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DECARBONIZATION PATHWAYS FOR OIL AND GAS

CONTENTS

INTRODUCTION

The contraction in oil demand due to the spread of COVID-2019 and dissolution of the OPEC+ agreement in March have combined to generate shockwaves through the energy and financial markets. As governments all over the world grapple with one of the most severe economic crisis since the Global Financial Crisis and as the oil and gas industry is focusing on how to survive yet another extreme price cycle, some are of the view that climate change issues and decarbonization efforts will reduce in importance and may even fall off the agenda of some companies. However, energy companies have a long-term horizon, their investments extend for multiple decades and the projects planned and delivered today will go through many cycles. Over these cycles, energy companies should not be distracted from the structural trends shaping the industry. The issue of transition and decarbonization will remain dominant, driven by environmental concerns, changes in public perceptions, investors' attitudes, energy and climate policy, and the development of new technologies. In fact, one could argue that the current instability witnessed in oil markets and its underlying causes may render the oil and gas sector less attractive to investors and reinforce calls for an even faster transition from hydrocarbons.

The energy transition is a complex phenomenon and an inherently risky process, so its speed and trajectory are associated with high uncertainty. This is especially true when it comes to the core of traditional energies – oil and gas. The oil and gas industry is considered the biggest part of the climate problem, as fossil fuels are responsible for the main share of greenhouse gas (GHG) emissions – so oil and gas companies are already facing growing political, societal, and financial market pressures. At the same time, it could also become a part of the solution if the world finds pathways to accelerate decarbonization of oil and gas using new technologies and business models introducing new regulations and policies. To meet energy demand, which is projected to continue to increase for the next few decades, making the best of the existing energy supply chain through decarbonization seems to be the most realistic and cost-effective option for the mid-term.

This issue of the *Forum* is focused on the potential for transformations in the oil and gas industry during the energy transition and its dramatic decarbonization. It opens with an article by *Jorge Blazquez, Spencer Dale, and Paul Jefferiss*, who give a detailed argumentation that **carbon prices** can, and should, play a central role in driving the application of these technologies and alternative energy sources, providing incentives to everyone – energy producers, consumers, investors, and financial markets – to shift towards low-carbon technologies and activities. This is a critical regulatory precondition for fast and massive decarbonization. The article proposes five principles to help guide future carbon pricing policies. The authors convincingly argue that carbon pricing is the most efficient policy tool for achieving the decisive shift in carbon emissions needed for the world to have a chance of hitting the Paris climate goals. Moreover, the revenues raised by carbon pricing can be used to help support a fair or just energy transition and, in so doing, help to increase the political and social acceptability of carbon pricing.

This fundamental topic of **justice in the energy transition** is continued by *Raphael Heffron*, who shows that there is now an acceleration of justice in the energy sector. He gives 10 key reasons why conditions have been created that are accelerating the concept of justice in the energy transition: new macroeconomic and regulatory trends, certain legal actions and supranational agreements (Paris Agreement, UN Sustainable Development Goals), penetration of personal technology, and the role of imagery. The energy industry can no longer afford to focus solely on profits but has to consider how new energy projects will result in just outcomes, in which considerations of social and environmental impacts are of vital importance alongside meeting new standards of commercial practice. Justice in the energy transition is set to become the key influencer in government and business strategy and behaviour. According to the author, we are on the verge of a just transition to a low-carbon economy.

Jim Herbertson looks at possible **pathways to a low-emissions future**, most of which share three common elements: improving efficiency and saving energy (the most cost-effective method of reducing GHG emissions); reducing emissions from power generation; and deploying alternative low-emission options in end-use sectors. In the power sector in the near term, one of the most cost-effective and impactful steps is to switch from coal to natural gas. Longer term, the deployment of gas and biomass-based power generation with carbon capture and storage (CCS) would enable near-zero- or negative-emissions electricity. For the end-use sectors, alternatives include hydrogen, biofuels, industrial CCS, and bioenergy with CCS. CCS will likely be key for a transformation of the energy system; without large-scale commercial deployment of this technology, realizing a low-emissions pathway would be much more difficult and costly. The oil and gas industry can be an essential partner in this transformation of the energy system. The lowest-hanging fruit is reducing GHG emissions from the industry's own operations with a focus on energy efficiency and technological innovations in finding and producing oil and gas, which can not only reduce emissions but also produce energy savings. The industry has also been taking action to reduce methane emissions and gas flaring – both independently and in collaborative initiatives and voluntary industry groups. Another opportunity is helping consumers to reduce their emissions, including by replacement of higher GHG-emitting fuels with natural gas, improvement of vehicle engine design in ways that increase efficiency while lowering emissions, use of LNG for heavy-duty vehicles and ships, and use of advanced biofuels and hydrogen as energy carriers. These approaches have become mainstream in the energy transition discussion.

