipeline developers are not disincentivised for pioneering network development.**

→ Investment recovery challenge: concept



Footnotes: g) For a detailed explanation of this concept, see the EHB's November 23 publication.

By providing ~25B€ in construction and operating support, policymakers can ensure up to 20 Mton of hydrogen in the early 2030s

Construction and operating support helps to stabilise the early-market business model, de-risk investments in network build-out, and further encourage proactive early adopters

2022 · 2023 · 2024 · 2025 · 2026 · 2027 · 2028 · 2029 · 2030

2 Construction & Operations Phase (post-FID)

Estimated at 25B€, the amount of required construction and operating support is informed by a few key assumptions:

Extent of network build-out
31.000 km of pipelines operational prior to 2031

Projected long-term demand
14.7 Mton (490 TWh) H_2 throughput in 2030, and 40.5 (1349 TWh) Mton in 2040[h]

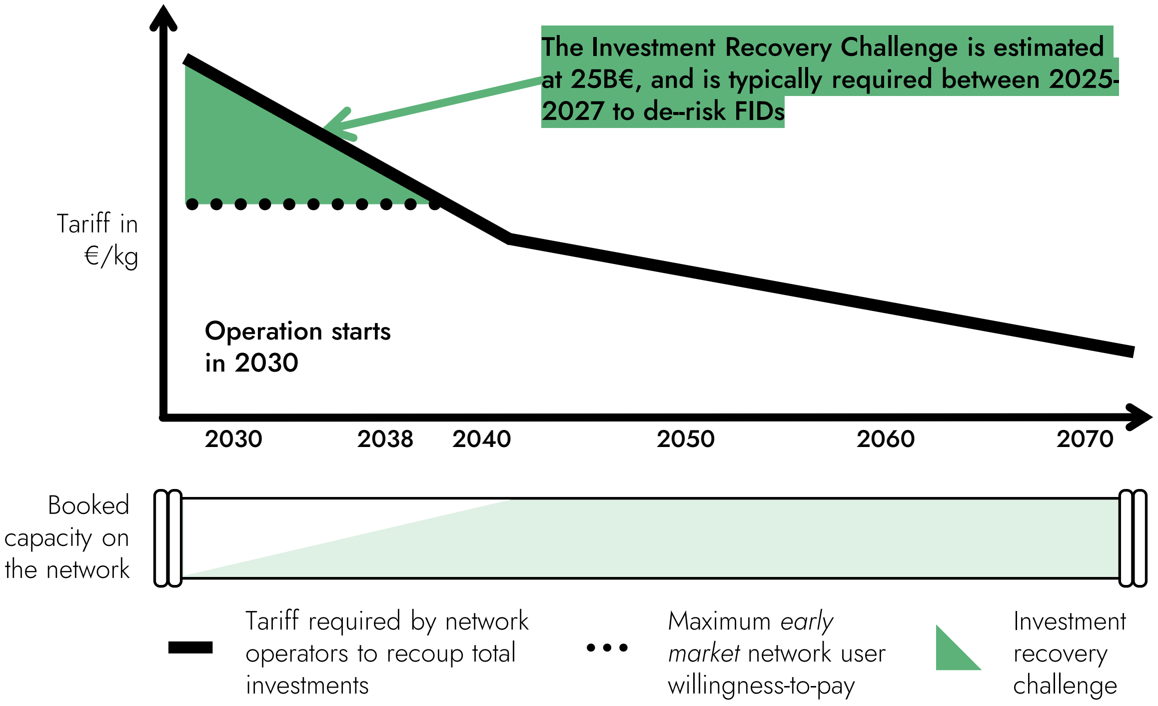
CAPEX costs for network build-out
Based on an internal survey of EHB TSO projects[6]

Additional assumptions
As detailed in the Appendix, slide 23

Compared to the amount of public support available today, significant additional allocations are necessary:

- CEF-E, the EU's only fund dedicated to transmission infrastructure, has only €0.5B available.
- Other funds are also relevant, but it is unclear how much support network operators can expect from the Recovery and Resilience Facility,[i] European Regional Development Fund, Modernisation Fund, Cohesion Fund, InvestEU, Horizon Europe, and others.

→ Investment recovery challenge: quantified



Footnotes: h) With a budget of over 700B€, the Recovery and Resilience Facility presents a significant funding opportunity. However, as the fund must be spent before mid-2026, it is not applicable to ***most*** EHB projects.
i) Calculations for hydrogen demand are based on a bottom-up analysis, by sector (2022 EHB analysis largely conducted prior to REPowerEU)

Emerging mechanisms like amortisation funds and contract for differences can reduce investment risk during the Construction & Operations phase

Beyond direct financial support, funding instruments like those under development in Germany and the Netherlands can ease the burden of up-front investment

2022 · 2023 · 2024 · 2025 · 2026 · 2027 · 2028 · 2029 · 2030

2 Construction & Operations Phase (post-FID)

1 STEP (Direct)

- The Strategic Technologies for Europe Platform (STEP) aims to reinforce, leverage, and direct existing EU funds to select sectors,[23] potentially including hydrogen infrastructure projects.[26]
- Projects that contribute to STEP objectives can apply for a Sovereignty Seal, improving their access to EU funding,[j] facilitating combined support from multiple programs, and helping to attract external investments.[24]
- However, Member States recently voted against providing additional funding for STEP, meaning it can now only draw from existing EU programs.[25]

2 Amortisation account — Germany (Direct)

- The German hydrogen network's €19.8 billion cost will be financed by a combination of equity capital, market investors, and grid fees paid by network users[20,21] without using dedicated state subsidies.
- Grid fees will likely be capped to ensure the competitiveness of the network for early adopters. The government will establish an amortisation account to secure the initial losses resulting from capped fees until payback has been completed (and anticipating a significant payback horizon).[k]
- In case of market ramp-up failure, the government can opt to cancel the account, with phased mechanisms to either transfer risk to network operators or take full governmental ownership of the network.

3 Subsidy — Netherlands (Direct)

- The Dutch government will subsidise 50% of the € 1.5B total costs to bring its hydrogen network to operation.[18]
- Funds will be used to (partially) cover CAPEX, OPEX, depreciation, and capital costs.
- A clawback is integrated into the subsidy: the actual subsidy spent through the end of the lead-up phase will be calculated after completion in 2030 and any paid-out surplus will be directed back to the government.[19]

4 Contract for differences – H_2 Global/HINTCO (Indirect)

- H_2 Global/HINTCO uses a Contract for Differences approach, coupling long-term purchase contracts from producers and short-term sales contracts from hydrogen users. This scheme helps to stimulate the market for hydrogen and therefore indirectly de-risks investments in hydrogen infrastructure.[17]

Sources: A complete reference list is provided at the end of the report on slide 22.

Footnotes: j) Co-financing (100%) and pre-financing (30%) rates apply to the 2021–2027 STEP programming period.[22-23]

k) The German government expects the account to ultimately be balanced by 2055, or the government will pay for a percentage of the shortfall (up to 74%), with grid operators having to fund the remaining fraction (up to 26%).[20-21] The exact division of costs in case of shortfall is currently under discussion.

A framework for intertemporal cost allocation provides critical flexibility to support early-market operations

Mechanisms proposed in the recent Gas/Hydrogen Package[l] would allow mature-market revenues to stabilise hydrogen market ramp-up and could significantly reduce required public support

2022 · 2023 · 2024 · 2025 · 2026 · 2027 · 2028 · 2029 · 2030

2 Construction & Operations Phase (post-FID)

A framework for intertemporal cost allocation (ICA) could significantly reduce the amount of public support required.

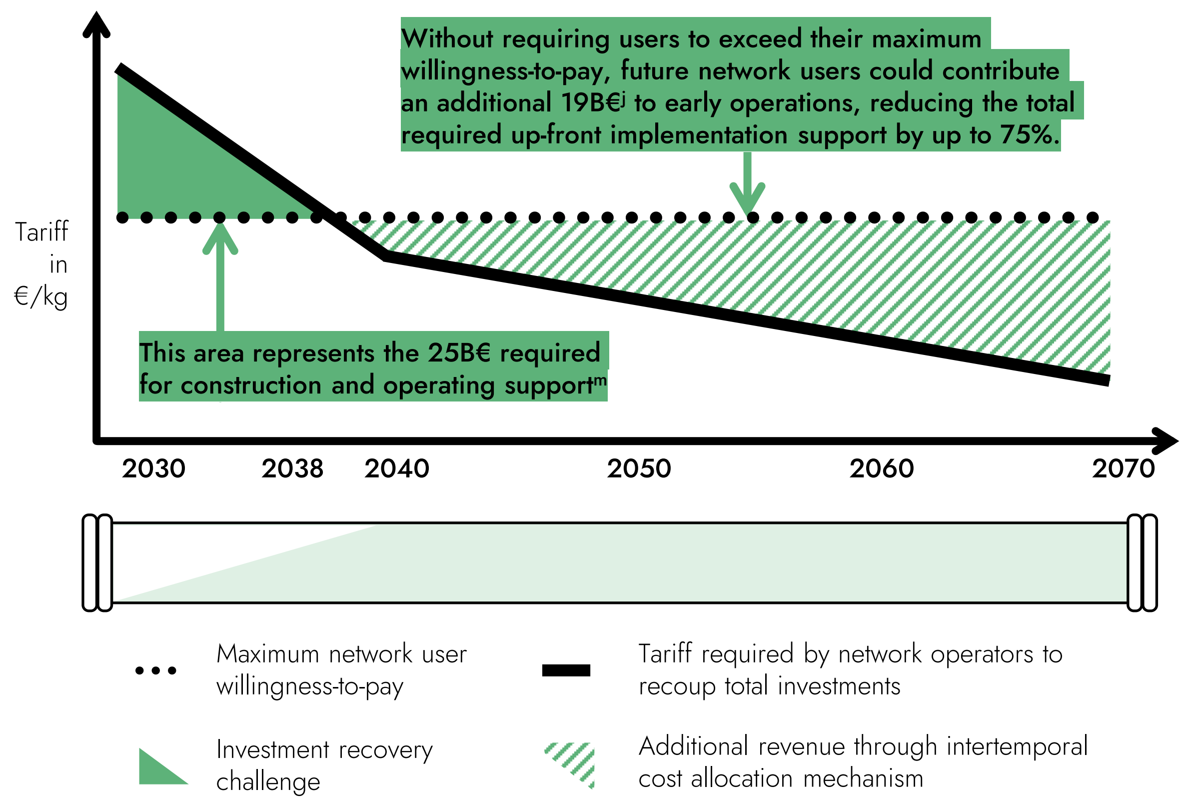
The graph at right shows that implementing a long-term ICA framework could potentially reduce the overall required implementation support by up to three quarters. It should be noted that—even with ICA—*some* amount of public support will still be required, and ICA may not be feasible in all countries.

