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Innovation Insights Brief | 2019

ENERGY INFRASTRUCTURE

Affordability Enabler or Decarbonisation Constraint?

ABOUT THE WORLD ENERGY COUNCIL

The World Energy Council is the principal impartial network of energy leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all.

Formed in 1923, the Council is the UN-accredited global energy body, representing the entire energy spectrum, with over 3,000 member organisations in over 90 countries, drawn from governments, private and state corporations, academia, NGOs and energy stakeholders. We inform global, regional and national energy strategies by hosting high-level events including the World Energy Congress and publishing authoritative studies, and work through our extensive member network to facilitate the world's energy policy dialogue.

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ABOUT THIS INNOVATION INSIGHTS BRIEF

This Innovation Insights Brief is part of a series of publications by the World Energy Council focused on Innovation. In a fast-paced era of disruptive changes, this brief aims at facilitating strategic sharing of knowledge between the Council's members and the other energy stakeholders and policy shapers.

This report was developed in collaboration with our Innovation Supporter Akselos.

If you wish to contact the Council on this issue, please write an email to **zafar@worldenergy.org**

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EXECUTIVE SUMMARY

Existing energy infrastructure has been built over many decades to support conventional energy uses including coal, nuclear, oil and natural gas. The rapid transition to a decarbonised energy system implies that some existing infrastructure will be either stranded or decommissioned early, therefore creating a need to assess and minimise the cost as well as mitigating the risk of cascading impacts. Consequently, the way we manage existing infrastructure will both affect and be affected by the chosen transition paths to decarbonisation. These choices determine the speed of decarbonisation and the affordability of the whole system transition. Existing infrastructure can play a big role, but there is a lack of coordinated vision of how infrastructure would fit into the broader energy transition agenda.

The World Energy Council has developed a set of **principles for designing an Infrastructure Action Plan** to ensure that decommissioning, stranded assets and/or repurposing does not become a barrier to affordable decarbonisation. These principles are based on deep-dive interviews with energy leaders from around the world, supplemented with research.

While the focus of this brief is existing infrastructure, a complimentary brief will be developed with the support and contribution of the global community, to plan for the new energy infrastructure associated with the growth and eventual dominance of new energies.

KEY FINDINGS

1. A successful energy transition depends on infrastructure that is adaptable, reliable and affordable. We need to find better ways to utilise existing energy assets as we transition to a decarbonised system
2. Use of existing infrastructure is a resource for more affordable transition to decarbonisation. Realising this opportunity must be a priority that requires consideration of infrastructure repurposing opportunities where these make sense.
3. The magnitude of stranded assets is unknown to the market. There is a potential risk that decarbonisation could become cost-prohibitive if large portions of existing infrastructure are stranded.
4. Businesses should reframe market strategies to explore the opportunities of reusing existing infrastructure to support transition to a low-carbon future.

RECOMMENDATIONS

1. EXISTING ENERGY INFRASTRUCTURE AND ITS POTENTIAL REPURPOSING OPPORTUNITIES SHOULD BE PART OF TODAY'S LONG-TERM PLANNING AND STRATEGIC DIALOGUE

Existing energy infrastructure has been built around conventional resources over many decades with trillions of dollars in investment. It will be a missed opportunity to not plan for the role of existing infrastructure in future energy systems.

2. NATIONAL GOVERNMENTS AND WIDER ENERGY STAKEHOLDERS SHOULD CO-DEVELOP AN ENERGY INFRASTRUCTURE ACTION PLAN

Energy leaders from around the world including national and regional policymakers have a critical role to play in driving forward the development of a coordinated Action Plan to better realise opportunities for aligning decarbonisation of energy supply with existing infrastructure that may need to be appropriately dealt with. In Europe, besides national governments, European policymakers will have a key role for energy infrastructure plan to ensure coherence for all the countries.

INTRODUCTION

Most existing energy infrastructure assets are designed and built to last for decades. These assets do not exist and function in a vacuum; it is only natural that changes in technologies, business models, and government policies will occur over their lifetime. Previously, these changes were simply an evolution of the existing mode of producing, delivering and consuming energy. Since 1970, the world has seen rapid growth in energy demand, mainly satisfied by fossil fuels and centralised power generation. The future, however, is expected to be different. Energy transition does not happen in a vacuum. It is shaped by a much broader and fundamental shift in prosperity, progress, politics, and planet. We call this wider and fundamental shift in context "**The Grand Transition.**"[1] This ongoing transition is not just about energy, or a switch from one fuel source to another, or the replacement of old for new generation technologies. What is happening today in the energy world is a paradigm shift. There is a move away from the core values of security, reliability, and robustness which existing energy systems were built on, to new values of sustainability, flexibility, and affordability, enabled by a completely new way of producing, delivering, and consuming energy.

> **"Current infrastructure was built to reflect values of reliability and low costs. Those values have now changed to include sustainability. The current infrastructure is essentially not compatible with the sustainability imperative and social and economic aspirations."**
>
> **RICHARD DOWLING, FARADAY GRID**

The new energy paradigm is characterised by the accelerating pace of end-use electrification, the rise of digitally enabled ecosystems, data-centric services, and the emergence of a new agent: energy prosumers – homeowners or individual users who both use and consume energy. It is evident also in the shift from centralised generation and vertically integrated monopolies towards decentralisation, digitalisation, energy clusters, micro-grids, interconnection, and diversification of supply and storage options.

Based on analysis of deep-dive interviews with energy leaders from around the world, and additional research, we found that one of the obstacles to a successful energy transition is how governments and the industry will deal with asset decommissioning, stranded assets, and repurposing of assets. What is more alarming, is that despite its significance, existing infrastructure has become an undiscussable challenge and is insufficiently planned for: **dealing with existing infrastructure is an afterthought to decarbonising the supply of energy.**

> **"Existing energy infrastructure is a valuable portfolio of assets that has been developed, permitted and built over the course of many decades. Adapting and repurposing these assets has an important role to play in global transition to low- carbon energy mix. Using existing assets, which is typically less expensive than building new ones, allows to mitigate cost, which is critical for broad societal acceptance of the transition."**
>
> **YURI FREEDMAN, SOUTHERN CALIFORNIA GAS COMPANY**

[1] https://www.worldenergy.org/publications/2016/world-energy-scenarios-2016-the-grand-transition/

For example, the impact of stranded assets alone can have a huge impact on the world economy. According to researchers, global fossil fuel assets' value could be reduced between $1 trillion and $4 trillion by 2035 as a result of stranded assets [1]. This already significant cost does not consider the additional cost of decommissioning and/or opportunities for re-purposing existing assets. Taken apart or considered together, these costs affect the pace, shape, and affordability of energy transition.

> **"Certainly, national governments and more specifically global bodies can play a role in setting a vision for the management of existing energy infrastructure; failure to do so could make decarbonisation policies cost prohibitive. Similar to the visions and policies created for reducing GHG emissions, these global institutions are also needed to set policies and push for roadmaps to cost-effectively decommission or repurpose existing infrastructure. Stranding assets should be the last option."**
>
> **AHMAD AL KHOWAITER, CTO, SAUDI ARAMCO**

Figure 1: Definitions

THREE OPTIONS FOR EXISTING INFRASTRUCTURE:

DECOMMISSIONING

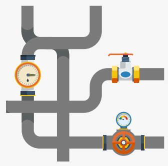
Returning a site to its original state prior to development, including removing structures, decontamination, and site restoration (e.g. shutdown of a power plant and subsequent site restoration).

STRANDED ASSETS

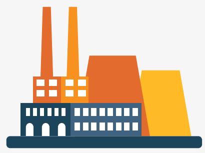
Stranded assets are those that have suffered from unanticipated or premature write-downs, devaluation or conversion to liabilities (e.g. coal power plants that can be used but are no longer needed).

REPURPOSING

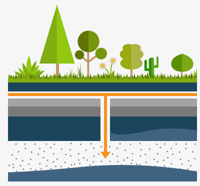
The use of an asset for a purpose other than its original intended use (e.g. repurposing natural gas pipelines to transport other gases, such as hydrogen). For example:



NATURAL GAS PIPELINES



POWER PLANTS



OIL &GAS FIELDS

Dealing effectively with existing infrastructure, whilst not inevitable, is not impossible. Two action plans offer innovative models for success.

1. NexStep, a joint initiative of EBN and the Dutch oil and gas industry, is the only holistic action plan developed in the world to date to deal with existing infrastructure.

2. California's *Action Plan*, although not directly dealing with infrastructure, offers an effective model of how to bring an industry together under a common vision. Both plans are featured as Figures 7 and 8.

INTERVIEWS, KEY INSIGHTS & ANALYSIS

We interviewed leading experts from around the world to get an understanding of how decision makers think about existing energy infrastructure designed for fossil fuels as they transition renewable energies to decarbonise the supply side.

