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Port energy supply for green shipping corridors

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About us

About Arup

Arup is a global independent firm of more than 15,000 designers, planners, engineers, architects, consultants and technical specialists, working across every aspect of today's built environment. The company was founded on the belief that the built environment has a central role in creating a safer, more sustainable planet. Together we help our clients solve their most complex challenges – turning exciting ideas into tangible reality as we strive to find a better way and shape a better world.

About Lloyd's Register

Lloyd's Register is a global professional services company specialising in marine engineering and technology.

Our Marine and Offshore business is a leading provider of classification and compliance services to the marine and offshore industries, while our Maritime Performance Services help businesses to reach their full potential – now and into the future. Our Digital Products combine modern digital tools with deep technical expertise.

The Lloyd's Register Maritime Decarbonisation Hub is working to accelerate the sustainable decarbonisation of the maritime industry.

Lloyd's Register is wholly owned by the Lloyd's Register Foundation, a politically and financially independent global charity.

All of this helps us stand by the purpose that drives us every single day; working together for a safer world.

About The Resilience Shift

The Resilience Shift is a global hub for resilience, building awareness about resilience thinking and practice through convening, capacity building and thought leadership. The Resilience Shift is part of the Resilience Rising consortium that also includes Navigating a Changing Climate, a multi-stakeholder partnership of ten organisations with interests in waterborne transport infrastructure.

Communities globally depend on resilient, low carbon ports to prosper. Resilience4Ports is a multi-stakeholder, whole-systems approach to enhance the resilience of ports, as a nexus of critical infrastructure systems. With our partners, we are exploring opportunities for resilient, system-wide, transformation through the lenses of decarbonisation, technology and port cities. See the full report: Resilience4Ports: Gateways to a resilient future.

Executive summary

Executive summary

International shipping is a vital industry, facilitating global trade and transporting people around the world. At the same time, it produces greenhouse gas emissions – comparable in scale to industrialised nations such as Germany or Japan - and is a significant source of air pollution. Urgent action is required to reduce emissions in a sustainable manner. The production, supply, and use of alternative fuels – many of which are linked to the hydrogen economy - are essential to this aim.

This report explores the opportunities and challenges associated with developing infrastructure for alternative fuels, through a case study of a green shipping triangle in the Atlantic. We do this by considering this global challenge at an initial project scale, considering how demand for alternative fuels could grow at a port level to realise ambitious climate action. We explore the infrastructure required for low carbon fuel supply, demonstrating the significant scale required even for initial projects, highlighting the need for an integrated approach to their development. We frame how a Total Value approach to these initial projects can unlock significant co-benefits, strengthening their case for investment.

Decarbonising shipping: The global challenge

Reducing emissions from shipping, in line with Paris Agreement goals, requires largescale investment in landside infrastructure, for production and supply of alternative fuels, involving commercial-scale pilot projects in the next decade. Shipping's international nature, along with the relatively high cost and uncertain route to decarbonisation, make this a particularly challenging area of action. But delivering resilient and low carbon energy systems, production facilities and refuelling infrastructure for shipping fuels can realise significant co-benefits for the planet and the economy.

This transformation at the heart of global transport and energy systems is a key opportunity to realise a step-change. Resilience and a whole-systems approach can help ensure this change is holistic, making the most of opportunities on land and ocean, for people and planet.

Seth Schultz

CEO, Resilience Rising

Estimating fuel demand in green shipping corridors

At a port level, the estimation of future demand of alternative fuels can be extremely complex and uncertain. This key input for the landside infrastructure needs can be explored by analysing shipping movements and by using a scenario-based approach. Our approach demonstrates that a green shipping triangle in the Atlantic involving three different ports could be high-impact and scalable, with well-defined key trade routes, high renewable energy potential and a strong potential for strategic partnerships to form.

Our fuel demand projection shows an increasingly wide envelope for alternative fuel demand, driven by different assumptions around decarbonisation ambition and refuelling occurrence. The demand projections also show that a project in this region in 2025 with a time horizon of 10 years (up to 2035) would likely be categorised as a demonstration project of significant impact.

Port energy supply: infrastructure to meet growing demand

The demand at hub ports supporting green shipping could be supplied in several different ways: fuel locally generated from renewable energy (green ammonia), from natural gas with carbon capture (blue ammonia), or by importing the fuel by ship. We have explored the key challenges and opportunities for the two local generation opportunities, considering the scale of infrastructure required for pilot projects in the coming decade.

This demonstrates the need for energy infrastructure at a 100s-of-megawatts or even gigawatt scale, requiring a significant area of land. The supply options could all benefit from integration with wider energy systems. The availability of renewable energy in the short term for green ammonia is contrasted with challenges around supply-chain emissions and carbon storage for blue ammonia: both approaches require a whole-systems approach with holistic consideration of sustainability.

Building a Total Value case for pilot projects

Production and supply of low-carbon fuels for shipping requires substantial capital investment and relatively high operational costs, with the end costs per unit of fuel being significantly greater than the fossil fuel equivalents. For pilot supply projects, as part of green shipping corridors, we envisage that a Total Value approach – one that shapes, captured and leverages social, environmental, financial and economic value - can unlock investment as well as sustainable outcomes.

Green shipping corridors are an ideal space in which to bring an integrated total value approach to support and shape the case for investment. Embedding this thinking from the early stages of such initiatives can help drive value creation beyond climate mitigation, building a broad coalition of benefactors so that we can accelerate short term action on decarbonisation.

Filippo Gaddo

Head of Economics, Arup

Decarbonising shipping

The global challenge

Decarbonising shipping

The global challenge

Decarbonisation of shipping is a key component of global climate action. Its international nature, high relative whole-life cost, the uncertainty of technology pathways and the long lifespan of vessels make it a particularly challenging area. At the same time, there is a huge opportunity to create a resilient and low carbon global shipping system, while realising co-benefits for people and planet.

International shipping, facilitated by ports and their hinterland, is the backbone of our global economy, facilitating increasing volumes of trade and transporting people around the world. At the same time, it produces greenhouse gas emissions comparable to an industrialised nation (such as Germany or Japan) and is a significant source of air pollution. Our increasingly complex and uncertain world means that shipping must also be resilient to a range of future shocks and stresses.