There are still aspects of the mechanism to be clarified, such as the timing of the implementation, specific rules governing its applicability, and the expected level of participation from future users.

Network-user willingness-to-pay, the speed of hydrogen network adoption, and specific rules for cost allocation will play a major role in determining the effectiveness of the framework. To navigate these uncertainties, the EHB recommends that national regulators work closely with network operators to provide guidance to project developers.

Even pending clarification, the ICA framework remains one of the most effective tools available to accelerate early development of the hydrogen market.

→ Intertemporal cost allocation mechanism



Footnotes: l) While the final regulation is not published yet, the EHB assumes minor changes to the text based on reached political agreement
m) IRC and ICA values represent time-discounted amounts

Efforts to set up the network for early success and accelerate market adoption will reduce the total amount of investment required over time

Activities that act to de-risk and mature the hydrogen market are likely to stimulate additional, simultaneous drivers of network growth

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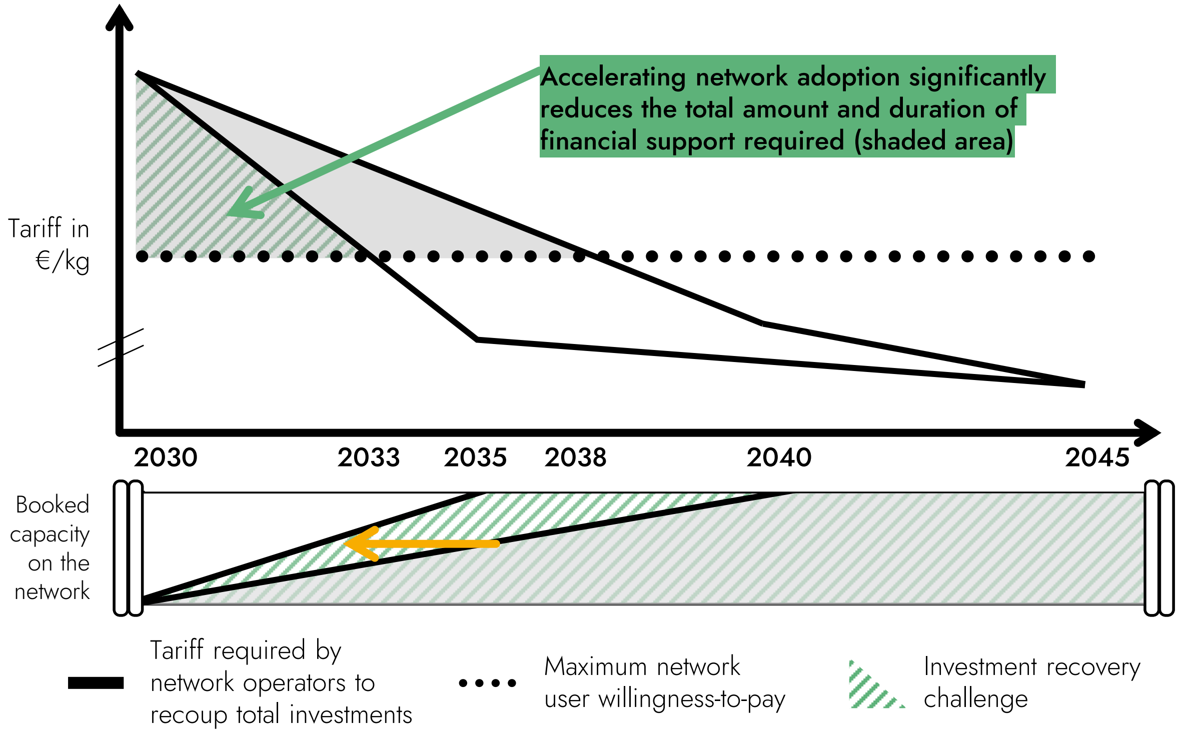
2 Construction & Operations Phase (post-FID)

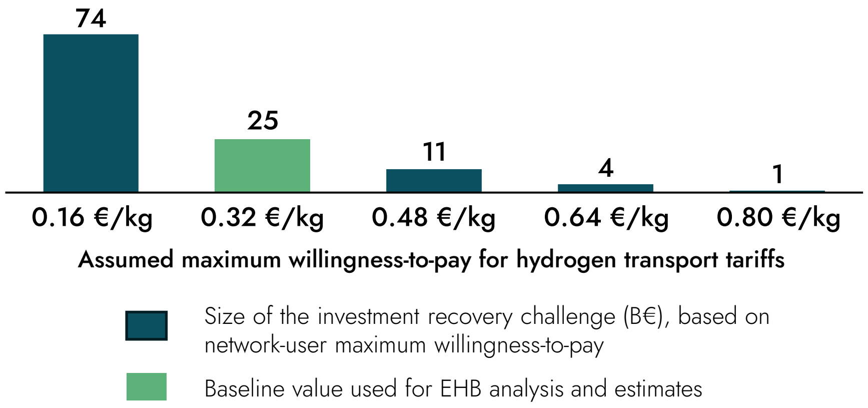
Financial, political, and regulatory efforts that work to accelerate the maturity of the hydrogen market *also* work to **reduce the size and duration of public support required for the EHB,** benefiting both policymakers and citizens that contribute to public financial pools.

→ Benefits of Accelerated Market Development



Estimating the amount of required public support involves key assumptions about the emerging market. The gap between TSO break-even costs and network user willingness-to-pay is perhaps the most important factor for determining the amount of support required (chart below).

→ The impact of network user willingness-to-pay:



Willingness-to-pay is likely to vary by location and end-use sector, while TSO break-even costs are driven by geographic, population, and political factors. Given the significance of this gap in driving overall economics, support mechanisms that specifically target either of those factors are likely to be most effective.

Successful planning for hydrogen infrastructure necessarily includes coordination with other energy vectors

Integrated planning for hydrogen and electricity transmission infrastructure allows for a more cost-effective, reliable, and timely energy transition

Consistent standards and regulations governing the technology, processes, sustainability, and safety can drive down costs along the value chain—both for hydrogen and for electricity. The EU's draft Gas/Hydrogen package underlines the need for cross-sector network development plans that accommodate multiple energy carriers.[26] The draft Gas/Hydrogen package further mandates EU-level integrated network planning between the future ENNOH, ENTSO-E and ENTSO-G.[27] The EU Action Plan for Grids calls for the inclusion of hydrogen stakeholders in the preparation of Offshore Network Development Plans (ONDP).

An integrated infrastructure planning approach necessitates a shift towards a longer-term view to identify strategic investments and drive down costs for consumers in the future. Such a system enables supply to be optimally located and sized to serve both electric and hydrogen demand.

Integrated infrastructure planning provides benefits for both energy vectors:[28]

- Integrated, whole-system transmission planning delivers infrastructure optionality and can lower risk for new projects, increasing the likelihood and quality of investment.
- Intermittent renewable energy requires an increase in demand-side flexibility and dispatchable peak generation—an ideal match for hydrogen storage infrastructure—increasing the security of energy supply and reducing curtailment.

Key recommendation: Support schemes should be designed to de-risk investment decisions and unlock the system-wide benefits of integrated infrastructure development across electricity and hydrogen vectors, rather than focusing solely on one or the other.

Power infrastructure enabling hydrogen production

Pipeline infrastructure enabling transport and storage of hydrogen

Drivers for the H_2 economy

- Consistent standards and regulations across vectors
- Permitting and safety
- Early, targeted financing decisions to unlock private capital

System integration benefits

- Optionality of infrastructure
- High levels of system flexibility enabled by hydrogen production
- Whole system decarbonisation including hard-to-abate sectors

Challenges

- Several technologies are not yet competitive in many applications or regions, with a need for improved performance, design, and operational standards.
- Lack of stability in regulatory and market conditions results in high uncertainty and deters investment.

Sources: A complete reference list is provided at the end of the report on slide 22.

The European Hydrogen Backbone Roadmap: the most cost-effective path forward to spur hydrogen market development

Early-stage public support is required to unlock the full-scale connectivity and decarbonisation potential of a pan-European hydrogen network

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01

Hydrogen is critical to Europe's decarbonisation goals: The EHB will provide connectivity, security, and cost-effective decarbonisation, while serving as cross- sector catalyst for further climate efforts.