1. Michael Webber – Chief Science and Technology Officer, Engie
2. Dr Shihab-Eldin – Secretary General, OPEC (ret.)
3. Nils Cohrs – Head of Decommissioning for UK Oil and Gas Authority
4. Ahmad al Khowaiter, CTO, Saudi Aramco
5. Paul Simons – Deputy Executive Director, IEA
6. Pete Milojevic – President, Midland Cogeneration Venture (ret.)
7. Lee Krevat – CEO, Krevat Energy Innovations
8. Ken Cronin – CEO, UK Onshore Oil and Gas
9. Hassen Bali – Co-founder, Ion Ventures
10. Jim Avery – Director, Western Electricity Council
11. Kendall Dilling - VP of Health, Safety, Environment and Regulatory, Cenovus Energy
12. Anastasios Papandreou - Directorate General for Energy, European Commission
13. Renee Orr – Strategic Resources Chief, Bureau of Ocean Energy Management (US)
14. Yuri Freedman – Sr. Director, Business Development, SoCalGas
15. Dag-Erlend Henriksen – Sr. Advisor for the Norwegian Ministry
16. Jeanne Ng – Director, CLP Research Institute
17. Sam Muraki – Asia R. Vice Chair, World Energy Council (ret. EVP, Tokyo Gas)
18. Jacqueline Vaessen – General Manager, NexStep
19. R. Andreas Kraemer - Founder and Director Emeritus, Ecologic Institute in Berlin
20. Nuno Silva – Technology and Innovation Director, EFACEC
21. Richard Dowling – Chief Economist and Head of Regulatory Affairs, Faraday Grid
22. Dan Sadler – H21 Programme Director and Project Originator, NGN

Figure 2: Key Interview Questions

Key Interview Questions

- What is the role of the existing infrastructure in a decarbonised world? Can it be re-used or repurposed? Or will it be recycled, decommissioned or even stranded?
- What are the plans in place, if any, and are the liabilities defined?
- Should there be an overarching and coordinated vision to plan for the fate of the existing infrastructure?
- What is the role of regulatory bodies in promoting or hindering the management, planning and building of assets in the transition?
- Can the electrification and liquid and gaseous fuel routes and their relative infrastructures support each other in the transition?
- Can the climate change predicament be turned into an opportunity in the field of infrastructure?

The overarching perspective emerging from the interviewees is that a **successful energy transition depends on infrastructure, however, shared vision and long-term plans are not in place because infrastructure is treated as an afterthought of decarbonisation.**

The renewables revolution supply-side movement has the backing of powerful international bodies, such as the United Nations. Accelerating investment and access to zero margin cost, renewable energy is promoted by international, national and regional visionaries who are tireless in their efforts to warn against the continued dominance of fossil fuels in the energy mix. However, net-zero carbon pathway visions are missing from the existing energy infrastructure process. This bias and polarisation of perspectives is reflected in the concerns expressed about the absence of a coordinated vision and policy for dealing with existing infrastructure.

> **"Infrastructure transition should be government led, because of the huge impact on the consumers."**
>
> **KEN CRONIN, UK ONSHORE OIL AND GAS**

Most interviewees said **that businesses are largely driven by short-term profit strategies and, as such, are not changing the way they operate or plan business based on the speed, need for, and cost of infrastructure transition.** Existing infrastructures, specifically those that were put into place decades ago with expected long asset lifetimes, were not designed for the full lifecycle: technical and environmental issues of decommissioning, re-use, or repurposing, were not taken into account. In a sector like solar, where infrastructure turn-over is relatively faster, a different model of agile design learning is possible. For conventional energy (nuclear, oil, gas, hydro) with long-lived assets, it is harder to plan for a system that will not be in place decades from now without shared vision. Any shared vision, in turn, needs to be developed through multi-stakeholder dialogue involving existing and new infrastructure developers and owners, regulators, and end-users to identify technologically feasible, economically viable, and socially acceptable (affordable and fair) long-term approaches and solutions.

> **Markets have trouble having long-term view, building 100 years infrastructure on their own. Government is not as efficient in owning and operating the assets.**

Government should encourage long-term infrastructure by setting the standards and setting goals for what kind of infrastructure should be build.

MICHAEL WEBBER, ENGIE

Many of those interviewed warned of **risks to successful energy transition increase with the accelerating the pace of energy infrastructure transition,** especially without a coordinated vision for dealing with existing energy infrastructure. For example, they highlighted the impact of increasing international support for rapid electrification is not sufficiently taking into account the role and opportunity of repurposing the gas infrastructure. The common belief is that 100% electrification of commercial and domestic heat is unrealistic, as it would imply heavy capital costs on and significant disruptions to consumers, which will increase resistance. In the short to medium term, the majority of interviewees concluded that there is no economic case for 100% electrification but it should be complemented by other fuels such as hydrogen and possibly nuclear.

As the world transitions to a new energy system the interviewees **all agreed that circular economy[2] models will be developed.** This implies a transition to viewing the lifecycle of infrastructure as a resource that should be planned in view of sector coupling opportunities and benefits of switching options (supply and storage) and maximum re-use and recycling of assets and/or components.

According to 85% of the interviewees, a vast proportion of existing assets in the energy sector have reached or are reaching their late asset lifecycle stage [8-13]. This is the case of the North Sea assets [8-10]. The magnitude of the decommissioning problem is being underestimated while it is constantly growing in scale globally: current forecasts indicate that an unprecedented wave of simultaneous asset decommissioning will begin to take place in this very decade, especially across the oil and gas upstream sector. This is a challenge of staggering proportions and significant consequences to the financial health of both the companies directly dealing with decommissioning as well as on the entire economic, social, and environmental system, and cannot be overlooked or under-emphasised.

The ageing of infrastructure is taking place at a crucial moment; a multitude of zero carbon and/or net-zero carbon energy transition pathways are emerging. Against this wider context, **greater priority needs to be given to the ways in which ageing assets can be better managed as a major factor in defining and driving successful energy transition.**

[2] An economic system aimed at minimising waste and making the most of resources. In a circular system resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing energy and material loops; this can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.

> **"Policy makers and regulators will have a key role in developing approaches to deal with energy transition implications on infrastructure liability."**
>
> **NILS COHRS, UK OIL AND GAS AUTHORITY**

Given the increasing number of assets in the oil and gas industry that are reaching their late-life stage, companies and operators owning the liabilities will have to deal sooner rather than later with the decommissioning process and site restoration, where appropriate.

To ensure companies meet their responsibilities, **regulatory oversight of decommissioning and site restoration activities is needed across different energy sectors in order to avoid economic, social, and environmental crisis.** For example, the UK Sellafield nuclear site decommissioning costs have increased by nearly £1 billion more than initially forecasted and taxpayers have already paid £500 million without seeing much progress [14]. Lack of oversight on operations and performance has been indicated as one of the main reasons leading to large budget overruns and major delays in decommissioning projects execution.

Figure 3: Cost Estimates for Decommissioning

Decommissioning: Cost Estimates

- The 2018-2022 global forecasted decommissioning costs for offshore assets are about $32 billion.
- **North Sea** The decommissioning costs for 600 installations in the North Sea alone over the next 30 years could reach $65 billion.
- **Asia-Pacific Region** Approximately 2,600 platforms, 35,000 wells, 55,000 km of pipelines and 7.5 million tonnes of steel will have to be decommissioned in the Asia-Pacific region over the next decade with a potential cost of $102 billion.
- **Gulf of Mexico** Decommissioning costs for offshore production facilities, including 3,000 platforms, is forecasted to be $40 billion. These costs are subject to uncertainties and can increase considerably due to several factors that are discussed in this brief.

NOTE: Governments are in most cases responsible for a share of the costs of decommissioning in their region. For instance, the UK government is forecasted to burden 45% of the total UK decommissioning bill, while Norwegian government's share would amount to 78% of Norway's total costs.

KEY INSIGHTS FOR DECOMMISSIONING

The widespread short-termism: more than 65% of interviewees said incumbents focus on reliability and profitability, leaving important aspects like infrastructure decommissioning to the future. Moreover, 90% of those interviewed warned that this lack of foresight impacts whether late-life assets and their decommissioning are managed in an economically, socially and environmentally feasible and efficient way. The responses also highlight existing infrastructure for conventional energy supply has not traditionally been designed and planned for full asset lifecycle or to enable new circular economy models.

The majority of interviewees felt that **decarbonisation targets are not main drivers for the decommissioning and site restoration of existing infrastructure in the oil and gas industry.** The pace of infrastructure transition is mostly determined by economic lifetime and market signals. However, there was unanimous agreement that the economic implications of **decommissioning and site restoration liabilities could have a significant negative effect on whole energy systems transition.** For this reason, the identification of liabilities, the definition of careful and timely decommissioning planning, and, the support and guidance from regulatory bodies have now become an urgent concern.