In the next article, *Ahmad Al Khowaiter* and *Yasser Mufti* present an alternative pathway enabled by the oil and gas industry toward energy transition. It is based on the concept of a **circular carbon economy** – a framework in which emissions of carbon from all sectors are addressed through the 4Rs: reducing (prioritizing resources with low carbon intensity and low operational GHG emissions, increasing transport efficiency), reusing (mobile carbon capture technology for transportation that captures and stores carbon onboard the vehicle using a redesigned exhaust system, and CO_2-enhanced oil recovery [CO_2-EOR], which uses injected CO_2 to extract oil that is otherwise not recoverable), recycling (the use of hydrogen-based synthetic fuels to recycle CO_2), and removing (carbon capture, utilization, and storage [CCUS]). The authors explore these different technological options available for oil and gas in order to reduce not only scope-1 and scope-2 but also scope-3 emissions.

This topic of the **pathways towards decarbonization** is further developed by *Rob West*, who argues that meeting growing global energy needs while decarbonizing global energy is achievable. This is not a devastating scenario for the oil and gas industry, as some claim. However, in order to achieve decarbonization, these remaining fossil fuels must be made as efficient and low-carbon as possible and their CO_2 must be offset through next-generation combustion technologies, CCS, CCUS, and reforestation. There are several major investment tracks in this scenario: reallocating portfolios into renewable energy, further extending the gas lead with new technologies that decarbonize gas-fired power generation, improving upstream CO_2 intensity (reduction of flaring and methane emissions, digital optimizations, use of renewables to power oil and gas upstream, hybrid industrial engines, and improved logistics), improvement of the downstream oil industry CO_2 profile, and catalyst development. Most challenging today is finding investors to back energy technologies; this is the most important component of achieving an energy transition. According to the author, if next-generation energy technologies are de-risked, the industry can genuinely decarbonize.

Colin Ward focuses on one of the key technologies for decarbonization: **CO_2-EOR**. This is an option that both reduces the carbon intensity of oil and provides CO_2 storage. While the technology of CO_2-EOR is well established, it has not seen much use outside of North America. Specific conditions concerning the geology, availability of CO_2, economics, and local policy have meant that interest was minimal compared to easier and cheaper options. As these factors, and other concerns such as sustainability of supply and carbon impacts, evolve, CO_2-EOR is likely to become a first-line option when transitioning our energy system. Large-scale producers with low costs (United Arab Emirates, Saudi Arabia) are the most likely first adopters, as their profit margins allow for investment in CCS projects, but other locations with high CO_2 taxes (Norway, Europe), or the need for secure supplies (China) will also play a part in wider growth. An immediate technical opportunity exists to store over 40 gigatonnes (Gt) of CO_2 with existing source-sink pairs, and 6 Gt could be implemented economically at an oil price as low as $50. Under less strict criteria, where projects are not limited by local supply of CO2, the full storage potential jumps to over 200 Gt.

Another extremely promising technological track for decarbonization is **hydrogen**, and *Nathan Meehan* provides a comprehensive overview of the main technologies for production, transportation, distribution, and consumption of hydrogen today and in the future, also illustrating its economics and costs. Hydrogen will continue to require government subsidies for some time, and numerous technical challenges remain, but in the longer term it holds the potential to provide a new market for natural gas that (coupled with CCUS) will lower the carbon intensity of the oil and gas industry.