02

With limited public funding available, it is crucial to use it efficiently. DEVEX support is an enabler of strategic planning and access to further market capital: Early-term development support used as 'seed funding' can put the network on its most efficient path to successful deployment.

03

Construction and operating support is also imperative to overcome temporary early-market dynamics and to guide further build-out: Early pioneer projects will serve as successful case studies that create momentum as the network grows.

04

Regulatory and market mechanisms can help to ease the burden on public funding pools: Recent regulatory proposals from the Gas/Hydrogen Package and market mechanisms developing in Member States and could significantly reduce the direct funding required from the European Commission.

05

Economy-wide decarbonisation is an ambitious challenge requiring the resources, mechanisms, and political will to act, and the EHB is part of the solution: The EHB will play a crucial and multi-dimensional role in combating climate change, provided that early-stage support is allocated to spur its development.

The European Hydrogen Backbone – driving the vision for a connected, secure, and carbon-free energy system

The EHB's 33 member TSOs span the European continent, collaborating to lead the development of renewable and low-carbon hydrogen infrastructure

July 2020	April 2021	June 2021	April 2022	May 2022	November 2023
Visionary pan-EU maps	**Updated and extended vision**	Detailed **analysis of future hydrogen demand, by sector**	Projecting a substantial **acceleration** of hydrogen infrastructure build-out through 2030	Analysis of supply and demand of **five supply corridors connecting Europe**	Analysis of the most recent **hydrogen infrastructure developments and cost estimates**

The European Hydrogen Backbone:

- Is critical for the EU to achieve **net zero greenhouse gas emissions** by 2050
- Contributes to a **sustainable** and **affordable** energy supply for Europe
- Facilitates **transport of both domestically-produced and imported hydrogen** through pipelines as well as shipped liquids, enhancing security of supply
- Enables the fastest **integration of variable renewable** energies
- Allows for domestic hydrogen production that contributes to **European energy independence**

→ **The EHB has been providing leading-edge insights to drive the development of the hydrogen market since 2020.**

References

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16) The New York Times, BlackRock to Buy Global Infrastructure Partners for $12.5 Billion
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18) Tweede Kamer der Staten-Generaal, Kamerstuk 32813 nr. 958
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22) Council of the European Union, Strategic Technologies for Europe Platform: provisional agreement to boost investments in critical technologies
23) Science Business, The EU’s plan for critical technologies ends up as a shadow of the promised sovereignty fund
24) European Parliament, Strategic technologies for Europe platform (STEP)
25) Draft Gas/Hydrogen package directive
26) Draft Gas/Hydrogen package regulation
27) ENTSOG, ENTSOG 2050 Roadmap For Gas Grids
28) European Commission, Commission proposes new EU framework to decarbonise gas markets, promote hydrogen and reduce methane emissions

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Appendix

The goal of these appendix slides are to explain the data/methodology the EHB used to calculate the total needed implementation support

1

Quantitative input data
The slides in the first chapter are dedicated to explaining all the input data.

2

Conceptual modelling assumptions
The slides in the second chapter explain some conceptual assumptions informing the final modelling choices.

3

Model calculations
The final set of slides explain the calculations in the model in detail.

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CAPEX and compression needs for all size pipelines

Input data (1/3)

Parameter[1]		Value (M€/km)
Pipeline CAPEX, new	20"onshore pipes	1.80
	36" onshore pipes	3.20
	48"onshore pipes	4.40
	36" offshore pipes	5.44
	48"offshore pipe	7.48
Pipeline CAPEX, repurposed	20"onshore pipes	0.54
	36" onshore pipes	0.64
	48"onshore pipes	0.88
	36" offshore pipes	1.09
	48"offshore pipe	1.50

Parameter[2]		Value (M€/km)
Pipeline compressor need, new	20"onshore pipes	0.026
	36" onshore pipes	0.093
	48"onshore pipes	0.183
	36" offshore pipes	0.158
	48"offshore pipe	0.311
Pipeline compressor need, new[77]	20"onshore pipes	0.026
	36" onshore pipes	0.040
	48"onshore pipes	0.183
	36" offshore pipes	0.068
	48"offshore pipe	0.311

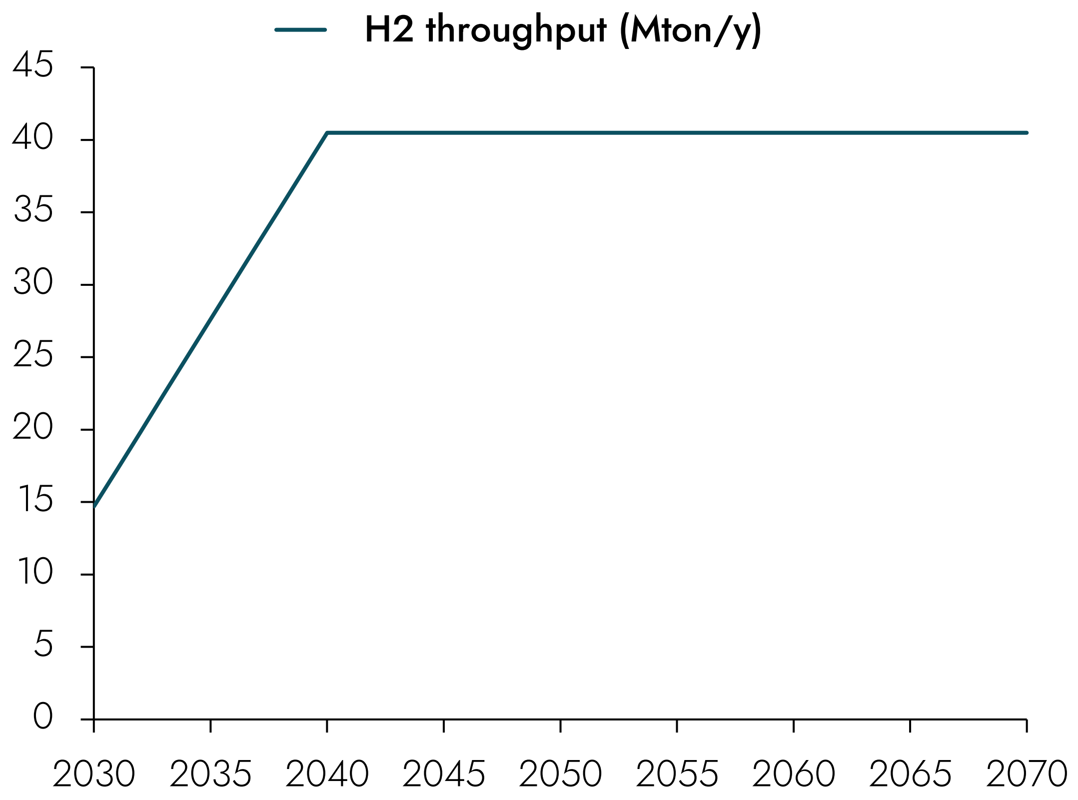
1: Survey EHB members 2023, 2: Hydraulic simulations conducted by network operators

Kilometers of expected operational pipeline in 2030 and assumed hydrogen throughput

Input data (2/3)

Type of pipeline	Kilometers operational in 2030[1]
New	15,752
Repurposed	16,864
Total	32,616

Assumed throughput through EHB 2030 network[2]



1: EHB maps, 2: Bottom-up EHB analysis

Additional financial and technical data

Input data (3/3)

Parameter[1]	Value	
Capex spend profile	1 year before operation	7%
	2 years before operation	21%
	3 years before operation	56%
	4 years before operation	16%
DEVEX spread (y)	3	
Maximum willingness-to-pay during initial market phase (€/kg)	0.33	
Compressor annual fixed OPEX as % of CAPEX (%)	1.7%	
Compressor operating hours per year (h)	5000	
Electricity price for compressor operation (€/MWh)	107	
Pre-tax WACC (%)	5.35%	
Depreciation pipeline (y)	40 years	
Deprecation compressor (y)	25 years	
Return on capital pre commercial operating date	40 years	
Compressor station CAPEX (M€/MWe)	4.0	
Pipeline annual fixed OPEX as (%) of CAPEX	0.9%	
DEVEX as (%) of CAPEX	2.5%	

1: EHB maps, 2: Bottom-up EHB analysis

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Modelling assumptions (1/2)

- From a network throughput perspective, the EHB is modelled as a single pipeline. From financial perspective, it is modelled as a combination of its component pipeline projects, including varying sizes, lengths, and implementation timelines.
- Conceptually, all European hydrogen supply enters the (single pipe) EHB infrastructure at one entry point, and all demand exits at a single point. In this formulation, specific location-based, distance-based, and cross-border tariffs are not considered. The choice to use a single tariff is a consequence of the choice to model the EHB as a single pipeline from a flow perspective and should not be interpreted as a preferred policy ask to introduce a single EU tariff.
- We only model the 2030 EHB network.
- The network is built to accommodate a mature hydrogen market, meaning that there will be an initial low utilisation rate that increases until 2040. EHB members believe that early clarity about the phasing of hydrogen network build-out enables the market to decarbonise the energy system at the lowest societal cost.
- A straight-line depreciation profile is used to calculate the value of the network assets.
- The hydrogen and decarbonised gas market package proposal states that cross-subsidisation of hydrogen networks by natural gas network revenues is allowed only under certain conditions4. As the regulation is still uncertain at this point, our methodology assumes no cross-subsidisation5. Again, this simplification is used for calculation purposes only and should not be seen as a policy preference by network operators toward policy makers.
- No carry forward mechanisms are assumed in the base-case implementation support calculations, if yearly revenue of a pipeline is below the regulated returns, it is added to the investment recovery challenge. Some countries may have time-limited carry forward mechanisms (e.g. max 5 years) — but on the timeline and scale of EHB this does not impact the system significantly.
- The revenue calculation of the modeled pipeline is based on a tariff charged per unit of hydrogen throughput. In real life, pipeline revenue is based on long-term/capacity booking, and revenues are often split into entry/exit charges. Please interpret mention of hydrogen throughput in the text as a proxy for capacity booked.
- All values are modeled are pre-tax. Tax systems and rates are different for each country; as the numbers in this report are applicable across Europe we report on pre-tax values only.
- The financial calculations in this report only consider the transportation of hydrogen, while in reality network operators could also operate storage facilities.
- The RAB model only accounts for hydrogen pipelines. For repurposed pipelines we assume the costs made to repurpose these pipelines are part of new hydrogen RAB model.