More than half of the interviewees advocated for a **government-led renewal of infrastructure late-life planning,** since decarbonisation, early decommissioning and re-purposing were not key design parameters decades ago, when the infrastructure was built. More specifically, the interviewees agree that companies cost-effective plan with regulatory oversight. The plan should:

1. Clearly define of what decommissioning and site restoration entails according to existing or imminent standards. Dismantling of part or the entire infrastructure? Designating some of the infrastructure for possible recycling, or repurposing? Restoring the site to certain conditions?
2. Cover all technical, safety and environmental requirements, and deal with the liability with solutions that are economically feasible.
3. Consider technological developments that could extend asset lifetime or open repurposing options and avoid premature decommissioning.
4. Demonstrate an understanding of the inter-dependencies between sectors. For instance, decisions on decommissioning onshore and offshore assets impact on each other.
5. Use a scenarios-based approach, exploring new risks and opportunity to existing infrastructure being repurposed as a resource for the transition.
6. Exploit infrastructure decommissioning, site restoration and the possibilities of infrastructure repurposing as potential new business opportunity for firms specialising in such operations.

The interviewees agreed that the asset lifecycle planning should be led or at least facilitated by government and that the market should find the best way to implement solutions to meet the policy goals. **Asset lifecycle planning goals should be part of the global agenda on decarbonisation, however, the regulations and policies should be region-dependent.**

A consistent message, or rather concern, from the interviewees was that **the pace of transition away from fossil fuels to renewable energies should be gradual,** to allow enough time for companies to adjust plans and develop financial capabilities for decommissioning assets. Any sudden ban on fossil fuels would, for instance, lead to a rapid increase in decommissioning costs with accumulated liabilities that would be unsustainable for the companies first, followed by the entire economic system.

Another fundamental aspect of decommissioning is the identification of who owns the liabilities and what happens if they are not fulfilled. The scale of this problem is being severely underestimated according to our interviewees. **There was full agreement that the issue of who should be liable for asset decommissioning is not in dispute:** owners and operators in the industry should be accountable to an appropriate level of liability and should carry all the technical and economic responsibilities, including site restoration to regulated standards, while governments should try to minimise any possible burden on the taxpayers. However, if a large number of companies liable for decommissioning are insolvent, the accumulated economic strain on the system could potentially be disastrous, with the public ultimately ending up burdening all costs and the government funds that could be devoted to the advancement of the transition considerably curtailed.

The interviewees suggested **clear legislation on liability, defining who and what is liable is needed to ensure safety, reliability and affordability.** The European Union has already established provisions stipulating that from the beginning the operator should be able to carry operations throughout the lifecycle, including the decommissioning phase, so that the states do not have to pay for decommissioning. However, there is lack of clarity on the financial responsibilities of smaller operators who might not hold the financial capabilities for decommissioning. The majority of interviewees agreed **new legislation is required to prevent incumbents from minimising their liabilities at the expenses of taxpayers and the environment,** especially those traditionally entrenched with states and regulators.

Although regulators should make sure that companies do not leave liabilities to the taxpayer, interview responses frequently highlighted a **warning that governments need to be financially prepared in the case asset owners, operators or lessees are not able or willing to pay for all decommissioning costs.** This involves assessing short and long-terms risks and allocating a strategy to provide provisions and secure public funds as a last resort. As one interviewee pointed out, in case of insolvency, providing further tax relief plans or other forms of direct or indirect subsidies could inflame public sentiment against owners and operators, who having enjoyed the financial benefits, should be fully responsible for the decommissioning.

WHY DOES DECOMMISSIONING PLANNING MATTER?

Decommissioning plans are in place in parts of the energy sector. For example, the nuclear and offshore oil industries do have specific plans and set aside funds for decommissioning. However, these plans do not consider the drive for accelerating decarbonisation. The economic rationale to decommissioning and site restoration is to delay for as long possible. In turn, the lack of timely action results in an ever-increasing magnitude of liability, and, in the case of non-renewable resources, progressive decline of the financial capability to address it. It also reduces the opportunity to maximise efficiencies that early action can provide, including spreading the burden over a longer period of time to reduce the financial impacts at any one point.

Furthermore, **lack of planning exacerbates the already contentious issue concerning the unevenness with which current liabilities and regulations are tackled.** Since the mid-1990s the building of new offshore infrastructure has taken decommissioning into account. However, in some regions e.g. Indonesia, contracts did not include decommissioning clauses [12]. Similarly, protocols addressing the environmental issues around site restoration and material re-use, such as the London Protocol, are missing at a global level.

Successful delivery of infrastructure decommissioning and site restoration require very complex planning and operations, aimed at halting production, the removal of part or all of the infrastructure and the site restoration to conditions which are not harmful to people and the environment. Several barriers are encountered:

1. **Decommissioning and site restoration cost uncertainty.**
This will possibly increase depending on energy market fluctuations, new technologies, maintenance costs of the aging infrastructure, and inaccurate forecasts of technical and management costs required to conduct the decommissioning process.

2. **Limited decommissioning and site restoration capabilities and expertise.**
Practical experience is mostly lacking in the industry as many companies are at the early stages of learning about the actual cost of the various activities and how to maximise efficiencies. Likely planning and execution mistakes will inevitably increase costs.

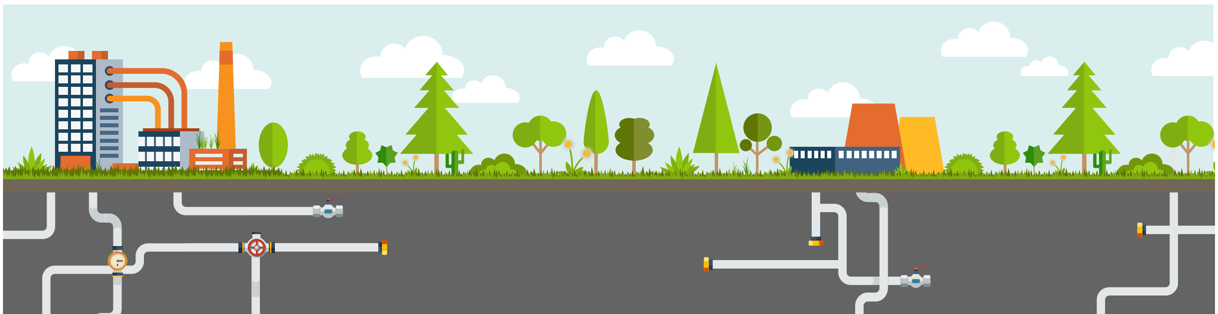
3. **Decommissioning standards definition.**
It is likely that those operators acting early will set the standards of decommissioning, which might result in technical and financial challenges for operators that will act later in different regions.

4 Decommissioning chain reactions.
The decommissioning of individual assets, such as pipelines, which are part of larger shared energy infrastructure systems, could have negative economic effects on the entire system, leading to accelerated decommissioning of other infrastructure within it.

5 Decommissioning extent.
Uncertainty in the definition of which parts of the infrastructure will have to be completely removed or kept on-site will greatly affect costs. Additional uncertainty for what type of site restoration must take place significantly increases the uncertainty of costs. This will also depend on environmental and health regulations, where they exist.

6 Financial capabilities.
Depending on established policies, the extent of decommissioning and site restoration costs burdened by tax payers and by companies may vary. The extent of incentives may change, affecting one party more than the other. Long term climate change policies may become incompatible with today's government support of the fossil fuel industry, therefore increasing the financial strain on companies having to manage decommissioning and site restoration. Efforts aimed at maximising the recovery of remaining oil and gas reserves, although representing a source of revenue both for companies and for governments, will ultimately affect the timing and financial availability to face current and future decommissioning and site restoration. Accurate forecasting and planning for these interlinked factors can be very problematic.

The most important questions to ask, therefore, are whether the industry will be **financially and technically** capable to properly carry out decommissioning and site restoration at the right time and burden the costs? Additionally, will governments and policy-makers define and enact legally-binding regulations identifying standards of decommissioning, the required oversight and management of liabilities? The answers lie in **awareness of the problem, careful planning, strategic decision-making, coordination between industry and regulators and early action**.



STRANDED ASSETS

While decommissioning can be argued to have plans in place from an asset-specific perspective, albeit insufficient for decarbonisation, the prospect of stranded assets is considered to be a 'wild card'.