Martin Lambert's analysis states that the natural gas industry is facing an existential threat and that if gas will be part of the energy transition, it cannot be unabated fossil-derived natural gas, but will have to be some form of **decarbonized gas**. He compares decarbonized gas alternatives (renewable methane, in the form of biogas and biomethane, and both 'blue' and 'green' renewable hydrogen), the pathways to produce them, and the advantages and challenges of each. There is clearly a case for gaseous fuels to play some role in the decarbonizing energy system. Less clear is the scale and extent of that role, particularly on account of the many uncertainties regarding technology choices, scale-up, costs, and government policy and regulations. To safeguard its future role, it is important for the gas industry to build a strategic direction and business cases to make the required investments to reduce those uncertainties and to demonstrate at scale the role which gaseous fuels can play in a decarbonized system.

Darcy Spady and Jackson Hegland focus on another challenge for the sustainability and acceptability of the oil and gas industry, **methane emissions**. Methane is one of the most powerful GHGs, estimated to be a 25 times greater threat to global warming over a 100-year period than carbon dioxide. At the same time there is a clear business rationale for producers: keeping methane in the system and monetizing it at the sales meter makes economic sense. But measuring and mitigating methane emissions require joint effort by and commitment from government, regulators, industry, and environmental NGOs.

This idea of joint effort and joint responsibility is further developed by *Johana Dunlop*, who leads Gaia, an **oil and gas industry sustainability initiative**. According to the author, the industry needs time, determination, and collaboration to create the technologies that will produce the solutions that can restore trust in the industry.

The world is on an unsustainable path and needs a decisive shift to a low-carbon pathway consistent with meeting the Paris climate goals. The current crisis should not distract the energy industry and its leaders from continuing to play, and accelerate, their role in achieving this goal and it could indeed present a real opportunity for the oil and gas industry to re-establish itself as a part of the decarbonized future. This *Forum* presents and analyses several pieces of this puzzle, exploring ways to achieve a sustainable energy future where oil and gas can play a key role as flexible and versatile energy carriers.

THE ROLE OF CARBON PRICES IN THE ENERGY TRANSITION

Jorge Blazquez, Spencer Dale, and Paul Jefferiss

The world is on an unsustainable path. Over the 10 years to 2018, annual carbon emissions from energy use grew by around 4 gigatonnes, roughly equivalent to the entire carbon emissions of Europe. Data from the US National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) show that the past decade was the hottest on record.[1] The world needs a decisive shift if it is to move to a low-carbon pathway consistent with meeting the Paris climate goals.

The good news is that many of the technologies necessary to achieve such a shift – renewable energies led by wind and solar power, biofuels, and carbon capture, use, and storage – exist today. These energy sources and technologies will improve over time, and their costs will continue to fall as their deployment increases, but the basic elements necessary for a rapid transition to a low- or zero-carbon energy system exist today. The challenge is to harness government and societal willingness to apply them at the necessary pace and scale.

Carbon prices can – and should – play a central role in driving the application of these technologies and alternative energy sources. They provide incentives to everyone – energy producers, consumers, investors, and financial markets – to shift towards low-carbon technologies and activities. This article proposes five principles to help guide future carbon pricing policies.

Principle 1: carbon prices should play a central role in reducing carbon emissions.

Economics is clear that the best policy instrument to deal with the negative externalities associated with carbon emissions is a carbon price.[2] Economists advocate for a so-called Pigouvian tax, which equates the price of carbon with the social cost of its negative externalities. The primary aim of such a tax is to change behaviour rather than to raise revenue (although the resulting revenue can be useful; see Principle 4).

There are two strong arguments in favour of carbon prices.[3] First, a price on carbon (such as a carbon tax or from a cap-and-trade system) directly penalizes the negative externalities according to the 'polluter pays' principle, ensuring that energy producers and consumers internalize the costs of carbon-intensive fuels and activities, encouraging the use of alternative lower-carbon energy sources and activities. Second, by ensuring a level playing field for all emitters – and so equating the marginal abatement cost of all sources of emission – their use can help minimize the cost of the energy transition. This second advantage implies that a carbon price should be applied across as wide a range of sectors and regions as possible.

These advantages are not abstract economic ideas; they are central to achieving the widespread support necessary for a speedy and successful transition. Inefficient policy design, which raises overall costs or leads to different prices being paid by different groups or sectors, risks undermining that approval. Efficiency and fairness in policy design will be key to ensuring widespread support and legitimacy for the energy transition.