The goal of these appendix slides are to explain the data/methodology the EHB used to calculate the total needed implementation support

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Model calculations

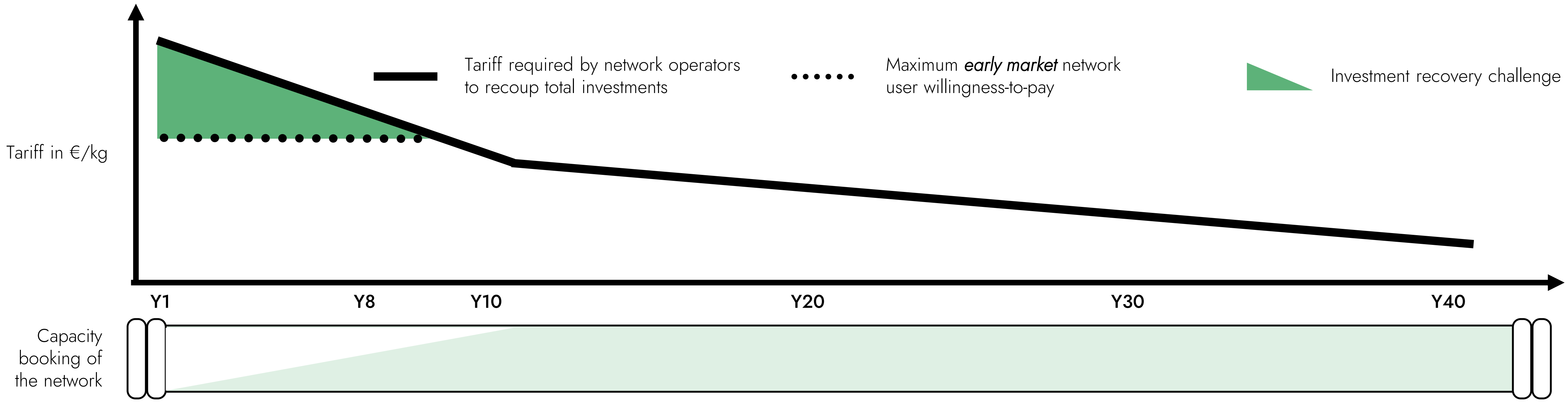
To arrive at the total implementation support calculations, these slides will first explain how the EHB calculated the tariff required by network operators to recoup total investments

Tariff required by network operators to recoup total investments

- **Definition:** The maximum yearly revenue that the regulator allows to be recuperated divided per kg of hydrogen throughput.
- **Calculation:** (Yearly OPEX (€/y) + yearly asset depreciation (€/y) + return on capital (asset value at the beginning of a year (€/y) x WACC (%)) / hydrogen throughput

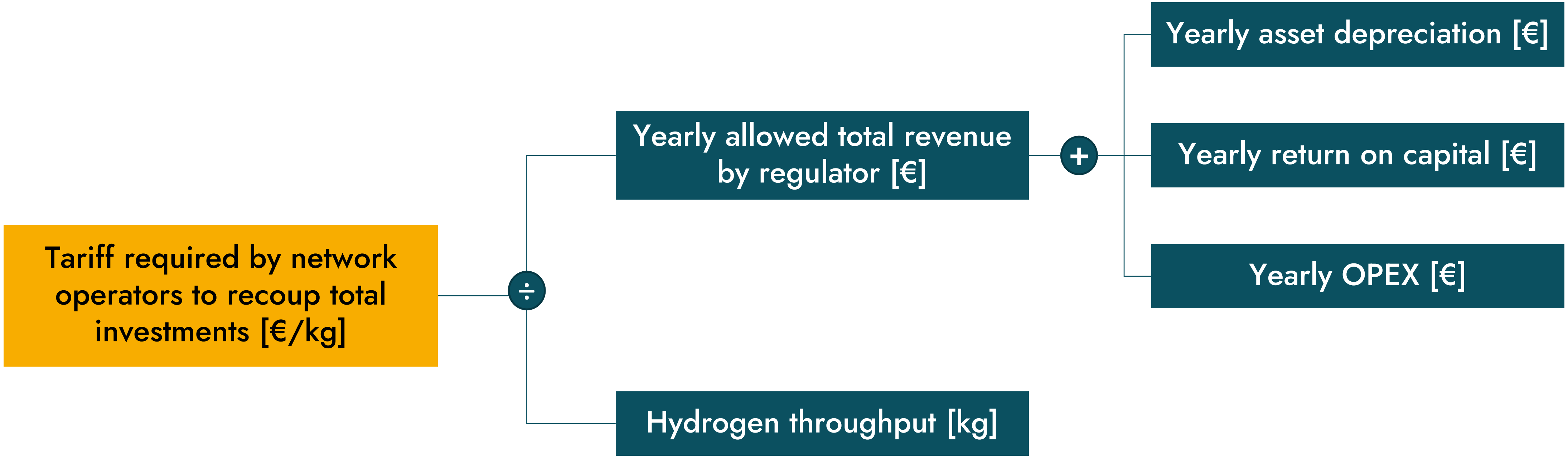
Implementation support need (investment recovery challenge)

- **Definition:** The financial disparity between tariff required by network operators to recoup total investments and the revenue that can be realistically obtained from end users.
- **Calculation:** (Tariff required by network operators to recoup total investments (€/kg/y) – maximum early market network user willingness-to-pay €/kg/y) x hydrogen throughput (kg/y)



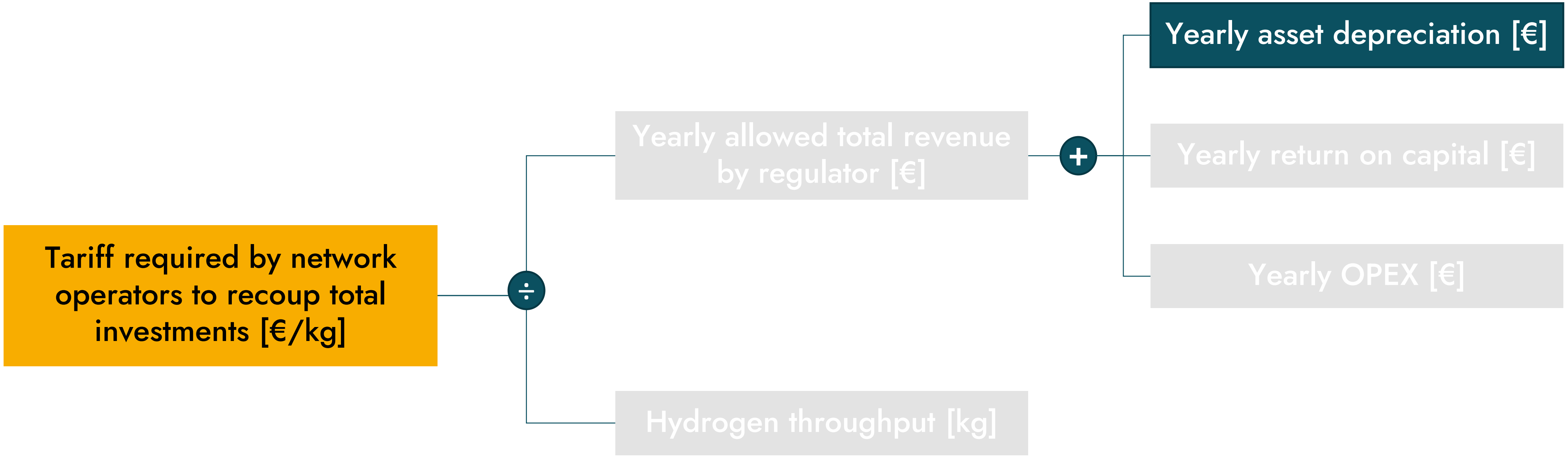
The yearly allowed revenue by a regulator is a function of three categories which are explained in the next slides