Stranded assets could even be considered an "epidemic" threatening the economic viability of a decarbonised energy vision, because the magnitude of potential assets that may need to be stranded is unknown. Determining the magnitude of stranded assets is not a straightforward task as it strongly depends on sector interdependencies and, especially, on the definition and pace of successful transition e.g. zero-carbon, net zero carbon, etc. To date, reports of cost modelling estimate **the value of stranded assets might reach $20 trillion across all energy sectors,** if early action is not taken to minimise costs

[1]. Studies also show that the **operational and embodied greenhouse gas (GHG) in existing and planned infrastructure are incompatible with the target of containing global warming to 2°C** thus indicating the likelihood of a stranding of productive stocks in the event of a low-carbon transition [15,16].

Furthermore, **the pace of decarbonisation can further exacerbate the costs associated with stranding.** In fact, rising carbon prices and emission reduction targets are increasing the amount of stranded resources (unburnable coal, oil and gas). This is already a stranding of assets in the fossil fuel industry, creating a wave of capital divestment [16-18]. If policies suddenly accelerate decarbonisation, without the industry having a coordinated infrastructure plan in place, the stranding of assets will accelerate and could lead to cascading failure in other sectors.

The geographic distribution of stranded assets varies greatly. Europe, Japan and North America would see the majority of stranded assets concentrated in the building sector. This is due to the fact that the upstream and midstream energy infrastructure in these regions is already ageing and closer to the decommissioning stage. In China and India the power generation sector would incur in the largest proportion of stranded assets, reflecting their investments in new coal power plants. Australia, Brazil, Canada, Indonesia, Mexico, the Russian Federation, Saudi Arabia and South Africa would see the largest proportion of stranded upstream assets. Stranding of industrial assets would occur in places such as Brazil and China, where large heavy-industry facilities are active [1].

Figure 4: Cost Estimates for Stranded Assets

Stranded Assets: Cost Estimates

Studies recently conducted on stranded assets vary a great deal on the forecasts of stranded assets. A source of uncertainty is the fact that predictions rely on possible scenarios that take into account variables such us climate targets and subsequent energy policies which may or may not be enforced. The figures referenced in this brief do, however, provide a measure of the possible proportions of stranded assets.

- The **global forecasted costs** of stranded assets across the upstream, power generation, industry and buildings could amount to $20 trillion over the next 30 years.
- The **upstream energy sector** could see between $1.8 trillion and $7 trillion in stranded assets.
- **Oil and gas** have already registered an estimated $ 1 trillion in stranded assets between 1997 and 2017.

KEY INSIGHTS FOR STRANDED ASSETS

With few exceptions, our interviewees expressed concern about the cost impact of stranded assets on the decarbonisation vision. More than 75% of interviewees expressed concern that **concrete planning and action in regard to stranded assets are missing.** Overall, the interviewees encouraged considering planning as early as possible, being aware that there is traditionally lag or inertia between identifiable potential outcomes being realised and those outcomes actually coming to fruition.

> **"In terms of planning for stranded infrastructure, there is definitely a large gap, as the majority of incumbents are still continuing to believe that the status-quo will prevail and thus short-term, profit-focused strategies will persevere."**
>
> **HASSEN BALI, CO-FOUNDER OF ION VENTURES**

Interviewees warned about the risks of decarbonising too suddenly as there would be neither sufficient funds in the public sector nor sufficient planning to be able to deal with stranded infrastructure. Interviewees recommended new energy policies and a new rate structure should be developed within a reasonable timeframe to incentivise firms, investors and utilities to find ways to gradually find solutions to achieve set goals while smoothly phasing out assets, and avoiding sudden stranding. Lastly, the majority of interviewees agreed that without regulation, incumbents would be too short-term focused. This would lead to a significant stranding of assets at a later stage, accelerated by growing decarbonisation targets.

WHY DO STRANDED ASSETS MATTER?

Stranded assets are a decisive factor in attenuating or heightening effects on the pace and path of the transition. An abrupt transition would have a twofold effect: it would destabilise the energy sector by accelerating the stranding of assets; and it would not allow long-term strategies and adjustments to be developed.

Instead, a strategy should be set as a result of collaboration between governments, policy-makers and the industry with the aim of acting early to minimise stranded assets, being financially prepared, identifying the sectors at higher risk and prioritising the stranding of polluting assets. There are several broad angles that can contribute to achieving this strategy [1, 8, 10, 19, 20]:

1. **Encouraging firms to increase disclosure about climate-change related risks.**
This would better inform investors and the industry about their decisions, averting riskier investments. It would also allow policy-makers to assess much better potential risks and produce adequate regulatory response. Systematic identification of assets at high risk of stranding due to decarbonisation is still an area which requires work.

2. **Encouraging firms and investors to see the transition as an opportunity.**
Diversifying portfolios including low-carbon technologies would decrease competition for remaining fossil fuel markets, lowering capital risk and providing resources for asset decommissioning.

3. **Policy-makers and firms should create mechanisms for early action towards the stranding of carbon intensive assets.**
This course of action would mitigate climate change and generate benefits in terms of human and environmental welfare which would economically far outweigh the damage caused by the stranding of such assets. Curtailment of investments in infrastructure energy and higher carbon prices would be possible ways to drive these mechanisms.

4. **Encouraging industry to upgrade to more carbon-efficient processes.**
The development and adoption of technologies such as CCS could extend asset lifetime, while simultaneously increasing energy efficiency to offset decarbonisation costs.

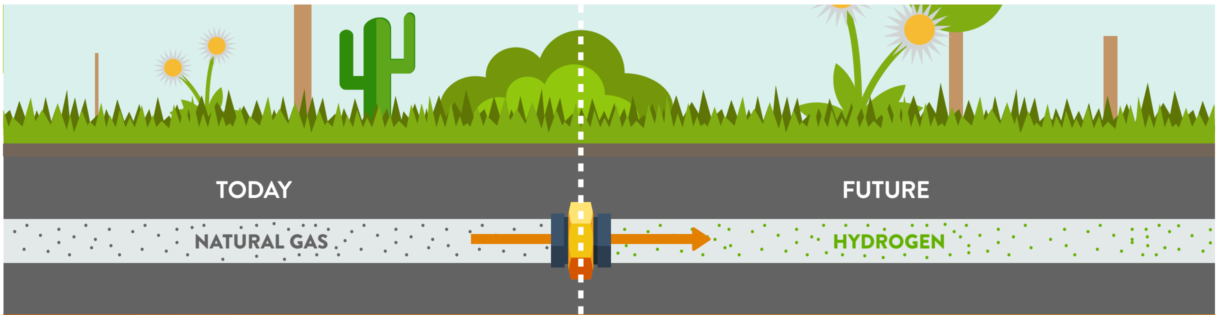
5. **Enacting a "just transition" by financially protecting weaker stakeholders.**
Workers whose employment is at risk and who could otherwise represent a source of opposition to the transition process should be financially protected.

6. **Avoiding investments that lock the economy into irreversible paths.**
Any investment done today on infrastructure that can potentially be stranded will have long-standing effects on the entire transition, limiting the benefits that could outweigh stranding of assets.

7. **Creating and training a new workforce**
Transition planning for skills is needed to mitigate the social impact of the Energy Transition.

Most of the research so far, as well as our exploratory interviews, has focused on stranded assets in the fossil fuel sector. However, a very interesting and fundamental aspect to consider is that of **stranded asset cascades, implying chain reactions of stranding in some sectors of the economy triggered by stranded assets in other sectors within a network of interdependencies, ultimately causing a systemic crisis.** A recent study [15] has analysed these effects on the European economy, concluding that stranding in the mining sector would have the highest potential to trigger capital asset stranding in the rest of the economy. Mining-sector stranded assets would directly affect the electricity and gas sectors, manufacturing activities such as coke and refined petroleum products and metals, transportation and storage. The electricity and gas sectors, in turn, would affect water services and public administration. The cascade would then continue through several other sectors including agriculture and food services, the chemical sector and the land transport and pipelines sector, fabricated metal products, the motor vehicles sector, trade and repair of motor vehicles, warehousing, and sewage systems. The most likely scenario exacerbating stranded asset cascades is an abrupt and unplanned transition.

The takeaway from these considerations is the **potential risk of a systemic financial crisis caused by stranded assets and the error of not taking them into account early in the transition.** Several parties could be directly and indirectly affected by the stranding of assets. In fact, although stranding will occur primarily in the energy sector, other sectors such as mining, utilities, transport, agriculture, real estate will be affected. Furthermore, stakeholders like financial institutions and investors (e.g. banks, pension funds, insurance companies), governments and workers who all have shares in stranded assets will suffer.



REPURPOSING EXISTING INFRASTRUCTURE

At a time when the volume of existing infrastructure decommissioning and site restoration is going to significantly grow over a relatively short period, it is desirable to consider all possible options that can allow firms and governments to keep on utilising assets, either by extending their lifetime or by repurposing them. Decommissioning projects in the energy sector have a high potential of recycling (up to 97% by weight in certain cases [21]). However, options like repurposing have a much higher value and should be investigated before deciding on decommissioning.