The decarbonisation challenge

Recent research has shown that up to around $2 trillion of global investment is required to decarbonise shipping, with around 85% of this cost in landside infrastructure and production facilities for future fuels[9]. To align with Paris Agreement goals, 5% of global fuels need to be zero-carbon by 2030[10]. This requires commercial-scale pilots for low carbon fuel production and supply over the next decade and mass roll-out in the 2030s. As the costs of these low-carbon fuels are expected to be significantly greater than legacy fuels, novel approaches to the pilot projects are required.

The infrastructure opportunity

Key to unlocking this challenge will be investment in landside infrastructure: energy systems, industrial hubs and port refuelling facilities. These infrastructure systems will provide the fuels of the future for shipping, integrating with a range of other sectors. There is an opportunity for these investments to catalyse the wider energy transition and deliver broader social and environmental benefits. In fact, capturing and leveraging these wider aspects of value could be key to realising the pilot projects needed in the next few years.

Port infrastructure remains one of the costliest aspects for the decarbonisation of shipping. However, if the opportunities which this provides can be unlocked the benefits can be cascaded to local economies in addition to a sustainable acceleration in shipping's energy transition.

Charles Haskell
Lloyd's Register Decarbonisation Hub

9 https://www.u-mas.co.uk/new-study-by-umas-shows-that-decarbonisation-of-the-shipping-sector-is-a-whole-system-challenge-and-not-something-just-for-shipping/

10 https://www.globalmaritimeforum.org/content/2021/03/Getting-to-Zero-Coalition_Five-percent-zero-emission-fuels-by-2030.pdf

Our approach

In this report, we delve further into the challenge, exploring the constraints and opportunities associated with energy and fuel supply at a pilot-project level. By understanding the evolution of shipping fuel demands for an example green shipping triangle in the Atlantic, we explore two typologies for low carbon fuel supply, and frame how a total value approach can bolster the investment case for these projects. Through this we look to bring a whole-system understanding of the shipping, port and energy sectors, acknowledging the need to embed resilience and sustainable outcomes through the transformation.

We focus on hydrogen-based ammonia as a low carbon fuel, largely linked to sustainability and cost challenges associated with biofuels and synthetic fuels respectively, but note that they could also play a role in a diverse low carbon fuel ecosystem.

This builds on our recent and ongoing work in these areas, including

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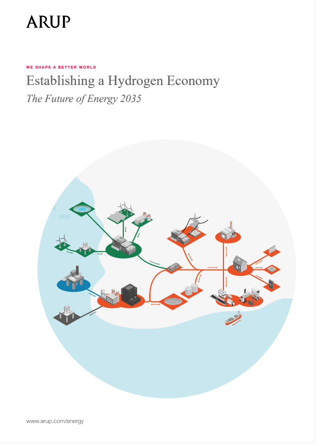

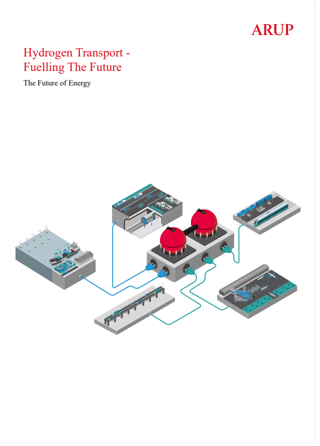

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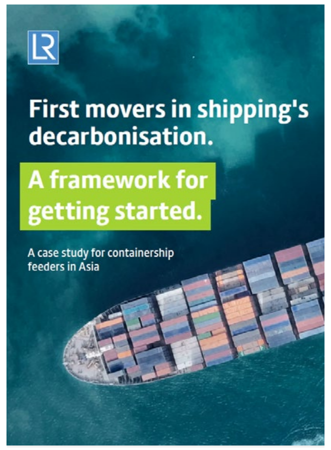
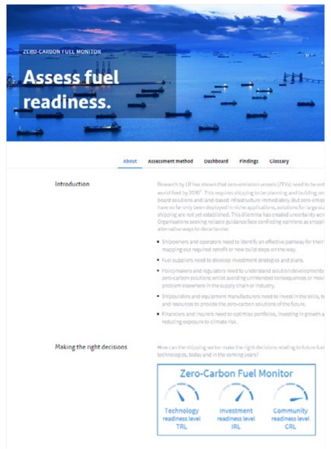
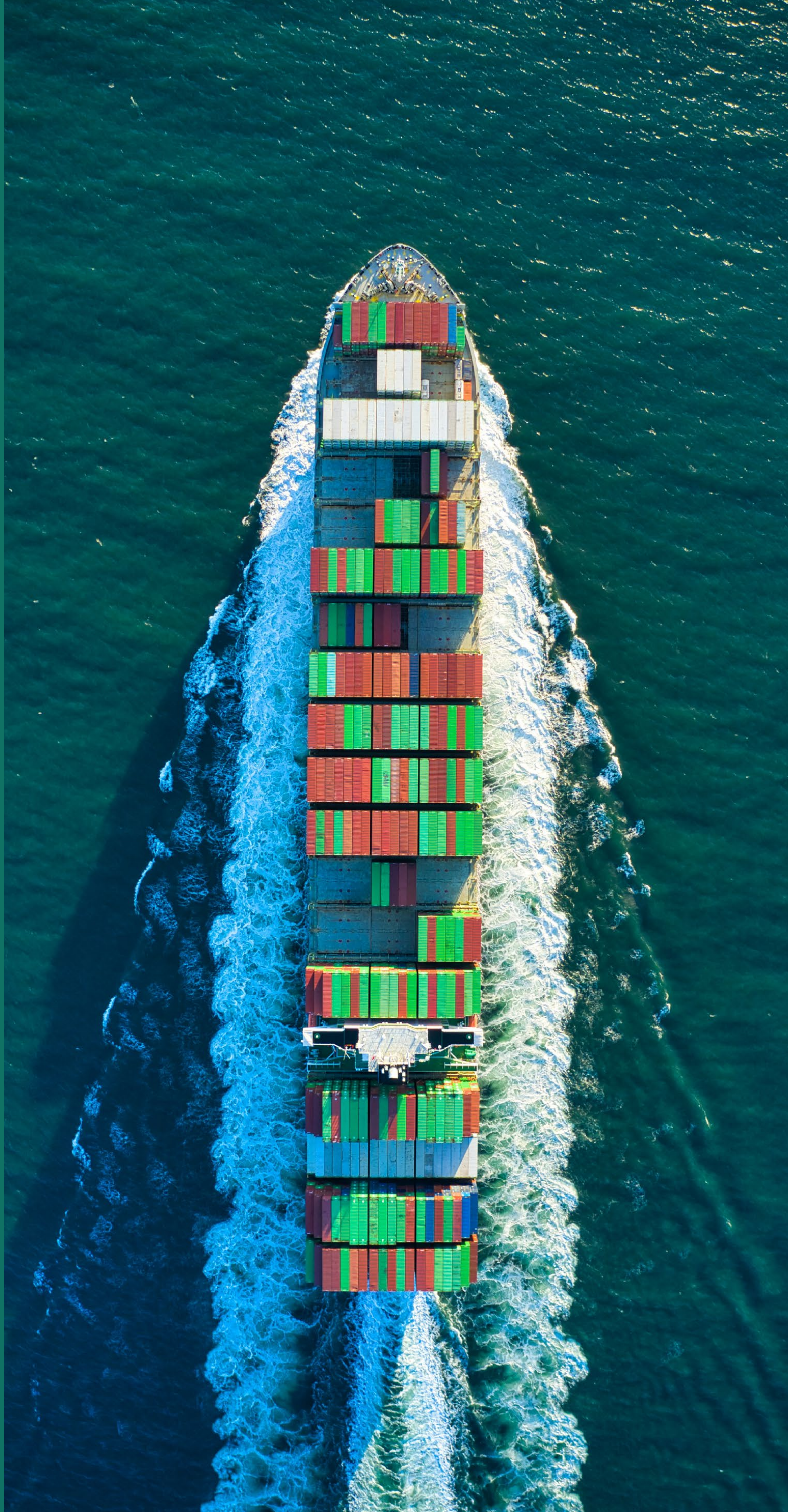