[1] See *Annual Global Analysis for 2019* (National Aeronautics and Space Administration and National Oceanic and Atmospheric Administration, 2020), https://www.ncdc.noaa.gov/sotc/briefings/20200115.pdf.
[2] See *Economists' Statement on Carbon Dividends* (Climate Leadership Council, 2019), https://clcouncil.org/economists-statement/.
[3] Andrea Baranzini, Jeroen CJM Van den Bergh, Stefano Carattini, Richard B. Howarth, Emilio Padilla, and Jordi Roca, 'Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations', *WIREs Climate Change* 8, no. 4 (2017), e462, https://onlinelibrary.wiley.com/doi/epdf/10.1002/wcc.462.

Principle 2: carbon prices are necessary but not sufficient.

Although economics is clear that carbon pricing should play a central role in reducing carbon emissions, it is unlikely to be sufficient, for a number of reasons. First, the sheer scale of the system-wide changes needed to support a low- or zero-carbon energy system may require other mechanisms of coordination and collective action, in addition to price signals.[4] Second, in the short run, introducing a carbon price at a high initial level, or raising the price too quickly, could lead to a premature scrapping of productive assets, which would raise the cost of the energy transition. As such, carbon prices might need to be reinforced in the near term by other measures which affect forward-looking decisions without penalizing past investments – such as policies to support new investment in hydrogen or carbon capture, use, and storage. Third, there is likely to be a need for public support for research and development in low-carbon energies and technologies until they achieve scale.

In practice, there may also be other factors, linked for example to market design or information costs, which limit the effectiveness of the price signals and incentives provided by carbon pricing. This may be particularly important in some emerging economies where market-based mechanisms are less well developed.

These factors mean that there are often likely to be advantages in augmenting a carbon pricing framework with other targeted measures or policies. The key design principle is that these other policy measures should complement the carbon pricing framework, targeting known weaknesses and avoiding policy overlaps.

Principle 3: as carbon prices rise, carbon border adjustments are likely to be an essential part of a carbon pricing policy.

In an ideal world, climate policies would be set and coordinated at a global level, reflecting the global nature of climate change. There are many efforts to achieve better global coordination, but in practice such consensus and agreement seem unlikely in the foreseeable future. Moreover, even in a world of greater coordination, differences in levels of economic development may mean that developed economies choose to decarbonize more quickly than some emerging economies.

The absence of a single global carbon price raises two related problems for the use of carbon prices at a country or regional level. First, the international competitiveness of domestic industry in that region will tend to be reduced, which in turn may undermine political support and legitimacy for a progressive carbon pricing policy.[5] Second, from a climate perspective, the so-called carbon leakage triggered by differential carbon prices – in which carbon-intensive activities migrate to countries or regions with less demanding carbon prices and regulations – reduces the effectiveness of any unilateral policy. These problems intensify as carbon prices increase and the differential between carbon prices in different countries and regions widens.

If carbon prices are going to be used as a central tool for reducing carbon emissions at a sub-global level, and free trade is to be protected, the only solution to these twin problems of competitiveness and carbon leakage is some form of carbon border adjustment (CBA) which adjusts the costs of imports and exports in a way that offsets differences in carbon prices. CBAs can be designed and implemented in many different ways, but their essential aim is to promote a level playing field, in terms of embodied carbon, between internationally traded goods and services. In that sense, CBAs should be seen as a way of avoiding trade distortions and increasing the effectiveness of domestic carbon price policies, rather than any sort of protectionist measure.[6]

The precise design of CBAs can give rise to complex trade issues and, as such, can be controversial. Moreover, unless designed carefully, CBAs can impose significant additional costs which in themselves can act as an impediment to trade. Avoiding these pitfalls requires careful policy design. But ultimately, some form of CBA is likely to be essential if carbon prices are to play a central role in reducing carbon emissions at a country or regional level.

Principle 4: revenues from carbon pricing can be used to support a just transition.

As discussed earlier, the primary aim of a carbon price or tax is to change behaviour rather than to raise revenue. Even so, the revenues raised by carbon pricing can be used to help support a fair or just energy transition and, in so doing, help to increase the political and social acceptability of carbon pricing.

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[4] Michael Grubb, *Planetary Economics: Energy, Climate Change and the Three Domains of Sustainable Development* (Routledge, 2014).