> **"There is significant potential to repurpose existing infrastructure, yet the discussion is still nascent. It will take a change in mindset that must be led at a government and regulatory level. We have the technology to repurpose production platforms for CCS, to use them as conversion and storage units for offshore wind energy, and to repurpose jackets for wind turbine foundations. The question is how to align incentives to make it happen."**
>
> **THOMAS LEURENT, AKSELOS**

Repurposing of infrastructure represents a multi-faceted endeavour with implications that are not merely limited to economic considerations. They place additional value on assets which could otherwise be decommissioned or stranded. They can serve as enablers of decarbonisation as essential technical components of low-carbon engineering solutions. They can be a key component of mechanisms that allow existing asset life extension. They can influence energy policy decisions and the nature of the future energy mix and future infrastructure of a region, which in turn has effects on the type of future business ecosystems revolving around the energy infrastructure. They can also be an active part of efforts made towards moving to a circular economy [22].

✓ KEY INSIGHTS FOR REPURPOSING

Interviews provided valuable insights on the benefits and possibilities of repurposing in the energy sector. Interviewees agreed that firms and governments should consider asset life extension and repurposing possibilities before decommissioning is approved. Moreover, 85% cautioned that repurposing and asset-life extension should always be looked at within the target energy system structure. However, in the fast-moving energy world of today this target structure is continually changing making it difficult to plan

The majority of respondents focused their attention to the possibilities and controversies surrounding the role of Carbon Captured in Storage (CCS) in repurposing of upstream oil and gas assets, and the repurposing of gas infrastructure, in particular of the transmission and distribution grid. These are not redundant assets for the transition and it is important to try to successfully re-use and repurpose them as this would lower potential sunk costs and contribute to decarbonisation. Transmission and distribution pipelines could be partially re-used for other low-carbon gases and liquids, the proportion of which is dependent on the nature and expansion timeline of projects they can serve. Repurposing for other gases would imply maintenance and possibly re-furbishing and, as an essential step, stipulating safety regulations following thorough assessment, which is necessary for any conversion to any new gas or liquid.

Examples of initiatives for the repurposing of gas infrastructure are happening in Europe. The European Commission, as part of its Long Term Strategy, analysed various scenarios on how to meet the EU's long-term decarbonisation commitments, including the potential role for alternative gas fuels in the gas grid, such as hydrogen and bio-methamne. Further analysis of these topics is on-going with the engagement of stakeholders through the Madrid forum and other fora. The H21 project is proposing the gradual conversion of the UK gas distribution infrastructure to 100% hydrogen. CCS would be coupled to the production of blue hydrogen via autothermal reforming (ATR). The project is based on extensive engineering and financial data which demonstrate its technical and economic feasibility [23]. CCS can also contribute to extending the lives of existing infrastructure. However, the biggest issue with CCS is its lack of cost effectiveness. Currently, CCS technology presents high associated costs. Appropriate investment and subsidies allowing wider adoption, can decrease costs that, in conjunction with the added asset value deriving from their repurposing, would make it cost effective to the point of representing a viable option to deliver low-carbon heat with minimum disruption to the system. The other issue with CCS that must be addressed is public sentiment. CCS is associated with the possibility of extending the use of fossil fuels which is becoming increasingly unacceptable in many parts of the world.

> **"There is a lot of investment going into CCS. The Oil and Gas Climate Initiative has invested a billion dollars in innovative companies that can lower the carbon footprint of the energy and industrial sectors. At this point, direct air capture remains too expensive (about $600 per ton) although costs are coming down. On the other hand, capture from stationary points is cost effective – $60 to $70 per ton. The issue today is not technology or price but regulation."**
>
> **AHMAD AL KHOWAITER, CTO, SAUDI ARAMCO**

Figure 5: Carbon Capture and Storage – Renewed Interest?

The major barrier to CCS is no loger technological, but political and commercial.

According to the CCS Institute there are currently 43 large-scale CCS facilities - 18 in commercial operation, five under construction, and 20 in various stages of development.

While CCS is principally an emissions mitigation technology, it is also able to contribute to broader energy security, environmental, societal and economic goals during this period of global enerrgy system transformation. However, according to IEA's 2017 report on CCS an estimated $10 billion in capital investment has been made in large-scale CCS projects within this decade. This is in contrast to almost $2.3 trillion of investment in renewable technologies between 2010 and 2016.

The renewed hope in CCS is particularly interesting, because of the government bodies that have concrete action steps in favour of it. In particular China and California both are not excluding CCS in their planning or subsidies programs. China's supporting CCS pilots, providing grant funding for CCS research projects, amending their Environmental Impact Assessment Guidelines to better address CCS projects, and establishing a CCS capacity building project. On the other side of the world small, but concrete signals are taking place in California with California Air Resources Board's decision to include a protocol for CCS in its Low Carbon Fuel Standard (LCFS), a rule which became effective on January 1, 2019. The protocol allows transportation fuels whose lifecycle emissions have been reduced through CCS to become eligible for credits under the LCFS. Japan, Australia and UK also are actively engaging in CCS investments and projects.

WHY DOES REPURPOSING MATTER?

Although we started the discussion with decommissioning and stranded assets, repurposing represents a significant opportunity to facilitate the success of the energy transition. While it can be argued that decommissioning plans exist, even if they are not a holistic approach, and stranded assets are an enigma in terms of overall planning, repurposing as the third and final category is the most unknown and possibly the most controversial. In terms of repurposing there is not enough research or planning that has been done, leaving much for conjecture. This lack of planning reduces the possibility to make better use of the infrastructure, whether in the energy sector or others.

There are, however, some discussions around the world and some siloed planning. In the case of offshore gas and oil rigs, **one of the most immediate concerns is pollution that the process of dismantling could cause.** It is in this context that a repurposing option could prove beneficial both economically and environmentally: repurposing rigs as artificial reefs [13]. This process is referred to as “rigs-to-reef” and has the potential of benefiting the marine ecosystem. However, although there would be clear economic and environmental benefits, policies facilitating these conversions are still lacking.

Primarily components of coal power plants could be extracted for re-use. However, in places like Japan, refitting coal plants with ammonia-burning technology is also being utilised a repurposing opportunity. These plants could be repurposed for other energy uses: waste-to-fuel plants, biomass plants, interconnectors. Their land could be repurposed to parks and historical sites via bioremediation or sold for redevelopment [26].

One of the biggest and most interesting opportunities for infrastructure re-use and repurposing are utilising oil and gas fields and gas pipelines for CO2 storage and transport as well as hydrogen and other liquid transport.

The storage of CO2 using CCS would allow for the repurposing of depleted oil and gas reservoirs and the repurposing of pipelines for the transportation of captured CO2 to their storage site [24,25]. Both pipelines and fields would have to meet certain requirements to be suitable for repurposing and thorough geological and technical assessments and any potential intervention should be performed before proceeding with repurposing plans.

Interviewees also forecasted that hydrogen could be partly mixed with natural gas or be used as a replacement of natural gas altogether. The two scenarios are very different. Blending hydrogen to natural gas for volumes up to 20% [25] would be equivalent to 6% on an energy basis and, although it could be used with existing domestic gas appliances, it would have a modest contribution to decarbonisation. Mixing hydrogen with natural gas would allow the utilisation of the existing grid, with minimum infrastructure investment. In regions with high renewables potential, it would allow gradual scaling up of electrolysis. This hydrogen blending route would be technically easier and economically more convenient to implement than a conversion to 100% hydrogen and appears to be the most widely supported. However, blending hydrogen into natural gas offers a cost-efficient pathway of gradual transition to higher concentrations of hydrogen and perhaps eventually pure hydrogen over time

Switching to 100% hydrogen, on the other hand, is a significantly more complex undertaking according to most of the interviewees. It also has a greater emissions reduction potential. The repurposing of pipelines for transmission, distribution and storage of pure hydrogen, has the potential to decarbonise the hard-to-abate sector of industrial, commercial and domestic heat, amounting to a 30% reduction of global emissions.

Since switching of various end-use sectors such as transportation, industrial, power generation, residential and commercial from natural gas to hydrogen is likely to be a gradual process, it is likely to progress via blending of hydrogen with natural gas in gradually increasing concentrations and, where warranted by demand, complete switching to hydrogen on select segments of natural gas grid that will expand in line with demand. The main factors determining the possibility of repurposing pipelines revolve around 1) materials suitability and 2) rate of the conversion to the new gas.