The Resilience Shift

Estimating demand for fuels in green shipping corridors



Estimating demand for fuels in green shipping corridors

It is essential to first consider alternative fuel demand evolution, at a port level, before planning and designing the port energy supply for green shipping corridors. The approach developed and used in this example shows that the selected ports have potential to be part of a large demonstration project.

The green shipping triangle

By analysing the shipping movements in the South Atlantic Ocean (see figure 3), we have focused on containers and bulk carriers operating between the ports of Santos (Brazil), Casablanca (Morocco), and Cape Town (South Africa). Our analysis identifies a potential green shipping triangle, based on several criteria:

- **High impact and scalable:** Cape Town and Casablanca are well-positioned strategic refuelling locations that could help drive additional long haul routes to quickly decarbonise – creating scalable opportunities.
- **Well-defined, key trade routes:** Brazil is the largest exporter of soybean, with the route to China and the Mediterranean a well-defined, seasonal, trade flow that can help fuel suppliers plan for more stable projection of fuel demand.
- **High renewable energy potential:** locations that benefit from high wind, tidal and solar energy potential. Morocco has a head start with its existing ammonia fertiliser production.
- **Potential for strategic partnerships:** Opportunities for intergovernmental collaborations and involvement of large shipping operators (over half of the ships calling at these ports have the same operator, so efforts to switch to a new fuel could be simpler to execute).
- **Containers and bulkers:** These fleets see significant pressure from end consumers to accelerate decarbonisation efforts. All other ship types are excluded, most notably vessels involved in fossil fuel trades.

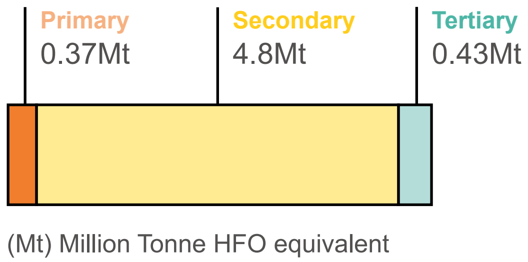
Much of the demand comes from voyages that extend beyond the green triangle

We have categorised fuel demand into three broad markets:

- Primary, fuel demand from containers and bulkers trading within the triangle.
- Secondary, fuel demand from containers and bulkers calling at least once in one of the ports for international voyages only.
- Tertiary, fuel demand from containers and bulkers trading in domestic voyages in each port

The diagram below shows that the majority of current demand (i.e. for fossil-based fuels) is driven by voyages that involve onward legs, beyond the three main ports, i.e. secondary demand. This is a major reason for the variations between projections in the scenarios, described below. The higher volume scenarios are those where significant secondary demand has been pulled into the market.

Figure 2. Breakdown of fuel demand for all three ports in the green shipping triangle for 2019:



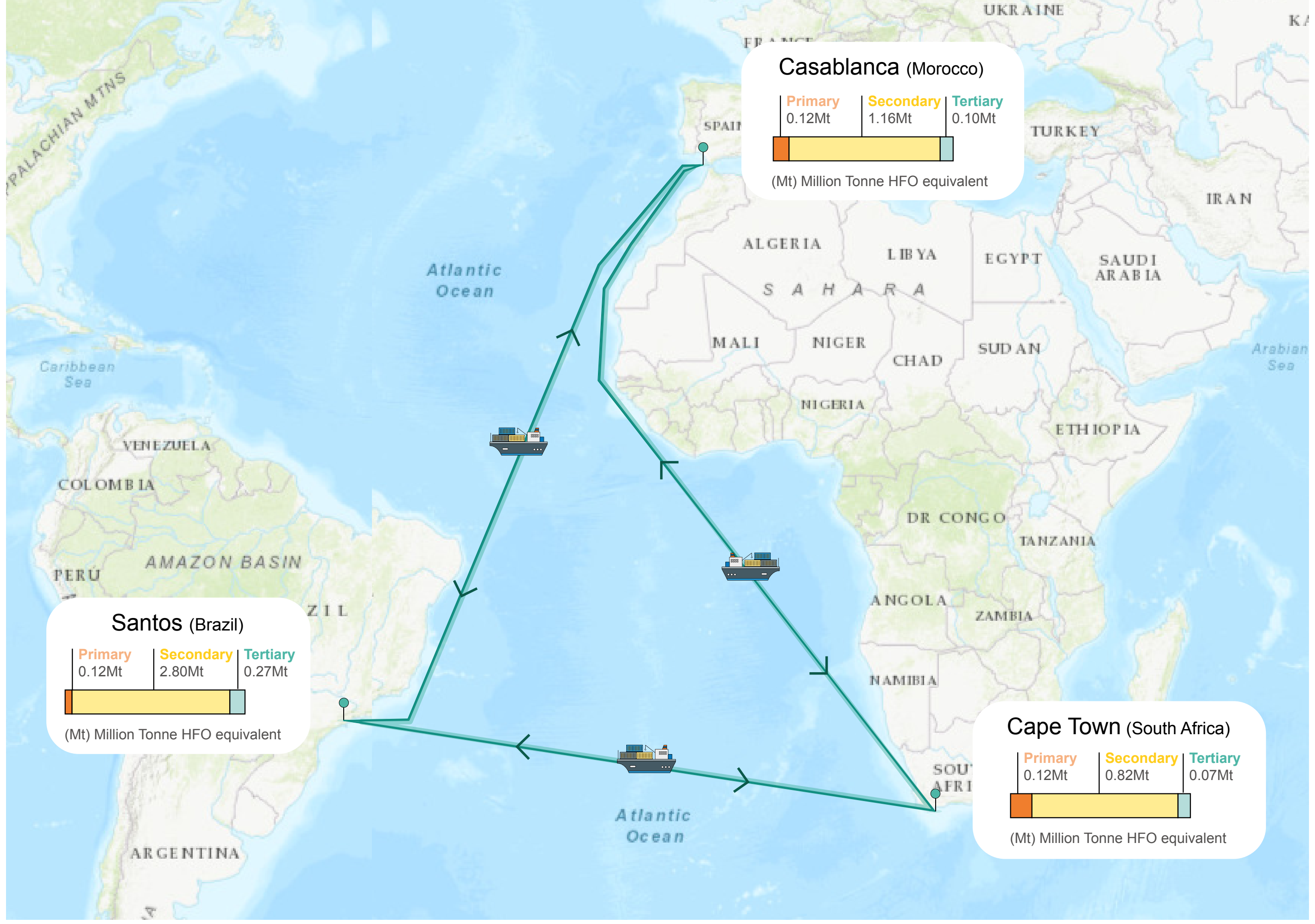


Figure 3. Primary routes for a green shipping triangle
The annual 2019 fuel demand estimate is illustrated for each port on the triangle

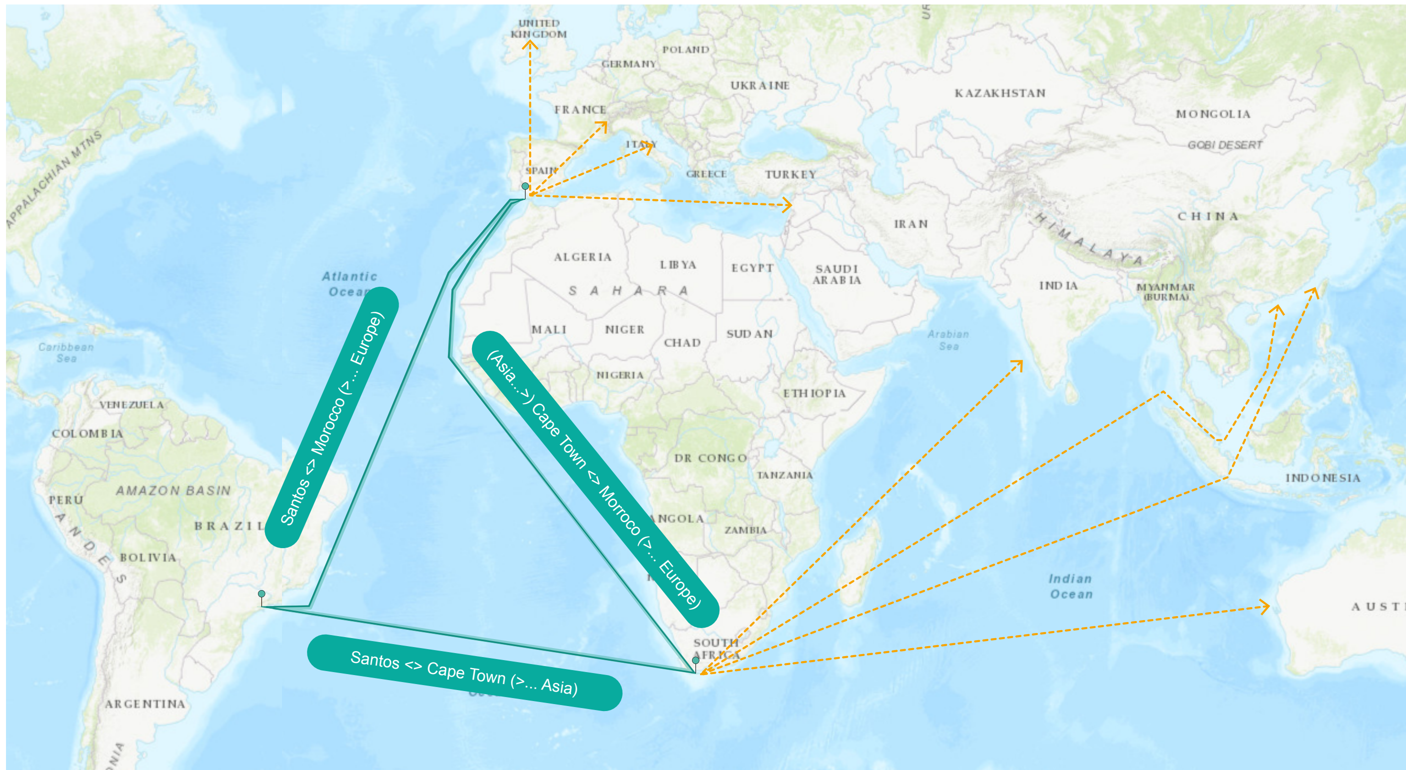


Figure 4. Onward voyages for a green shipping triangle

Estimating demand for fuels in green shipping corridors

Assessing alternative fuel demand: A scenario-based approach

Modelling shipping fuel demand is complex, involving multiple factors. We have handled this significant uncertainty by creating alternative scenarios based, among other factors, on two key parameters:

- Decarbonisation ambition: reflecting how policies, regulations and decisions lead to alternative fuel uptake.
- Refuelling occurrence: a statistical distribution of vessel refuelling patterns, recognising the lower energy density of fuels.