[5] Andrea Baranzini, Jeroen CJM Van den Bergh, Stefano Carattini, Richard B. Howarth, Emilio Padilla, and Jordi Roca, 'Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations', *WIREs Climate Change* 8, no. 4 (2017): e462, https://onlinelibrary.wiley.com/doi/epdf/10.1002/wcc.462.

[6] *Report of the High-Level Commission on Carbon Prices* (Carbon Pricing Leadership Coalition, 2017), https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf.

There are potentially several dimensions to a just transition. This concept was first raised in the context of people employed in industries particularly affected by the energy transition, such as coal-mining communities. One aspect of a just transition would be to use some of the revenues raised by carbon pricing to help retrain and reskill displaced workers or otherwise support affected communities.

Another dimension of fairness is the recognition that carbon pricing can lead to regressive distributional effects if low-income households spend a greater proportion of their budget on carbon-intensive products, especially energy. This problem can be addressed by returning at least some of the revenues to households in the form of a lump sum or progressive payment. For example, the Climate Leadership Council in the United States proposes that all carbon tax revenues are returned to households on an equal basis.[7]

There is also an international dimension to a just energy transition. What would make the transition just from an international perspective is not obvious.[8] Many developing economies are more exposed to carbon-intensive energies and industries than developed economies and may also lack the social and economic institutions necessary for a successful transition. As a result, they may be disproportionately affected by the transition.[9] In addition, many developed economies historically have emitted proportionally more carbon than developing countries. In a just transition, developed countries might recognize these issues, for example, by reinvesting the revenues raised from CBAs to help finance the transition in emerging economies.

Principle 5: expectations matter.

Energy is a highly capital-intensive sector. Power plants can operate for 30 or 40 years, hydropower and nuclear plants even longer. Similarly, passenger cars persist in the global car parc for as long as 15 years. As such, the effectiveness of carbon pricing can be greatly enhanced if energy producers and consumers have a clear sense of the likely future path of carbon prices. In so doing, a shift in carbon prices today can impact both the current fuel mix (through current consumption decisions) and, potentially more importantly, the future fuel mix (through current investment decisions).

This expectations channel does not require complete certainty on the future level of carbon prices. Indeed, there are good reasons why carbon prices might depend on future developments. But it does require the commitment of public authorities to a clear carbon target and to using carbon prices as a central way of achieving that target. In that context, there is a parallel with independent central banks who commit to using monetary policy to achieve an inflation target, even though the precise path of interest rates depends on future economic developments.

Conclusion

The world is on an unsustainable path, with carbon emissions continuing to increase. Carbon pricing is the most efficient policy tool for achieving the decisive shift in carbon emissions needed for the world to have a chance of achieving the Paris climate goals. The World Bank estimates there are over 50 carbon pricing schemes currently being implemented or scheduled for implementation, covering around 20 per cent of global greenhouse gas emissions.[10] The number of these initiatives and the level of carbon prices will likely have to increase significantly over the next decade to achieve the Paris goals. The five principles outlined here can help to guide that policy process.

JUSTICE IN THE ENERGY TRANSITION

Raphael J. Heffron

The research and practice literature clearly shows that the energy transition is under way. What is not clear is how justice will be achieved in this transition. Until relatively recently (perhaps only four to five years ago), there was no real focus on this issue. The energy sector itself has always sought some level of justice, but it is one sector that has lacked justice and is considered one of the most corrupt economic sectors in many countries.

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[7] *Economists' Statement on Carbon Dividends* (Climate Leadership Council, 2019), https://clcouncil.org/economists-statement/.
[8] See, for example, Thomas Hirsch, Manuela Mattheß, and Joachim Fünfgelt (eds.), *Guiding Principles & Lessons Learnt for a Just Energy Transition in the Global South* (Friedrich-Ebert-Stiftung, Global Policy and Development, 2017), http://library.fes.de/pdf-files/iez/13955.pdf.
[9] Florian Ranft, Sabrina Schulz, Johannes Uhl, Philipp Wendel, and Fiona D. Wollensack, *Foreign Policy and the Just Transition: Dimensions, Challenges, Opportunities* (policy brief, Das Progressive Zentrum, 2019), https://www.progressives-zentrum.org/wp-content/uploads/2019/09/Policy-Brief_Foreign-Policy-Just-Transition_final.pdf.
[10] *Carbon Pricing Dashboard* (World Bank, 2020), https://carbonpricingdashboard.worldbank.org/.