1. MATERIAL SUITABILITY

According to our interviews, existing steel pipelines transporting hydrogen could be susceptible to material fatigue and embrittlement, degradation processes heavily dependent on the hydrogen pressure and pressure cycles in the pipelines. For this reason, this argument can be conveniently divided into two categories: transmission and distribution. As stated in the H21 report, distribution pipelines operate at very low pressures and, hence, their conversion from natural gas to hydrogen is already possible and would present risks comparable to those of natural gas [23]. Furthermore, countries such as the UK and Australia are in the process of shifting the bulk of their distribution gas grid from steel to high-density polyethylene (HDPE) within the next ten years. There is general agreement that this material is suitable for hydrogen.

On the transmission side, there is less agreement about the possibility of repurposing to 100% hydrogen due to the high pressure of the gas which poses the risk of steel degradation and the formation of cracks. One possibility to address this risk would be to internally coat existing pipelines with material resistant to hydrogen penetration. In any case, the possible replacement of natural gas to hydrogen would have to be preceded by careful feasibility studies and, if positive, asset management systems to monitor integrity and direct maintenance would be put in place to prevent any risk.

2. RATE OF CONVERSION TO HYDROGEN

The data presented by the H21 project make it clear that the conversion of the transmission grid, although technically possible, would not be economically and practically convenient, at least in the short to medium term. The current transmission system can be thought of as a series of cascading reservoirs (from the production point down to the distribution grid). Given that the safety case and regulation would be in place, conversion at the production point would still imply a sudden shift of the entire system – transmission, distribution and appliances – to a new gas, presenting prohibitive practical challenges and precluding a gradual scale-up of the new gas, while the existing one is phased out accordingly. Thanks to the possibility of scaling up the Advanced Thermal Recycling (ATR) facility to gradually meet increasing demand, a more rational approach, both from the technical and business point of view is, instead, the construction of dedicated transmission pipelines aimed at transporting hydrogen to initial anchor points (such as combined cycle power plants, industrial clusters or commercial and residential areas). This approach allows the gradual conversion of natural gas to hydrogen appropriately meeting demand in time and allowing a smooth transition of the entire gas system. Once a full conversion is achieved, the existing transmission grid can then be repurposed to hydrogen.

Nevertheless, even this approach opens opportunities for repurposing part of the existing transmission grid. In fact, a portion of the transmission pipelines could be used for two main purposes: the transportation of CO2 captured during the production of hydrogen to storage sites; the temporary storage of hydrogen at much lower pressures than those required for transmission.

Although repurposing part of the gas infrastructure to 100% hydrogen presents hurdles, it should nonetheless be considered as a valuable option by governments, especially within a long-term whole-system approach. Projects like H21 could serve as examples for a replicable model, it would provide the infrastructure to support other sectors such as fuel cell vehicles, and would be a source of testing and data gathering to validate and improve concepts and executions. The use of hydrogen, due to the infrastructure investment required, becomes an energy choice which has to be made or at least facilitated and supported by governments in coordination with energy firms, both financially and through suitable policies.

Overall, the repurposing and the extension of asset life can be a valuable instrument to support the energy transition and to add economic and strategic value to assets which would otherwise have to be decommissioned. Governments and the industry should see an opportunity in identifying which assets can be repurposed before their decommissioning is approved. Investments in technologies such as CCS and hydrogen, which would enable extensive repurposing and asset life extension, should be supported by regulation and investment. Some repurposing solution could be implemented in the near future, while others would require long-term planning. In both cases, a coordinated approach between industry and governments is essential.

Figure 6: Akselos is offering a new approach to repurposing

Akselos has commercialised emerging structural simulation software, developed over 15 years at MIT. The technology is capable of unprecedented structural analysis, allowing the creation of exact, structural digital twins of infrastructure of limitless scale. These digital twins are used to understand, monitor and predict remaining structural capacity to support asset life extension and repurposing strategies. A recent Joint Industry Project in upstream oil and gas determined that a 50 year old asset that was presumed fit for decommissioning, was safe to continue operating for at least another 20 years.

This matters because one of the most significant barriers to sustaining infrastructure well beyond its intended design life, is the overly conservative estimates made in relation to structural capacity. Consideration for the repurposing of infrastructure has not traditionally been part of the planning process for decommissioning due to the risks associated with the structural integrity of ageing assets, and the limitations of the technology used to clearly assess and mitigate this risk.

The repurposing of infrastructure may be a grey area in terms of research and planning, but Akselos is presenting a clearer path to an operational future for ageing infrastructure.

PRINCIPLES FOR DESIGNING AN ENERGY INFRASTRUCTURE ACTION PLAN

We began this effort in order to understand the state of existing energy infrastructure and its role in a successful energy transition. Existing infrastructure will have a significant impact on shaping the new energy mix and the future and pace of decarbonisation efforts, but in order to keep transition costs low, some parts of infrastructure present opportunities for repurposing. The interviewees fully agreed on the need for a new approach, which uses four principles to guide better action:

1. There is a need to decommission large parts of the existing infrastructure.
2. There will be stranded assets
3. Not all existing infrastructure can be repurposed
4. A new holistic approach is needed – and desired by the market - which is different from the asset-specific safety measures in place in most countries,

Similar to *California's Energy Action Plan* (Figure 7) building a shared vision forges new common ground and enables the industry to move forward along an aligned path. In the Netherlands, in addition to the unified plan, there has been the creation of a new body/organisation, called NexStep (Figure 8) to implement their vision.

The interviewees also agreed that although government should initiate the process, they should leave it to the market to implement the vision in a manner that stimulates healthy competition and business innovation. Both the Californian and Dutch plans create enabling conditions which allow the market to innovate and implement based on a best-fit/least-cost approach.

> **"A coordinated plan is needed. It needs strong guidance from government and regulators, but implementation of those decisions must be market based and grounded in strong economics."**
>
> **RICHARD DOWLING, FARADAY GRID**

> **"Now is a golden opportunity to replace assets over the course of the next 50 - 70 years from now. We need to have a planned approach. The timeframe is very different from the past. The system will change a lot faster than we have ever observed before, and I believe in the next 20-30 years there will be more change than in the last 130 years."**
>
> **NUNO SILVA, EFACEC**

In response, we propose key principles as a starting point for dialogue to create an Energy Infrastructure Action Plan ("EIAP") with shared goals and a flexible framework that can be adapted to the diversity of any region/country.

An EIAP is an instrument that aims to enable a more cost-effective and well-managed energy transition. As the energy mix continues to transition from the scarcity of fossil energy resources to an abundance of clean and renewable energy supply, existing infrastructure will experience decreasing levels of marginal return on investment.

THE KEY PRINCIPLES FOR DESIGNING THE EIAP ARE:

1 Limiting negative impacts on the global economy caused by uncoordinated and untimely decommissioning and stranding of assets.

By planning coordinated and timely actions involving all stakeholders, stranded assets can be minimised and the cost, liability, decommissioning and site restoration of existing infrastructure can be dealt with in a cost-effective manner and within financial capabilities. Decommissioning can also represent a business opportunity facilitating operations, lowering costs and minimising delays.

EARLY ACTION

Time is of the essence. Decommissioning and stranding of assets should be weighed against long-term economic, health, environmental and decarbonisation benefits. It is widely accepted that early action is key to creating the conditions for achieving such benefits. Decommissioning operations take years to be carried out and the more they are delayed, the higher the forecasted decommissioning cost. Costs are affected by energy market fluctuations, new technologies, maintenance costs of the aging infrastructure, and inaccurate forecasts of technical and management costs required to conduct the decommissioning process. Dealing too late with the challenge of decommissioning will result in major drawbacks of companies' performances in the oil and gas sectors. Plans should therefore be defined as soon as possible, aiming to ensure early action towards safe, efficient and effective decommissioning of infrastructure with the focus on optimising costs, adjusting business models and asset portfolios, and reusing and repurposing as much of the existing infrastructure as possible.

Policy-makers could also create mechanisms for early action towards the stranding of carbon-intensive assets. Curtailment of investments in upstream energy and higher carbon prices would be possible ways to drive these mechanisms. Stranding of polluting assets would mitigate climate change and generate benefits in terms of human and environmental welfare which would far outweigh economically the damage caused by the stranding of such assets.

REGULATION, OVERSIGHT AND LIABILITIES

Regulators often develop suites of standards and requirements that outline what must be accomplished in order for assets to be considered decommissioned. What is lacking is a holistic approach that guides the management of assets such that the risk to the environment and public safety is minimised, financial exposure to the public is minimised, and financial resiliency in the sector is optimised. This approach requires an integrated multi-dimensional management system which includes considerations for what decommissioning work needs to occur and when it needs to occur, whether financial guarantees need to be collected and if so how much, whether the standards that have been created are appropriate and promote efficient and effective decommissioning activities, and numerous other factors.