Decarbonisation Ambition	Refuelling Occurrence		
	Higher refuelling occurrence	Middle refuelling occurrence	Lower refuelling occurrence
Higher ambition[3]	Scenario 1	Scenario 2	Scenario 3
Lower ambition[4]	Scenario 4	Scenario 5	Scenario 6

We have modelled how demand for alternative fuel is likely to evolve these ports. This highlights upper and lower bounds for fuel demand in the identified scenarios (see figure 4).

For simplicity our projections focus on a single alternative fuel, ammonia. As we show later, this approach can be used for other alternative fuels. The charts show demand for ammonia at each of the three ports, for each scenario, projected to 2050. Uncertainty increases over time, resulting in a widening range of estimates over time, driven largely by the level of ambition for decarbonisation and assumed level of refuelling frequency.

We found that fuel demand is largest in Santos. This is based on the frequency of vessel calls at port and fuel demand for associated voyages.

3 Assumes 5% alternative fuel uptake by 2030, which ramps up to almost 100% by 2050.

4 Assumes 5% alternative fuel uptake by 2030 and gradually increases to 50% by 2050

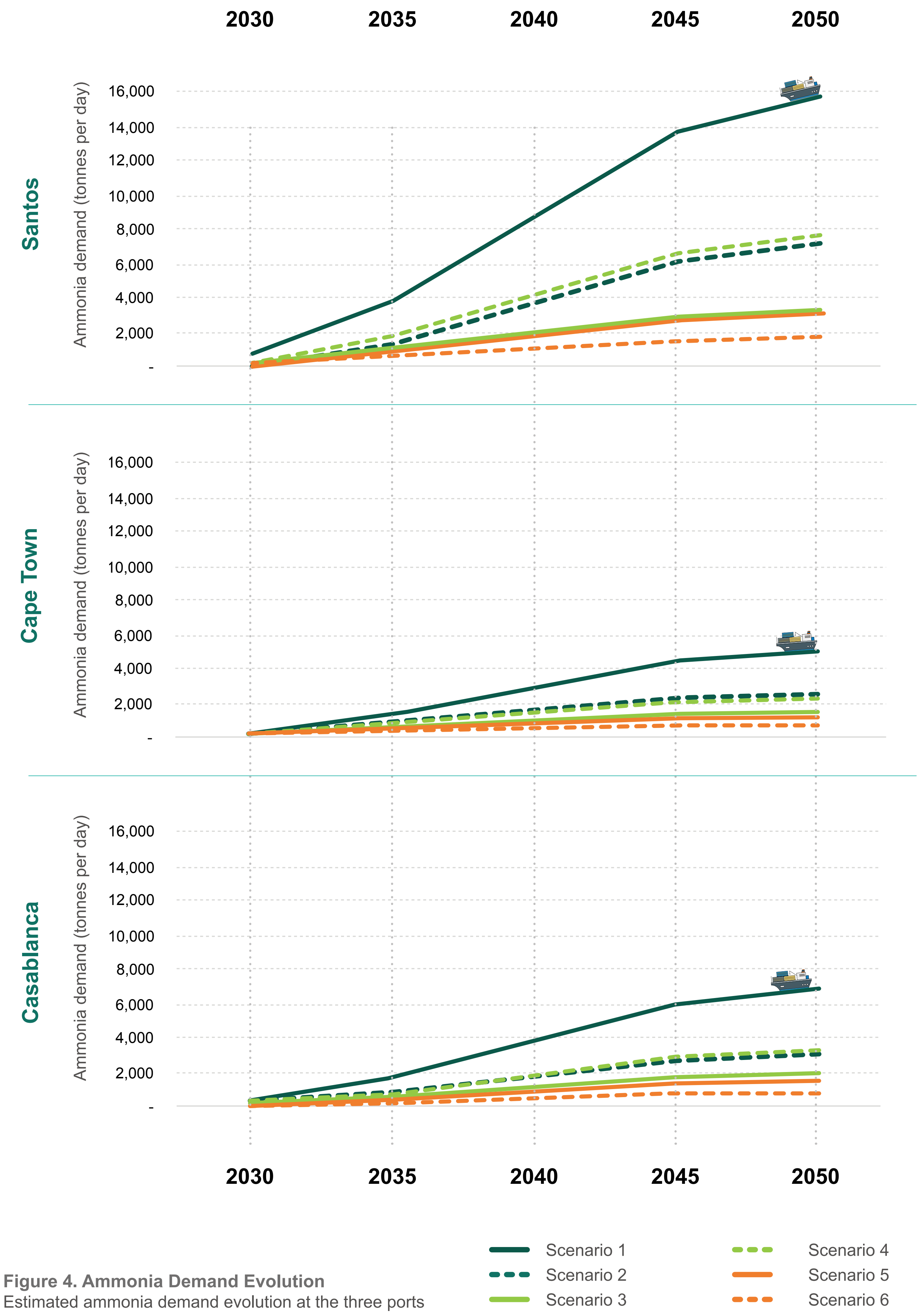


Figure 4. Ammonia Demand Evolution
Estimated ammonia demand evolution at the three ports

Estimating demand for fuels in green shipping corridors

A demonstration project in this region would have significant impact

The global maritime forum (GMF[9]) categorises decarbonisation demonstration projects by capacity in tonnes per day: small (225 tonnes per day) reference (700 tonnes per day) and large (950 tonnes per day) in order to gauge their impact. The demand projections show that a project in this region in 2025 with a time horizon of 10 years (up to 2035) would likely meet or exceed the reference and the large categories, making them demonstration projects of significant impact.

9 The-First-Wave- link to pdf: A-blueprint-for-commercial-scale-zero-emission-shipping-pilots.pdf (globalmaritimeforum.org)

The methodology developed here can be applied to other green corridors

We have developed this methodology to allow us to consider alternative fuel demand evolution, at a port level, for green shipping corridors. The approach can be applied to other alternative fuel and is based on three steps:

1. **Identification,** this involves identifying plausible shipping routes (green corridors) where shipping companies operating along these routes could gain a competitive advantage by simply being the first using zero-emissions ships (first movers). The criteria listed above can be applied.
2. **Calibration and categorisation**, this involves examining different type of fuel markets that the selected ports could reach by calibrating to a base year and by categorising the estimated fuel demand. Automatic identification system (AIS[10]) data is used to identify vessels calling at the key ports along the route.
3. **Projection.** A number of assumptions are made to cover all plausible scenarios. This include transport demand growth, alternative fuel uptake versus other options, level of decarbonisation ambition, and refuelling frequency.