Yearly asset depreciation + return on capital + yearly OPEX



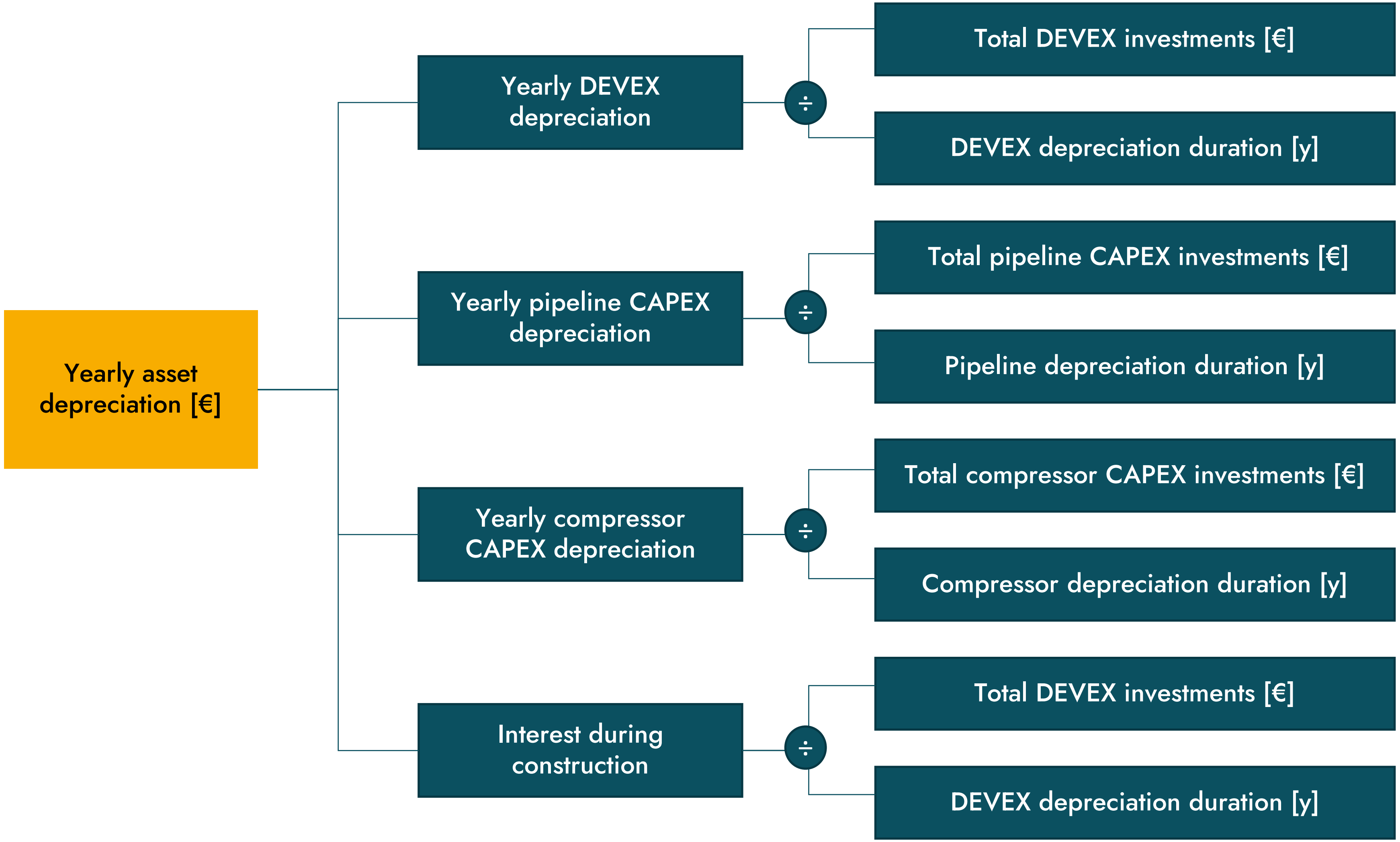
Yearly asset depreciation — the role in the overall tariff calculations (1/3)

Yearly asset depreciation + return on capital + yearly OPEX



Yearly asset depreciation — conceptually explained for straight-line depreciation (2/3)

Yearly asset depreciation + return on capital + yearly OPEX



- Calculated as a % of CAPEX
- Investment are spread out over three years

- Calculated by multiplying the unitary cost of per size of pipeline (€/km/per size) times the kilometres of installed pipeline of a size (km/per size)
- Investments are spread out four years before operation

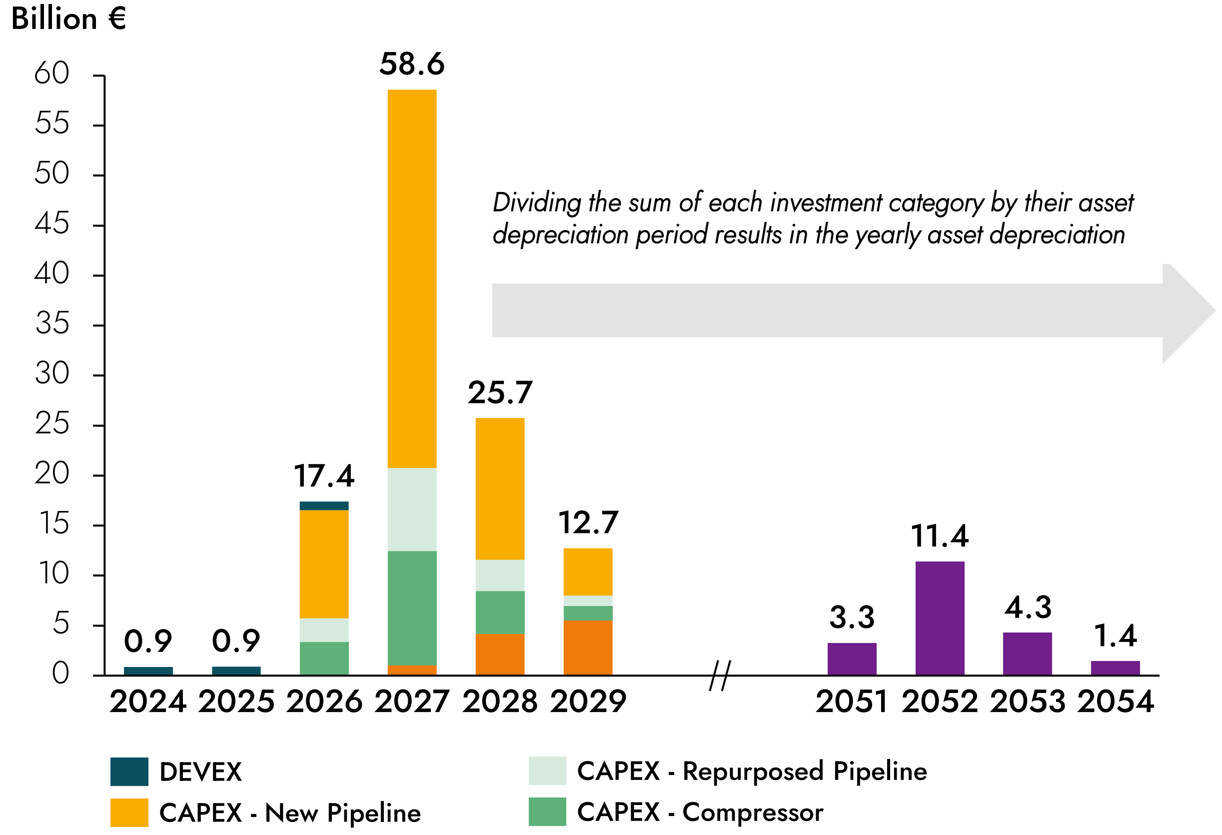
- Calculated by multiplying the compressor need of all pipelines (MWe/km/size) times the installed k compressor capex (€/MWe)
- Compressor need to be replaced after 25 years
- Investments are spread out four years before operation

- Calculated by taking the RAB pre-operation and multiplying with the WACC

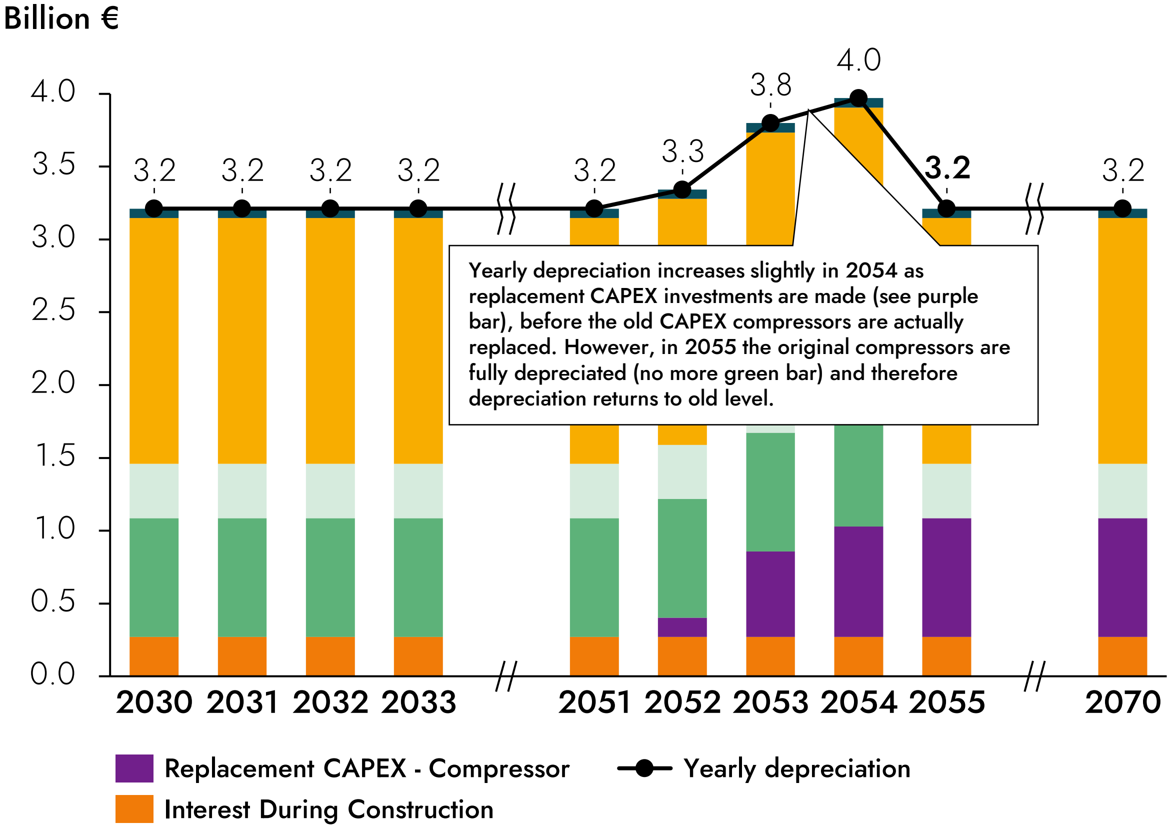
Yearly asset depreciation — results (3/3)