Ideally, international standards clearly defining what decommissioning and site restoration entails should be put in place with the aim of helping firms and governments plan, implement and oversee these processes successfully. Decommissioning oversight should be consistent as to ensure that standards are met. The extent of decommissioning should be adapted to the region in question and it should be a function of the native ecosystem health in such a way as to remove or leave infrastructure on-site to support full natural recovery. The extent of decommissioning will also significantly affect operations costs. The standards should define the possibility of recycling and re-purposing parts of the infrastructure and should also be set in a way that would make them technically and financially feasible for all operators. Compatibility with new infrastructure development plans should also be considered. For these reasons they should be the result of discussion between different fields of expertise, from engineering to economics to ecology.

Liabilities should be clearly defined so that no dispute would incur at the time of decommissioning and site restoration. Owners and operators in the industry should be accountable to an appropriate level of liability and should carry all the technical and economic responsibilities, including site restoration to regulated standards, while governments should try to minimise any possible additional burden on the taxpayers which, as it stands, is still very uncertain. Defined liabilities also provide companies financial responsibilities to plan for. Both governments and the market should avoid the possibility of a large number of companies unable to comply with their liabilities as the economic strain on the entire system could potentially be disastrous.

JUST TRANSITION

Besides governments, investors and companies, the stranding of assets can especially have an adverse effect on the livelihood of workers whose employment is at risk. This group could therefore create friction against decarbonisation efforts in order to protect their welfare. This can be avoided through a "just transition", if both governments and companies plan in advance and put into place protections for workers affected by the closure of carbon-intensive assets in the energy sector.

2 Magnifying the benefits of supporting clean energy sources during the transition through repurposing and asset life-cycle extension.

The Transition to renewable energies is unescapably linked to the infrastructure transition upon which it will be realised. Existing infrastructure can serve a duplicitous function: satisfy energy demand and base-load capacity as renewables penetration increases; being utilised as the backbone upon which new energy sources can be supplied and new technologies can be integrated. Attention should be devoted to anticipating the transition to new energy ecosystems and new business models and identifying the role the existing infrastructure can serve within them.

While postponing decommissioning has in most cases adverse effects, the premature decommissioning of assets that could be repurposed or whose life-cycle could be extended should also be avoided. Technological developments that could extend asset lifetime or open repurposing options. The industry could find opportunities in upgrading to more carbon-efficient processes through the development and adoption of technologies such as CCS which could extend asset lifetime, and increase energy efficiency to offset decarbonisation costs, while also allowing the conversion of gas transmission and distribution grid to hydrogen. Furthermore, the repurposing of assets such as the distribution gas grid to support hydrogen would have the effect of minimising the costs and disruptions associated with the difficult challenge of extensive electrification of sectors such as heat. When delaying decommissioning with the aim of repurposing it when mature and cost effective technology allows it, one aspect to consider is that of maintenance. The costs of maintaining inactive, non-profitable infrastructure would unlikely be burdened by the industry. Therefore, the responsibility of maintenance should be addressed through viable policies which could require financial intervention by governments.

3 Contributing to decarbonisation efforts to benefit the environment, the economy and society.

Profit oriented short-termism can be corrected by maximising dialogue between markets and governments for the definition of policies aimed at optimising and coordinating asset life-cycle planning in view of climate targets and the new energy system. The public can have a positive role in pushing the prioritisation of environmental and health benefits brought about by strategic stranding of polluting assets within a well-paced decarbonisation process. Closed life-cycle loops can orient the design of new and the recycling of old infrastructure.

The plan should begin with developing a typology of assets and where on the value chain such assets are located, i.e. upstream, intermediate (storage, conversion), distribution, end-use. This typology of assets is significant, because it allows, at the country or even at the asset owner level, the ability to have in one place a map of all infrastructure that may be re-used, repurposed, decommissioned, or is at risk of stranding. The infrastructure could be more easily ranked in terms of risk, potential for repurposing, etc., so that prioritisation of action could be more easily defined. Decommissioning procedures could be more easily tailored to the environment that the infrastructure is operating in. Decommissioning chain reactions could be better forecasted, as in the case of the decommissioning individual assets, such as pipelines, which are part of larger shared energy infrastructure systems, and would lead to accelerated decommissioning of other infrastructure within it.

Lastly, a coordinated plan leads to ensuring energy security within a gradual transition to the new energy mix. Coordinated plans for decommissioning taking place under new energy policies and regulations should aim at avoiding disruptions on both the supply and demand side. The existing infrastructure should be decommissioned as a function of the evolving energy mix, with a gradual phasing-out while clean energy sources are increasingly phased-in.

4 Encouraging Greater Disclosure

Transparency is essential to inform all stakeholders about stranded asset risks as well as directing decommissioning strategy to face financial risks. Currently, there is not nearly enough information about the value of these assets that have supported fossil fuel production, and transportation nor the financial health of many smaller firms in the energy sector who are operating those assets. Several studies have estimated the extent of stranded fossil fuel assets in an effort to predict and highlight this issue. We know that by 2030, for example, there could be close to 400 natural gas and coal power plants left stranded in Europe [28]. Systematic identification of assets at high risk of stranding due to decarbonisation is still an area which requires significant work and what is missing is greater disclosure of actual figures so that regulators can have a better understanding of the potential risks, investors are better aware and can make more informed decisions and consumers are aware of the enormous impact of these assets which they've paid for by and large through their energy bills. These companies could possibly go bankrupt (as in the telling case of the Trident Exploration Corporation with zero recovery expected for shareholders and creditors [29]) and that could have a strong negative impact on the financial markets, and on individuals, such as pensioners, who are relying on these companies financial viability, and on the public who may be burdened with the decommissioning costs.

5 Promoting Cross-Sector Coordination

Importantly, the key focus of this brief is not just the assessment of assets from the decommissioning perspective, but also the analysis of how re-use of infrastructure could contribute to the energy transition and how the existing infrastructure can serve the new energy system storage and transportation needs. Decommissioning and repurposing of existing assets should be planned for leveraging cross-sector synergies to ensure the most cost-effective and sustainable management of the infrastructure in order to maximise repurposing and development of resources, and to minimise the risk of stranded infrastructure and failure of the integrity of the infrastructure.

This requires strong and comprehensive cross-sector coordination. There is a need to develop a coherent timeline for the phasing out of the existing assets from traditional use while ensuring that there is enough generation capacity to meet projected energy demand. Additionally, a lack of planning will also increase the length of time that infrastructure remains uneconomic, and not contributing to energy generation, while it is being repurposed.

The inter-dependencies between correlated sectors should be better understood. For instance, decisions on decommissioning in onshore and offshore assets have an impact on each other, while stranded assets in one sector can potentially trigger cascades affecting several other sectors across the entire economy.

Finally, technological advancement has several implications. Within the removal operations field, technology can contribute to lower decommissioning costs, both through engineering and digital solutions. Within the clean energy sector it can lead to the acceleration of decommissioning timelines.

While we have offered a set of principles to design an action plan to properly plan for the transition of existing infrastructure these two action plans offer innovative models for success. NexStep, a joint venture of EBN and the Dutch oil and gas industry and California's Energy Action Plan both offer a living document that has shaped their respective visions and ensuing actions.

Figure 7: California's Energy Action Plan

California's Energy Action Plan

In 2003 California adopted a first of its kind Energy Action Plan ("EAP"). The EAP was in response to the energy crisis of 2000/2001 when the sixth largest economy in the world experienced electricity supply shortages as well as unprecedent natural gas prices leading to rolling blackouts costing the California economy billions of dollars. This plan was a set of shared goals and proposed specific actions to ensure that adequate, reliable, and reasonably priced electrical power and natural gas supplies were achieved and provided through policies, strategies, and actions that are cost-effective and environmentally sound.

The EAP proposed six sets of actions:

1. Optimise energy conservation and resource efficiency.
2. Accelerate the state's goal for renewable generation.
3. Ensure reliable, affordable electricity generation.
4. Upgrade and expand the electricity transmission and distribution infrastructure.
5. Promote customer and utility owned distributed generation.
6. Ensure reliable supply of reasonably priced natural gas.

This plan and ensuing loading order provided California with a roadmap of the actions necessary to ensure that the state met its energy needs going forward while controlling costs, maintaining leadership on energy efficiency, and renewable energy policies.

The loading order identified energy efficiency and demand response as the state's preferred means of meeting energy demand. After cost-effective efficiency and demand response, the state should rely on renewable sources of power and distributed generation, including combined heat and power applications. To the extent efficiency, demand response, renewable resources, and distributed generation are unable to satisfy increasing energy and capacity needs, clean and efficient fossil-fired generation is supported. Concurrently, the bulk electricity transmission grid and distribution facility infrastructure will be improved to support growing demand centres and the interconnection of new generation, both on the utility and customer side of the meter.