Now the need for justice in the energy transition is slowly beginning to receive more attention. This article considers some fundamental reasons why we need justice and then examines the reasons for the increase in attention to justice in the energy sector.

The need for justice in the energy transition

Generally the search for justice is driven by a need to rebalance a relationship that has become unbalanced. That is why governments, companies, and individuals enter into contracts. It is also why one goes to court, to ensure compensation or behavioural change as a result of an imbalanced relationship. In this context, what is in essence at stake is that an individual's or group's rights are being infringed. If you can prove that, you can achieve change.

At its simplest, justice in the energy sector means the application of human rights across the energy life-cycle (i.e. from extraction to production, operation, supply, consumption, and waste management).[11] When these rights are infringed, there is a call for justice. Such a right may already be established in legislation, or society may be of the view that it should be and that public policy needs to change (and following that, new legislation will reinforce that policy). An individual or group may then test whether the change has happened or will happen in the courts, such as is happening in the energy and climate change cases discussed later in this article.

Five forms of justice can be applied to the energy sector:[12]

- *Distributive justice* focuses on burdens, risks, costs, and benefits.
- *Procedural justice* assesses government and public decision-making and processes.
- *Restorative justice* aims to rectify or ameliorate existing harms or injustices.
- *Recognition justice* aims to ensure that all social groups participate in decision making.
- *Cosmopolitan justice* focuses on the impact of actions taken in one country on people in other countries.

Increasing attention to justice in the energy sector

In the past, society has unfortunately not realized all these forms of justice, but it is beginning to now, for several reasons. Public policy is shifting. It could be called a perfect storm of energy justice whereby the opportunity for justice to permeate the energy sector has arisen. The change began with the financial crisis of 2007–2009. As Plato stated, 'Accidents and calamities … are the universal legislators of the world.'[13]

As a result of that crisis, society began to reform, particularly in the financial sector, which is so vital to the energy sector, for which availability of finance is absolutely crucial and which needs to deliver more energy than ever before to ensure more energy access and to replace old energy infrastructure (not to mention the need for more low-carbon energy to address climate change). After a crisis, society's behaviour becomes risk averse and, added to the other changes that have occurred, this has resulted in more justice within the transition.

There are 10 key reasons for the growing interest in justice in the energy transition. The five forms of justice mentioned earlier are at the root of this trend.

Economics

After the crisis, a revision of economic thinking occurred. The education of economists across many countries has changed, and universities that once relied heavily on neoclassical economics are now accommodating more and broader economic perspectives. There has been an increased focus on inequality, for example in Thomas Piketty's *Capital in the Twenty-First Century*,[14] and Jean Tirole, a Nobel Prize-winning economist, stated in essence, in his book in *Economics for the Common Good,*[15] that justice (via law) has a key role to play in ensuring that society can address the issues of the energy and climate crisis. Changes to laws have increasingly begun to address issues of inequality across all parts of our societies, including the energy sector.

[11] R.J. Heffron and D. McCauley, 'The concept of energy justice across the disciplines', *Energy Policy*, 105 (2017), 658–67.
[12] R.J. Heffron and D. McCauley, 'The concept of energy justice across the disciplines', *Energy Policy*, 105 (2017), 658–67.
[13] Plato, *The Laws*, tr. Trevor J. Saunders (Penguin, 1970), 164.
[14] See for example T. Piketty, 2014. *Capital in the Twenty-First Century* (translated by Goldhammer, A.). Belknap Press of Harvard University Press: MA, US.
[15] J. Tirole, 2017. *Economics for the Common Good*. NJ, US: Princeton University Press.

Taxation

Since the financial crisis, society has begun to reassess the role of taxation. The use of tax havens is now well documented, and there have been major leaks that have promoted change (the Panama Papers and the Paradise Papers)[16]. Now more scrutiny is being paid to international transactions, particularly because energy companies were exposed as heavy users of tax havens. The OECD is aiming through several initiatives to examine the issues (particularly inequality) that the unfair world of international taxation is causing in the energy sector (and especially in mining).