Yearly asset depreciation + return on capital + yearly OPEX

Yearly investments, per investment category

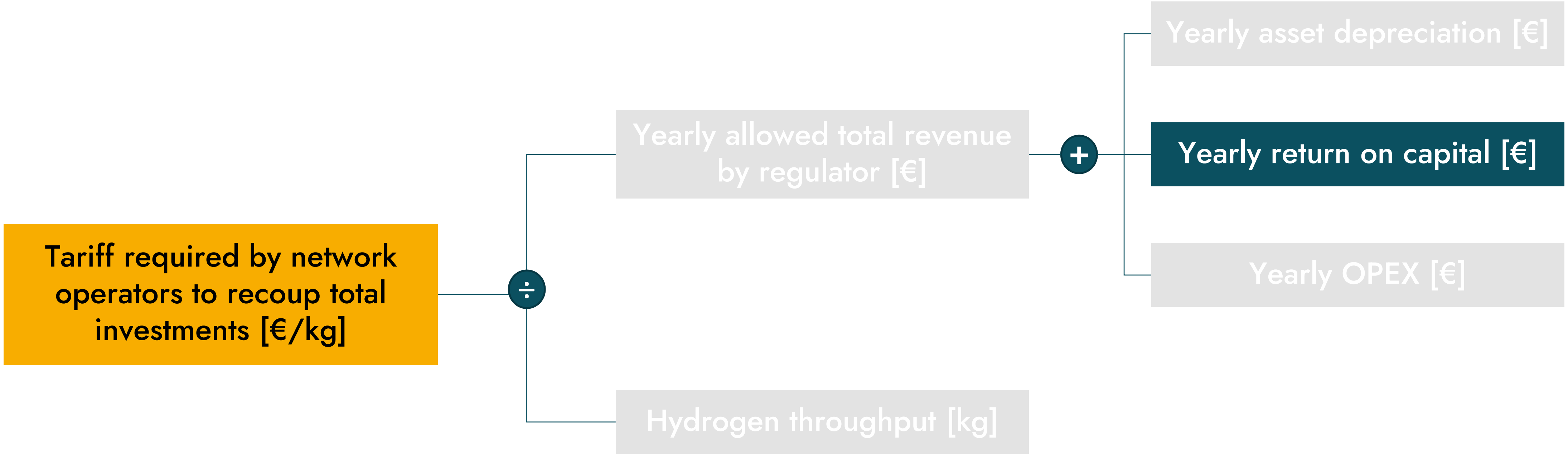


Yearly asset depreciation, per investment category



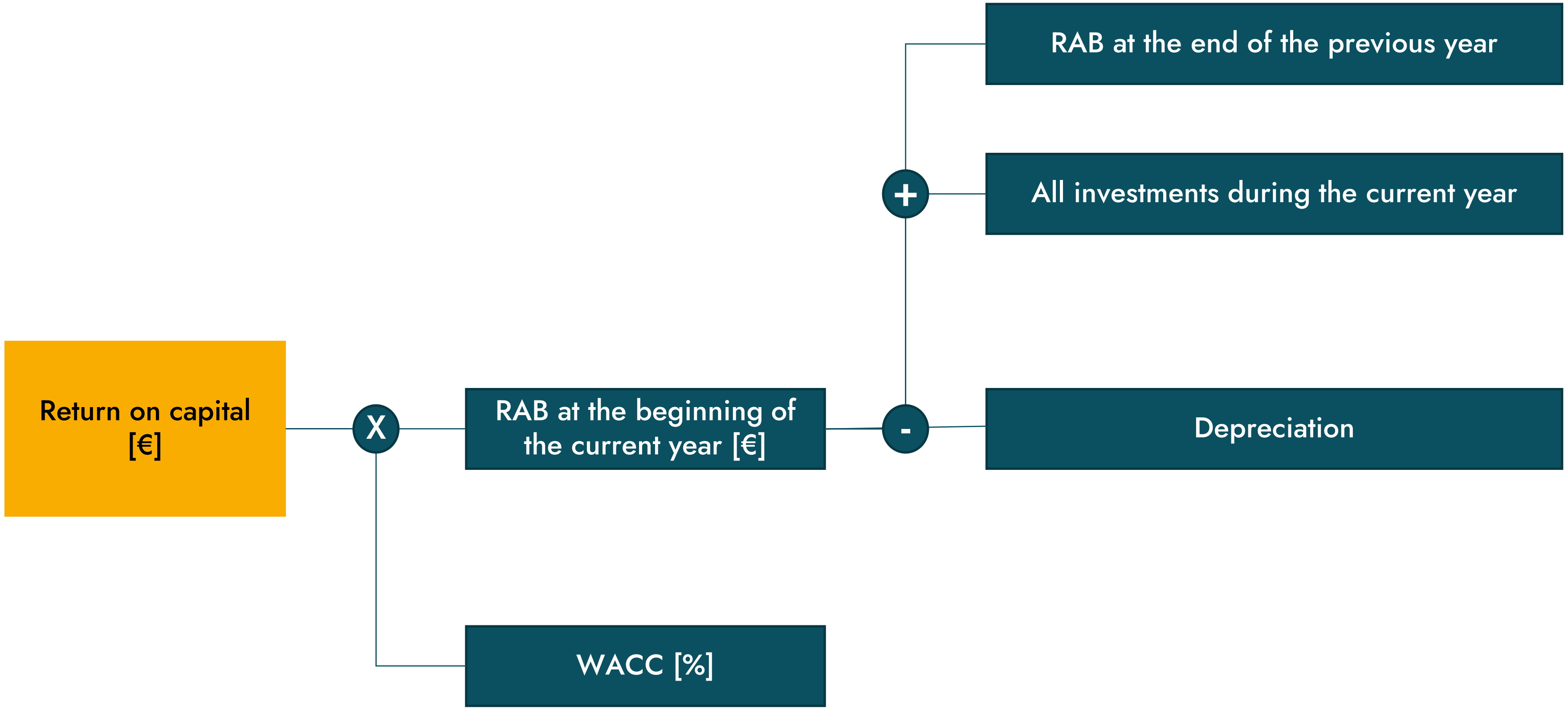
Yearly return on capital – the role in the overall tariff calculations (1/3)

Yearly asset depreciation + **yearly return on capital** + yearly OPEX



Yearly return on capital – conceptually explained for straight-line depreciation (2/3)

Yearly asset depreciation + **yearly return on capital** + yearly OPEX



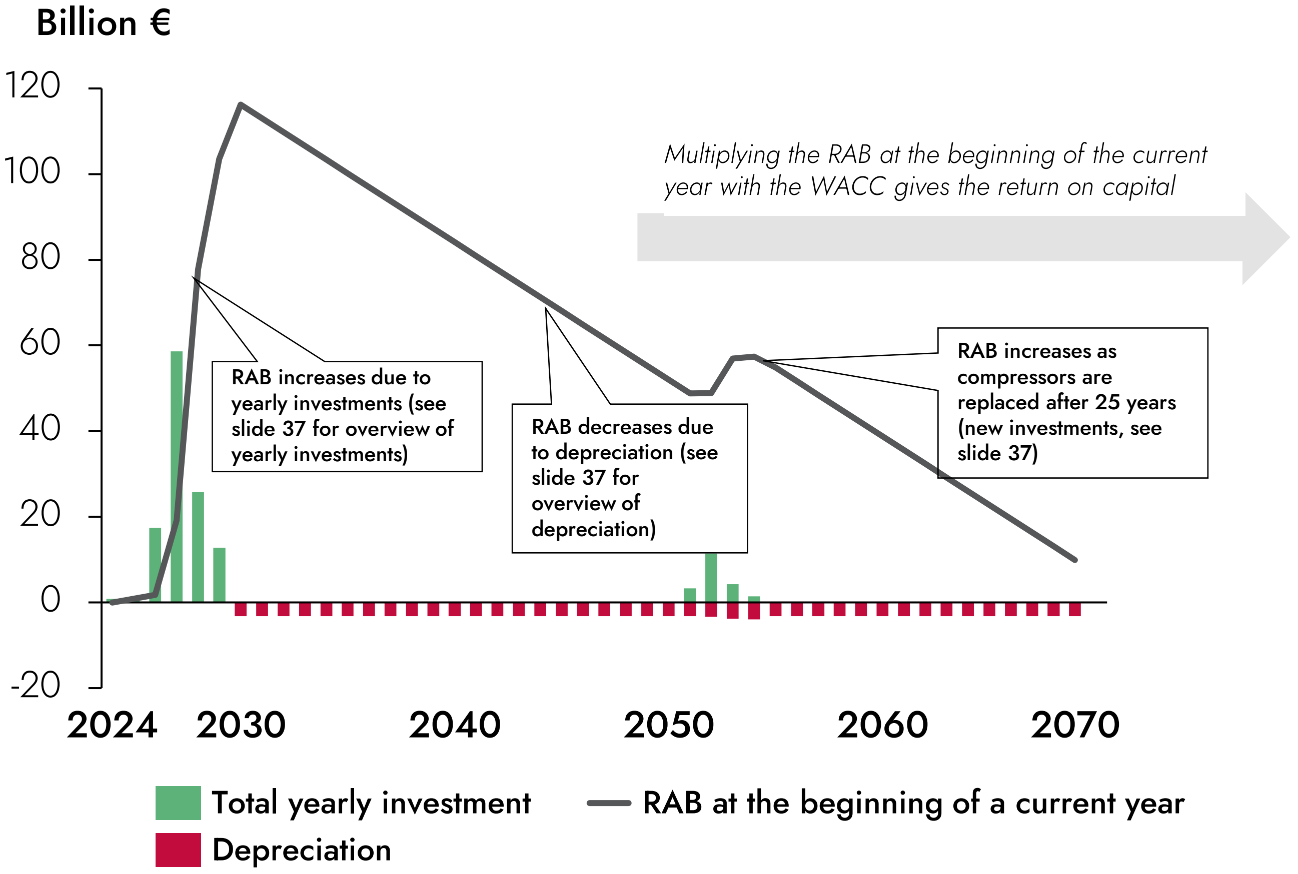
- Sum of all investment in a year across all categories, as shown in the previous slides