10 Automatic Identification System - link to website: https://en.wikipedia.org/wiki/Automatic_identification_system

Port energy supply: Meeting growing demand

Port energy supply

Meeting growing demand

The demand at hub ports supporting green shipping could be supplied in several different ways including: fuel locally generated from renewable energy (green ammonia), from natural gas with carbon capture (blue ammonia), or by importing the fuel by ship. We have explored the key challenges and opportunities for the two local generation opportunities, considering the scale of infrastructure required for pilot projects in this decade.

Our assessment of alternative fuel demand and supply demonstrates the significant scale of infrastructure needed over the 2020s, evolving to industrial energy hubs by mid-century. It makes clear that all supply typologies involve significant challenges, but also opportunities that can be realised through a whole-system approach, coupling with other sectors or even developing hybrid typologies. The importance of a whole supply chain approach to sustainability is highlighted, which can open the door to broad social and environmental value.

Port energy supply

Meeting growing demand

Green ammonia supply

This typology considers ammonia production at or near to a port, in an area:

- With high potential for low-cost and extensive renewable energy generation.
- With significant land suitable for hydrogen and ammonia production.

The type and scale of infrastructure required

A commercial-scale pilot project of this nature requires significant infrastructure. Around a quarter of a gigawatt of renewable energy supply, well over a thousand tonnes per day of water supply, over 25 medium-sized electrolyser units to produce hydrogen, an ammonia synthesis plant and significant storage facilities. By mid-century, a facility four times the size of this could be required.

This type of production facility will cost hundreds of millions of pounds (capex) and require several hectares of land. As well as producing low carbon shipping fuel, significant quantities of oxygen are produced as a by-product. Additionally, storage, transport and refuelling infrastructure will be required in the local port, appropriately integrated with the port's other facilities.

Demand evolution for Cape Town

For this typology we have considered the demand evolution for Cape Town in the green shipping triangle assessment: i.e., a commercial-scale pilot project constructed in 2025 for up to 620 tonnes per day supply, aligning with a high ambition for decarbonisation and considering demand to 2035.

Key feasibility challenges and opportunities, considering a whole-system approach

Supply constraints:
In the short to medium term renewable supply will be constrained, often competing with more efficient uses in direct electrification. Supply from the local grid will, in many places, not yet be fully decarbonised. The market availability of electrolysers could be a key constraint to development in the short term, however suppliers are investing in the supply chain to increase production capacity.

Operational feasibility:
Though the in-port infrastructure is small in scale compared to the production facility, the operational feasibility in terms of environmental safety and integration with other port operations may be critical to the overall feasibility of ammonia as a future fuel. A standardised approach between ports will be key.

Local renewable generation facilities:
Dedicated renewable generation facilities may be required, with large spatial requirements. Marine facilities such as floating solar or tidal lagoons could become favourable.

Fuel transportation:
For many city-ports, this scale of infrastructure is likely to be situated remote from the port, requiring transport of fuels for example via rail or pipeline. The resilience of this connection would be an important consideration.

Diversified supply:
The supply system can be designed to serve other sectors, including energy needs within the port and local transport systems. This could be appropriate for ports with high seasonal variability in shipping and help manage risks around demand uncertainty.

Co-location:
There could be a key advantage to locating blue and green ammonia supply infrastructure together, with the oxygen by-product from green production acting as a feedstock to blue production, improving the overall efficiency.

Air quality:
There are challenges around air quality, particularly in the short-medium term where receiving vessels use combustion engines rather than fuel cells. Shorepower provision could provide additional value, particularly for city ports.

Demand uncertainty:
The demand for fuels for shipping has significant uncertainty, in particular in the medium to long term.

Modular supply:
The nature of hydrogen production infrastructure can offer a more adaptive approach to supply, reducing risks.

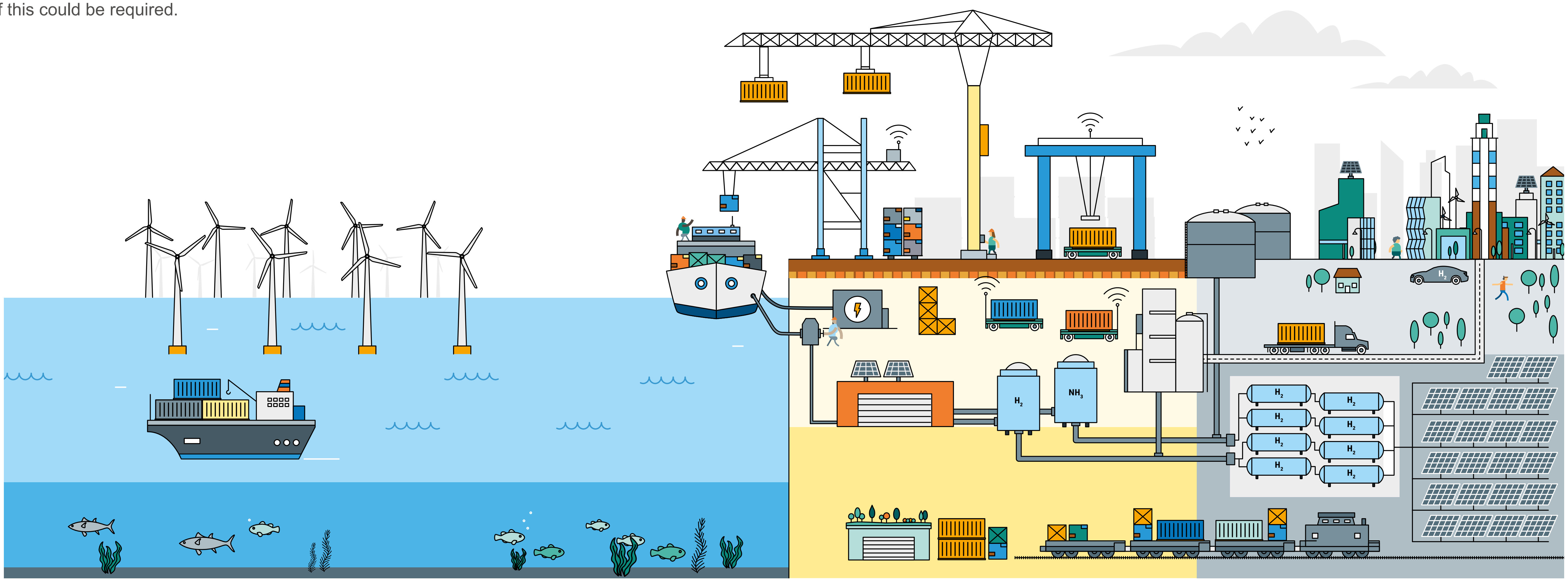


Figure 5 - Illustration
Green ammonia supply chain

Port energy supply

Meeting growing demand

Blue ammonia supply

This typology considers ammonia production at or near to a port, in an area:

- With constrained green electricity supply
- But with local natural gas resources and the potential for appropriate storage of captured carbon
- With sufficient land suitable for relatively heavy industry, likely as part of an industrial cluster

The type and scale of infrastructure required

At this location the demand is higher than for the green ammonia supply typology, and accordingly a significant industrial facility is required for fuel supply. Over 40 MMSCFD per day of natural gas supply would be required, alongside large volumes of water for heat and cooling, to feed reformers that produce hydrogen, which feed synthesisers to produce ammonia.