Disclosure and transparency

Several issues with an impact on the energy sector relate to disclosure and transparency. International accounting standards now require more disclosure specifically for energy projects. The international Extractive Industries Transparency Initiative (EITI) (if a signatory) requires a state and an investor to disclose the details of their taxation relationship (the EITI Secretariat will monitor the submission). There are then two emerging legal instruments that some countries are utilising to increase disclosure and transparency issues. The 'social licence to operate' (the relationship between energy corporations and the local community which is becoming formalised through a contract) requires more transparency between an energy project developer and the local community, and some projects have been stopped recently when the terms of the license were not honoured, for example, in high profile cases in Colombia.[17] Finally, the 'energy finance reserve obligation' requires through legislative change an operator to place money in escrow equal to the estimated cost of decommissioning an energy asset, to ensure that clean-up will be funded even if the operator goes bankrupt or sells the asset to a company without the financial capacity to pay for it.[18]

Insurance

After a crisis, insurance is also more difficult to obtain. And in light of changes in the commercial world alongside climate change issues, insurance for energy projects has now become very difficult to obtain. In 2019, coal projects found it very difficult to get insurance.[19] This will have a knock-on effect where there will be a rise in cases where the insurer of last resort – the state – will need to become much more active, and as a result, the public will increasingly question all the benefits of fossil fuel development and continuation.

Environmental impact assessments

The environmental impact assessment (EIA) has been around since the 1980s, but it has only now begun to really assist in developing a low-carbon economy. A procedure that is required before an energy project can be permitted, it assesses the project's environmental and social impacts in detail from an interdisciplinary perspective. The legislation internationally has changed over the last decade, partly in response to the economic crisis. It has become more strict at the national level, and also at the international level where international banking rules (known as the Equator Principles) now make the EIA a prerequisite for project financing. And further year-on-year the amount of data required in EIAs is increasing.

There are two recent examples of the latter issues where in 2019, two coal projects were stopped in Australia and Kenya because their EIAs were considered unsatisfactory. The key reasons for the failure were that the EIAs lacked completeness in terms of data provision, the poor assessment of the social and environmental impacts from the existing data and the projects' positive economic contributions were overestimated.[20]

Legal action on climate change

Legal action is beginning to influence company behaviour. In *State of the Netherlands v Urgenda,* the Netherlands Supreme Court ruled on 20 December 2019 that the Netherlands had an obligation to take action to prevent climate change and reduce greenhouse gas emissions by at least 25 per cent by the end of 2020 compared to 1990 levels.[21] The Supreme Court noted that its decision was based on the European Convention on Human Rights.

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[16] See both the following: Obermayer, B. and Obermaier, F. 2016. *The Panama Papers*. OneWorld Publications: London, UK; and Shaxson, N. 2016 (edition – original 2011). *Treasure Island.* Penguin, Random House: London, UK.
[17] Heffron, R. J., Downes, L., Ramirez Rodriguez, O. M. and McCauley, D. 2018. The emergence of the 'social licence to operate' in the extractive industries? *Resources Policy, Available early-access* -https://doi.org/10.1016/j.resourpol.2018.09.012
[18] Heffron, R. J. 2016. *The Global Future of Energy Law*. International Energy Law Review, 7, 290- 295.
[19] M. Sheehan, 'Coal exclusions double in 2019 as action spreads beyond Europe' *Reinsurance News*, 2 December 2019, https://www.reinsurancene.ws/coal-exclusions-double-in-2019-as-action-spreads-beyond-europe/.
[20] B. Nogrady, 'Landmark Australian ruling rejects coal mine over global warming', *Nature*, 11 February 2019, https://www.nature.com/articles/d41586-019-00545-8; D. Herbling, 'Kenya cancels environment license of $2 billion coal-power plant', *Bloomberg*, 26 June 2019, https://www.bloomberg.com/news/articles/2019-06-26/kenya-cancels-environment-license-of-2-billion-coal-power-plant.
[21] M. Minnesma, 'Not slashing emissions? See you in court', *Nature*, 576 (20 December 2019), 379–81.

This case will result in the recognition of human rights in energy development and the state's obligation to act on climate change, and consequently it will have a major impact on energy projects over the coming years. Further, it will have a degree of influence on judicial decision-making in other countries and ensure justice is taken into greater consideration in energy policy development.