- See slides in the previous category to understand how the yearly depreciation is calculated

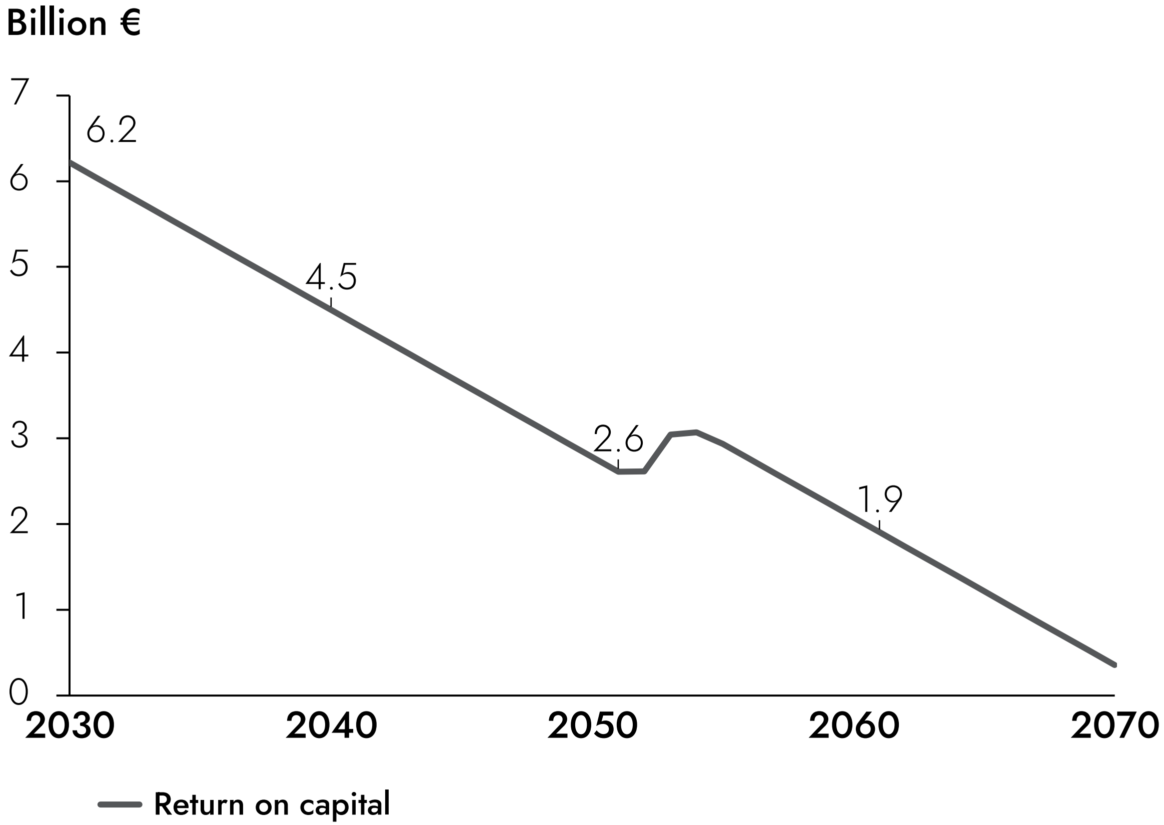
Yearly return on capital – results (3/3)

Yearly asset depreciation **+ yearly return on capital** + yearly OPEX

RAB based on total yearly investments and depreciation

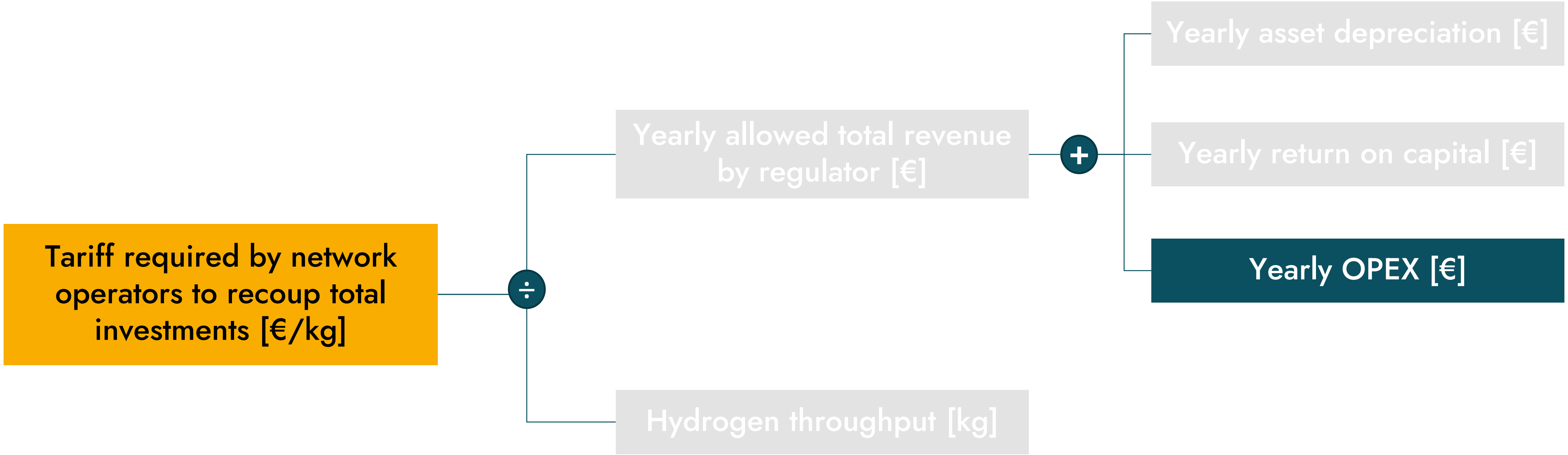


Return on capital



Yearly OPEX – the role in the overall tariff calculations (1/3)

Yearly asset depreciation + yearly return on capital + **yearly OPEX**



Yearly OPEX – conceptually explained (2/3)

Yearly asset depreciation + **yearly return on capital** + yearly OPEX

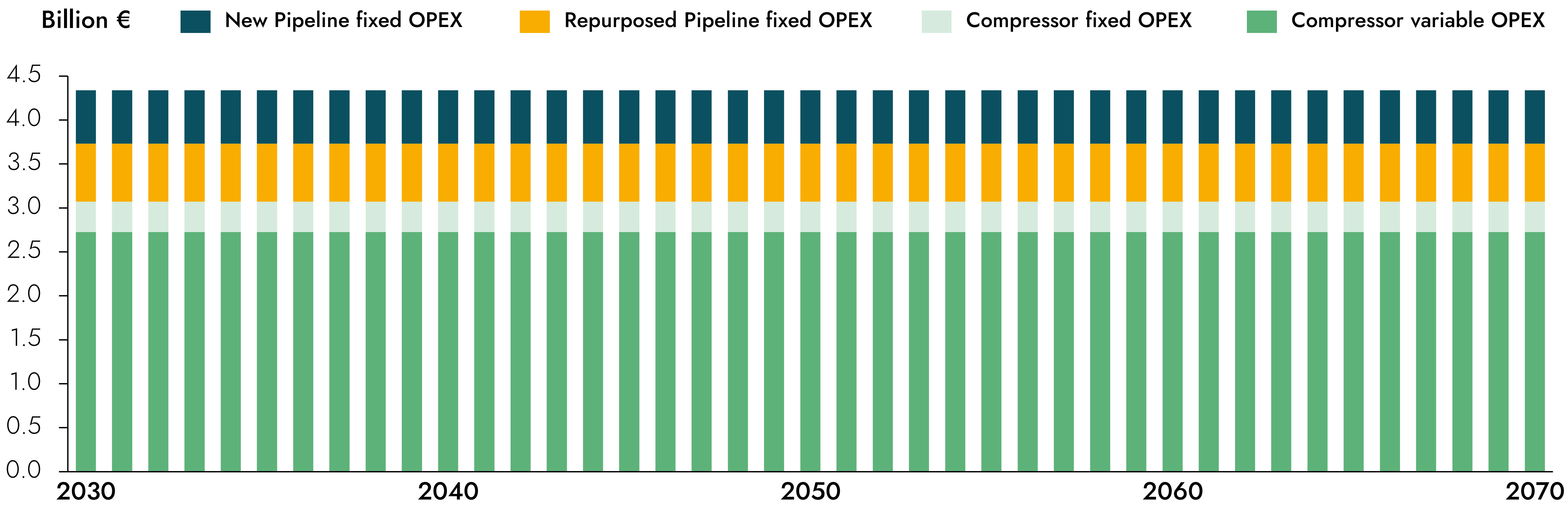
Yearly OPEX [€] =

Component	Calculation
Pipeline fixed OPEX	Calculated as a percentage of CAPEX
+ Compressor fixed OPEX	Calculated as a percentage of CAPEX
+ Compressor variable OPEX	Calculated as compression need of all pipelines [MWe] x electricity price [€/MWh] x compressor of operating hours [h]