Although the EAP can be perceived as a logical step its significance lies in laying a solid foundation for the whole industry to use as either a vision statement or a policy platform. For California it provided the industry with a starting point and the fact that it was adopted by its regulators it also provided the market with an overall vision that gave needed guidance to the market to innovate and implement a clean and cost-effective energy industry. Today, California is a leader in clean energy generation, consumption and continued and aggressive policies for deep decarbonisation. One of the key success factors for California is the EAP that set the industry on a common path forward.

Figure 8: NextStep – A Model Action Plan

NEXSTEP

An example of best practice in introducing and implementing an industry-wide action plan to prioritise and address energy infrastructure decommissioning in a comprehensive and coordinated manner.

In the late 2016 Energie Beheer Nederland B.V, an entity wholly owned by the Dutch government and mandated to execute parts of the energy policy on behalf of the Ministry of Economic Affairs and Climate Policy released the **Netherlands master plan for decommissioning and reuse** – a result of the coordinated effort of the government, operators, suppliers, and other concerned stakeholders. The plan's key mission is "to ensure a safe, efficient and effective decommissioning of Dutch offshore infrastructure" with the focus on optimising costs while reusing and repurposing existing infrastructure where possible.

The document sets out a long-term vision for an integrated approach to decommissioning as well as a 20-year specific plan to optimise the decommissioning of approximately 150 offshore platforms and 1,800 active wells.

Delivering on the first priority of the Master plan on the October 10th, 2017 the Netherlands launchedNexStep– the world's first national platform mandated to encourage cooperation in the area of re-use and decommissioning of oil and gas infrastructure.

NexStep's mission is to serve as an inclusive and collaborative umbrella that coordinates, facilitates, and seeks dialogue on the re-use and decommissioning agenda for oil and gas infrastructure in the Netherlands. Although one of the goals of the organisation is to reduce the costs of safe and environmentally friendly decommissioning in the Netherlands by 30%, this is neither regulatory nor a financial institution. According to the legislation the financing and the removal of installations are the responsibility of the operators. NexStep's role is to connect diversified actors with different objectives, interests and agendas and encourage them to coordinate and collaborate with each other to achieve the most efficient and safe way to re-use or remove superfluous infrastructure.

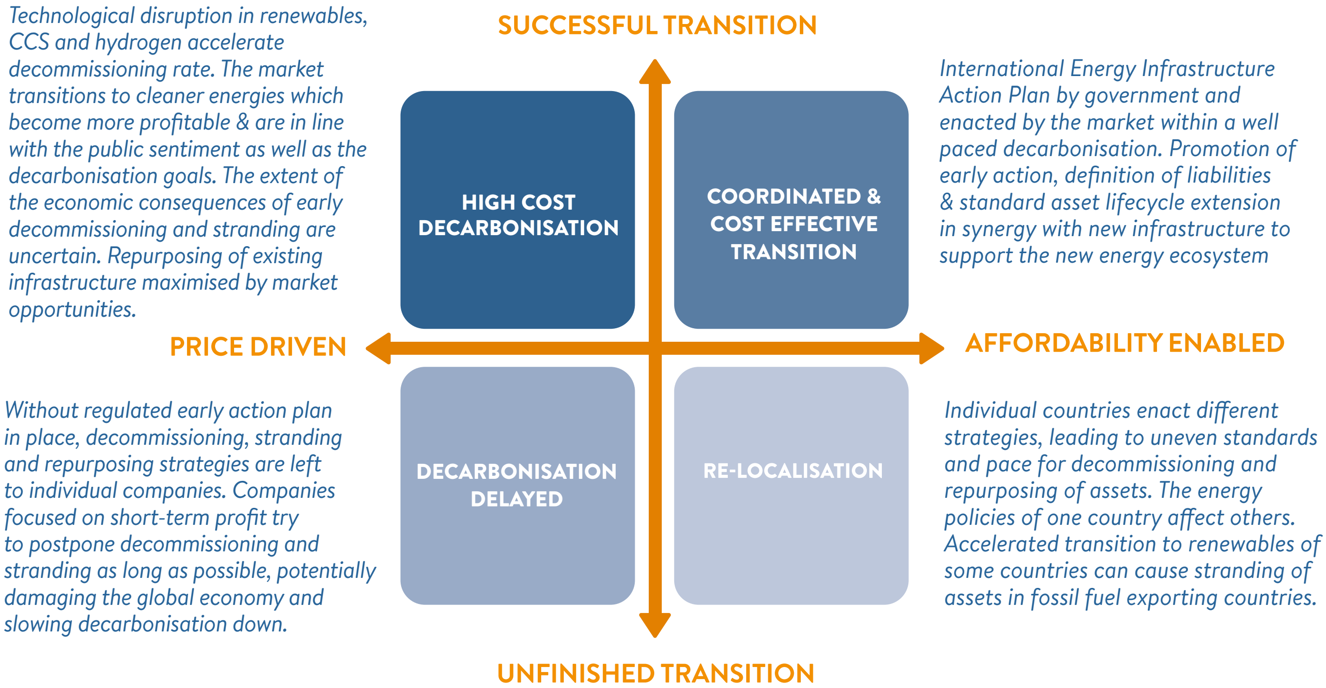
Tasked to identify the oil and gas infrastructure that will be taken out of use in the next ten years, in 2018 NexStep presented the first issue of the annual "Re-use and decommissioning report" analysing decommissioning expected and required in 2018-2027. Importantly the key focus of the report is not just the assessment of the assets from the decommissioning perspective, but also the analysis of how re-use of infrastructure could contribute to the energy transition and how the existing infrastructure can serve the new energy system storage and transportation needs.

FUTURE OUTLOOK

When considered through the lens of a whole-system transition, existing energy infrastructure has two connotations: **1)** it can represent a resource for the transition. In this context, there is no opposition between old and new infrastructure but, rather, a synergistic conversation between the two. Part of the existing infrastructure can facilitate the transition by supporting the energy mix assuring energy security and by providing assets that can be used by clean energy sources, **2)** part of the existing infrastructure will have no purpose in the new energy ecosystem, and this represents a hindrance to the transition if not dealt with in time, by slowing down the adoption of clean energy sources as well as unnecessarily burdening the economy by delaying its decommissioning or increasing the extent of stranding.

The transition to a new energy future cannot be predicted but it can be better prepared for using scenarios. Four scenarios are provided, each reflecting a plausible but different infrastructure transition pathway. Combined with a long-term shared vision it is possible to catalyse and guide an integrated approach to decommissioning, repurposing, life-cycle extension while minimising the risk of stranded assets.

Figure 9: Future Outlook- Infrastructure's impact on decarbonisation



NEXT STEPS

While the focus of this brief has been on existing energy infrastructure, the Energy Infrastructure Action Plan is intended to be a living and flexible framework. We chose not to include new energy infrastructures at this point to ensure existing infrastructure was not an afterthought. Due to its scope, breadth and importance, however, we plan to focus on new infrastructure in a separate brief, with the aim of addressing the following questions and further enriching the EIAP framework.

1. What will be the impact of new infrastructure on the pace and cost of decarbonisation?
2. What will the infrastructure look like within the new energy ecosystem and how will it serve it and the people of the planet?

3. How can the existing infrastructure be integrated with the development and deployment of new infrastructure to promote a virtuous transition?
4. Is the existing energy infrastructure system too constrained and can its design be successfully reassessed in a rapid, secure, just and sustainable way?
5. Can new technologies, such as the rise of digitalisation, automation and AI, help the infrastructure transition and how?

As an example of new infrastructure blending with the existing electricity system to allow more decentralisation and more digitalisation we offer a preview to our next brief focusing on new technologies by introducing here one such new technology that has the potential to transform the electricity grid.

Figure 10: An Example of New Infrastructure - Faraday Grid

Faraday Grid, the UK-based global energy technology company, has developed technology to maximise the capacity of existing electricity grids to integrate variable renewable energy and distributed energy resources in a secure and affordable manner, while simultaneously increasing system stability.

The Faraday Exchanger is a power flow control device that dynamically and autonomously maintains voltage and frequency, removes harmonics and optimises power factor. This device is agnostic to the type of generation and supply and is complementary to both existing distribution networks and other technologies.

The network effect of multiple Faraday Exchangers creates an autonomous, responsive, electrical meta-network, able to support frequency response and inertia to maintain grid stability. In addition to increasing capacity for renewable and distributed energy, this could make the existing system more resilient, flexible and efficient.

Technologies like the Faraday Exchanger can transform legacy infrastructure into a fit-for-purpose, robust system that can underpin the ongoing energy transition.

In addition to looking at new infrastructure and new technologies we plan to organise regional workshops around the globe to further the dialogue around an action plan for existing energy infrastructure. Regional workshops, forums and roundtables are an important starting point to discuss the importance of decommissioning and stranded assets and their impact on the local economy and the opportunities of transitioning new infrastructure supporting the new energy mix.

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