Electrical power would still be required, but at a much lower rate than the green ammonia typology. This type of facility can therefore, in the appropriate circumstances, be used to bridge the gap to a future where renewable energy supply is plentiful. Approaching a million tonnes of captured carbon dioxide annually will need to be safety stored in perpetuity. By mid-century, demand could increase four-fold, but we consider it likely that green or hybrid facilities will be required.

This type of production facility could cost over a billion pounds (capex) and require several hectares of land. The facilities for onwards transportation and sequestration of captured carbon will also be significant, and in the case of a marine-based export, could provide a key revenue stream for the local port.

Demand evolution for Santos Port

For this typology we have considered the demand evolution for Santos in the previous green shipping triangle demand estimate: i.e., a commercial-scale pilot project constructed in 2025 for up to 1720 tonnes per day supply, aligning with a high ambition for decarbonisation and considering demand to 2035.

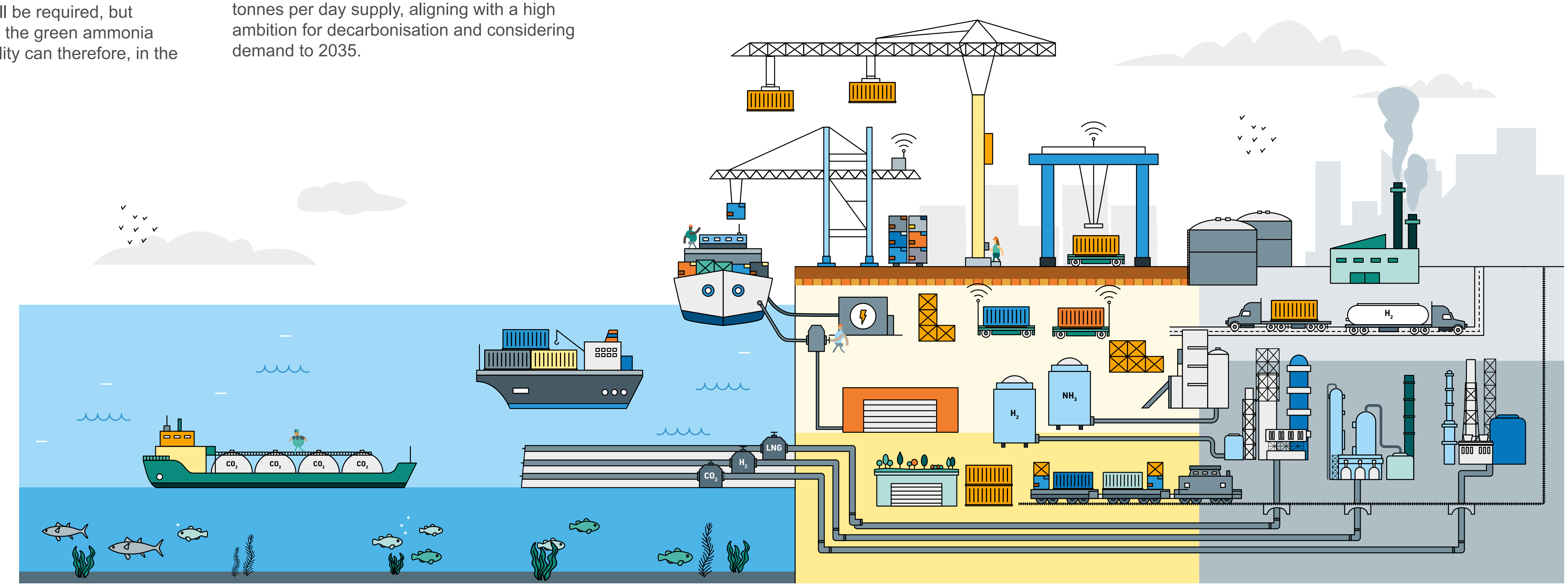


Figure 6 - Illustration
Blue ammonia supply chain

Key feasibility challenges and opportunities, considering a whole-system approach

Co-location:
There could be a key advantage to locating blue and green ammonia supply infrastructure together, with the oxygen by-product from green production acting as a feedstock to blue production, improving the overall efficiency.

Integrated industrial hubs:
Reformers, used to produce hydrogen, are non-modular in nature, which makes the uncertain picture of demand more challenging to manage. Creating integrated industrial hubs to supply multiple sectors, could help to appropriately manage risk.

Large land footprint:
Existing land-use will be a key consideration. Converting greenfield sites to industrial use can have a significant impact on natural carbon sequestration and on biodiversity, brownfield redevelopment and repurposing of existing infrastructure is preferable.

Accelerating near-term action:
Despite the significant challenges highlighted here, this type of project could be key to ramping up supply of fuels in the short term, an essential step to aligning shipping's decarbonisation in line with the Paris Agreement goals.

Whole life carbon management:
For the facility to produce truly low-carbon ammonia, the whole supply chain and lifecycle – from production and transportation of natural gas to carbon capture and onwards sequestration – must be tightly controlled and monitored. This type of system is yet to be proven in its entirety at scale, but evidence suggests it could be feasible. Projects put into operation beyond the 2020s would risk prolonged deployment or becoming stranded, and as such would require careful consideration.

Fuel transportation:
For many city-ports, this scale of infrastructure is likely to be situated remote from the port, requiring transport of fuels for example via rail or pipeline. The resilience of this connection would be an important consideration.