Yearly OPEX – results (3/3)

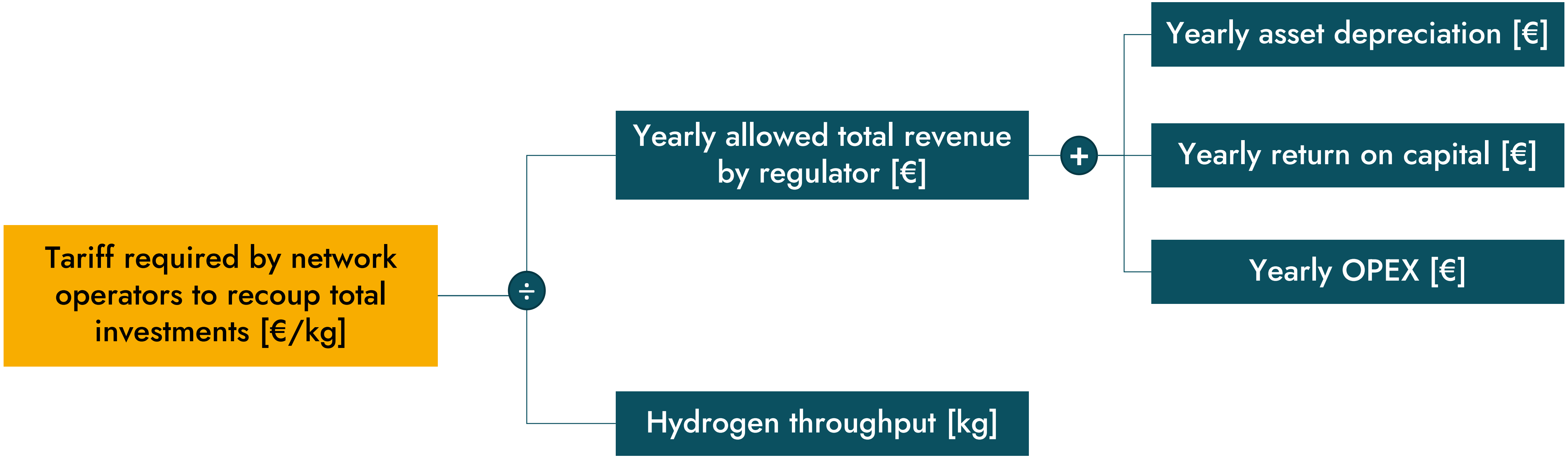
Yearly asset depreciation + yearly return on capital + **yearly OPEX**

Yearly OPEX, per OPEX category



Now, the tariff for network operators can be calculated by dividing the sum of yearly asset depreciation, return on capital, and OPEX by the hydrogen throughput

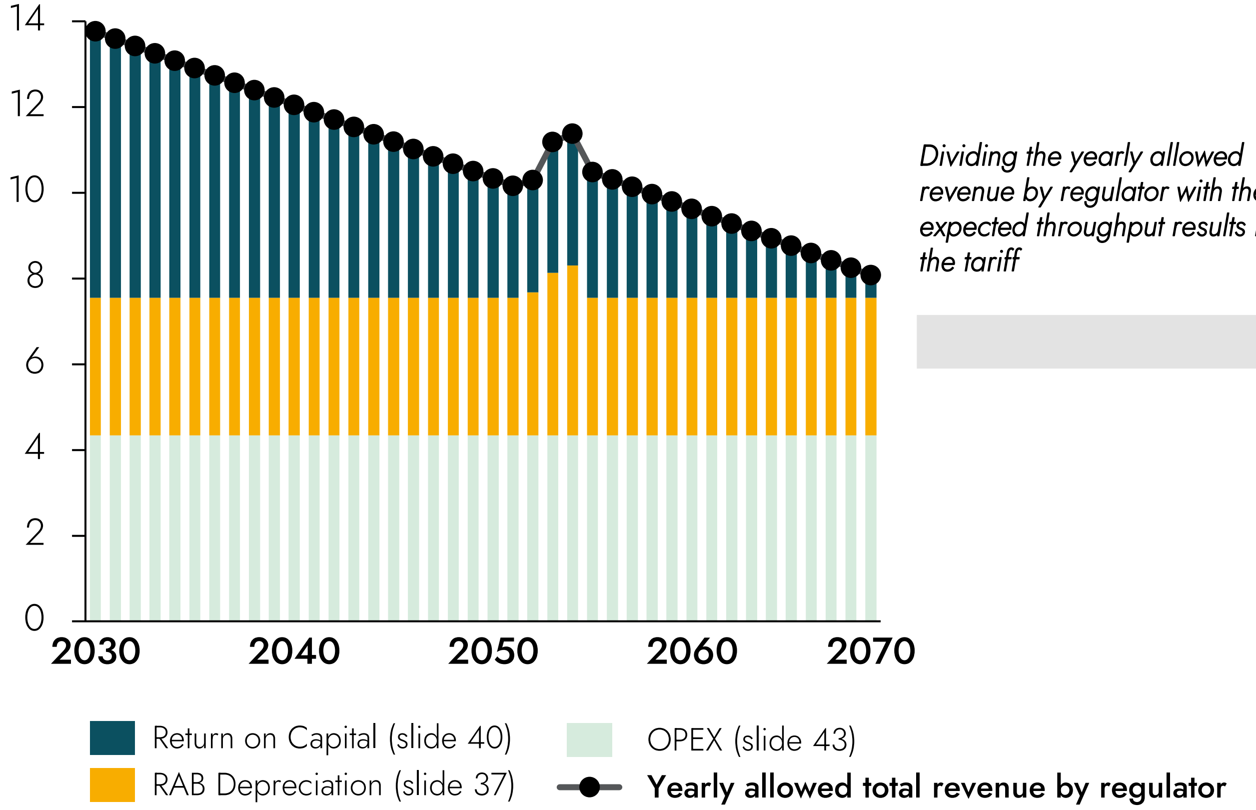
Yearly asset depreciation + yearly return on capital + yearly OPEX



Yearly allowed total revenue by regulator

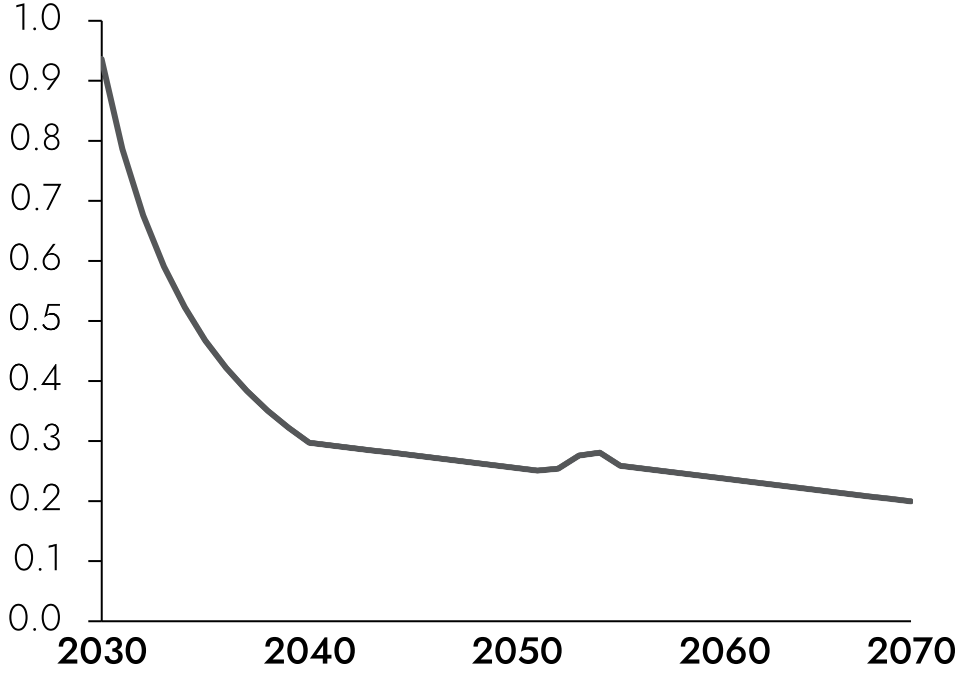
Yearly asset depreciation + yearly return on capital + yearly OPEX

Yearly allowed total revenue



Dividing the yearly allowed revenue by regulator with the expected throughput results in the tariff

Tariff required by network operators to recoup total investments



Implementation support calculation

Finally, the implementation support is calculated by subtracting the maximum early market network user willingness-to-pay from the tariff required by network operators and multiplying with the expected throughput