Cost:
Although this typology could unlock supply at scale in the short term, the fluctuating costs of natural gas as a feedstock and uncertain costs of long-term carbon sequestration could render this option uneconomical. Exploiting opportunities for repurposing existing infrastructure will be key to reducing costs.

Demand uncertainty:
The demand for fuels for shipping has significant uncertainty, in particular in the medium to long term.

Unlocking investment by building a Total Value case

Unlocking investment by building a Total Value case

Production and supply of low-carbon fuels for shipping requires substantial capital investment and will incur relatively high operational costs, with the end costs per unit of fuel being significantly greater than the fossil fuel equivalents (potentially up to five times the cost on an energy-content basis). For pilot supply projects, as part of green shipping corridors, we envisage that a Total Value approach can unlock investment as well as sustainable outcomes.

Commercial-scale pilot projects for low-carbon fuel supply are needed by 2025 to deliver 5% zero carbon fuels by 2030 to meet the Paris Agreement. At present, there is no global agreement on a taxation or subsidy regime to ensure cost competitiveness between low-carbon and fossil-based fuels. This equates to a market failure where polluters are not required to pay for the damage they cause. The result is an uneven playing field, where novel marine fuels with a higher cost of production must compete with conventional fuels with prices kept low artificially.

Using Total Value to respond to the decarbonisation challenge

Over a trillions dollars of global investment is needed to support the production of novel fuels to decarbonise shipping.

A broader approach to shaping, capturing and leveraging the wider value of the initial pilot projects could help improve their investment case and build a wider group of stakeholders who will benefit from their realisation.

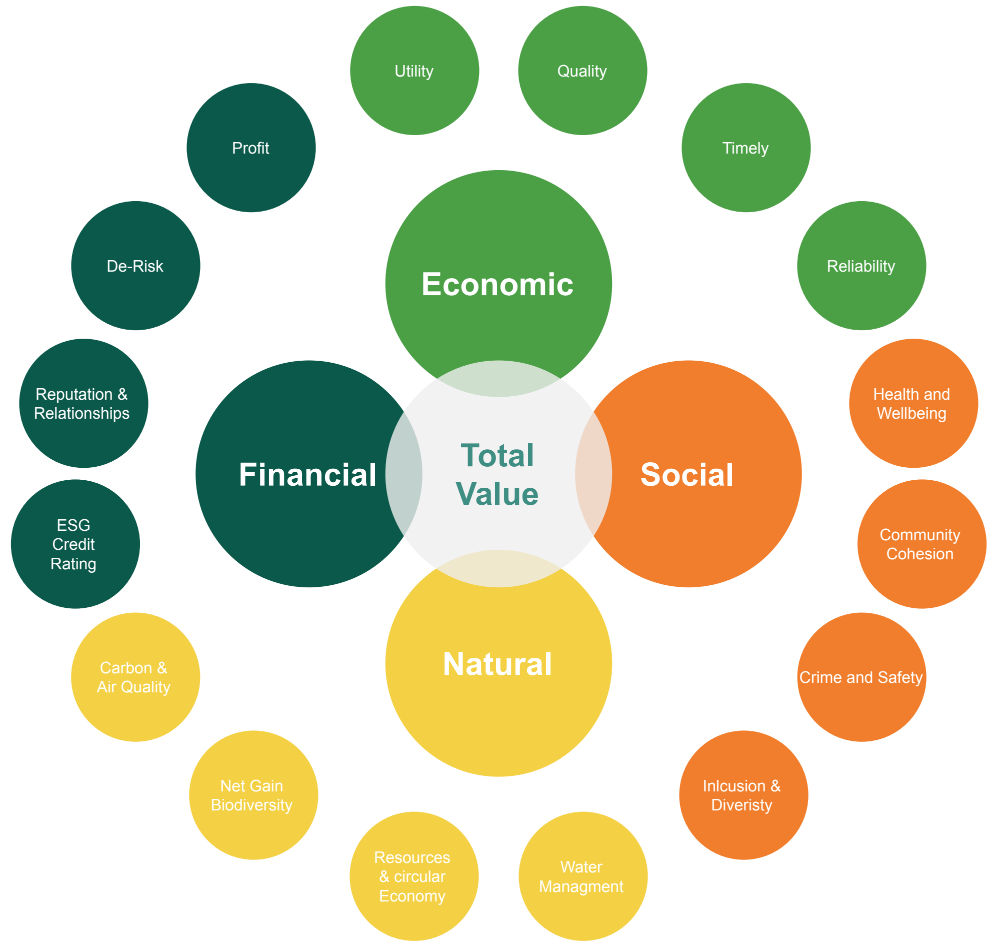
Work by the industry – such as that published by the Getting to Zero coalition[9] – has demonstrated the innovative mechanisms through which the cost and risks of pilot projects can be reduced and controlled.

'Total Value' assesses and quantifies a wider range of benefits than traditional methods, creating opportunities for more innovative solutions, new business models and collaborations. To implement sustainable investment decisions, it is essential that the world can deliver social and natural benefits alongside economic and financial value. Read more in Arup's paper which shows how a Total Value approach can close the value gap and drive change at scale.

9 www.globalmaritimeforum.org/publications/the-first-wave-a-blueprint-for-commercial-scale-zero-emission-shipping-pilots

Examples of Total Value from pilot green shipping corridor project

There is an opportunity to apply a Total Value framework to a pilot future fuel project or green corridor initiative, shaping, capturing and leveraging value to bolster the case for investment.



Financial

Decarbonising shipping along a green corridor may induce economic activity to the area to capitalise on the supply of decarbonised fuels. This induced activity can be captured as renewed foreign direct investment in infrastructure, higher income tax from wages and increased VAT receipts from local expenditure

Economic

Taking a whole-systems approach to the pilots, integrating with other sectors using circular economy principles, can unlock additional revenue streams, help manage demand uncertainty, stabilise costs for consumers and reduce waste.

Social

Reducing emissions at ports can improve air quality and thus health outcomes for local communities. Pilot projects and their supply chains, expected to grow in capacity over several decades, could provide green jobs and training opportunities, facilitating a 'just transition'.

Natural

As well as reducing greenhouse gas emissions, the provision and use of low carbon fuels can reduce emissions of pollutants within port cities and at sea, reducing environmental impacts. There may be opportunities for ecological enhancements to be undertaken alongside or integrated with pilot projects, ensuring a net gain in environmental value.

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THE RESILIENCE SHIFT

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