Legal action on rules of foreign investment

The role of energy arbitration is relatively unknown to interdisciplinary scholars, but this will change. Recent cases in Bolivia, Kenya, and Peru highlight key legal issues such as the importance of EIAs, social licenses to operate, and energy finance reserve obligations, as well as energy justice issues.[22] An ongoing case in Nigeria between the Nigerian government and a foreign investor,[23] with an approximately $9 billion award at stake, will be transformative on several issues. The first is whether foreign investments should receive full protection, and the second question then arises whether an energy arbitration case should be subject to advances in public policymaking. The answer should be a resounding 'yes', especially as an energy case involves energy, environmental, and climate-change issues and generally also includes closely related issues such as international development, finance, and taxation. The UK High Court in August 2019 stated there was no public policy issue.[24] However, if the energy transition is to happen, rules around investor protection will have to change. Poor or unjust investment choices should not be supported or protected by rules of foreign investment. This will be an area of transformation over the next decade and will put pressure energy projects, particularly on fossil fuel, which in the context of climate change could be classified as unjust or poor investment choices.

The 2015 Paris Agreement

The Paris Agreement was signed at the 2015 United Nations Climate Change Conference, and 188 countries ratified it within about three years, which is very fast for an international agreement. It is prompting change already. It requires countries to produce a plan for reducing their carbon dioxide emissions. Another key impact of this treaty is that it gets people to think of the energy transition as a 'just' transition to a low-carbon economy rather than a business-as-usual approach. We need an approach that has justice at its core, as there is a desire to have a more fair and equitable economy in the future.

Personal technology and the role of imagery

Personal technology is having a big impact in terms of using imagery to change public policy. Images play a role in both criminal and civil legal systems. That this should spread into mainstream society in terms of the effects of climate change should be no surprise, but it is having a major effect. Key issues around personal decisions on where to live, lifestyle, and tourism will change, and influence societal development.

UN Sustainable Development Goals

The 17 UN Sustainable Development Goals (SDGs) are having a major impact on a range of policies across society. The energy sector is obviously crucial here. One proposed assessment that demonstrates this was published in Nature Energy where it is determined that the UN SDG 7 on energy is the most influential of all UN SDGs and if the latter is resolved in will have a major impact on whether we meet the rest of the SDGs.[25]

Conclusion

Energy justice issues has created the opportunity for justice to be at the heart of the energy transition. All of these issues increase the commercial risk of investment decisions by energy-producing companies and affect public policymaking. The result is that energy project developers have to meet not only the demands of public policy but also their own internal requirements on investment risk and those of external investors (such as those providing project finance and insurance). These demanding requirements will mean that projects which can play a role in the energy transition become much more attractive.

[22] South American Silver Limited (Bermuda) v. the Plurinational State of Bolivia, PCA Case No. 2013-15; Cortec Mining Kenya Limited, Cortec (Pty) Limited, and Stirling Capital Limited v. Republic of Kenya, ICSID Case No. ARB/15/29; and Bear Creek Mining Corporation v. Republic of Peru, ICSID Case No. ARB/14/2.

[23] Process & Industrial Developments Limited v The Federal Republic of Nigeria, [2019] EWHC 2241.

[24] The foreign investor and the Nigerian Government agreed that should there be a dispute that the case would be heard in the UK (specifically England & Wales).

[25] Nerini F.F., Tomei, J., Seng To, L., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Castan Broto, V., Anandarajah, G., Milligan, B. and Mulugetta, Y., 'Mapping synergies and trade-offs between energy and the Sustainable Development Goals', *Nature Energy* 3 (2018), 10–15.

The energy industry can no longer afford to focus solely on profits, but has to consider how the project will result in just outcomes where social and environmental considerations are of vital importance alongside new standards of commercial practice and its limitations. Therefore, justice in the energy transition is set to become the key influencer of government and business strategy and behaviour. We are on the verge of a just transition to a low-carbon economy.

THE OIL AND GAS INDUSTRY, LOW-EMISSION PATHWAYS, AND THE ENERGY TRANSITION

Jim Herbertson

Access to affordable, reliable energy is essential for the growth of strong economies, sustained improvements in the quality of life, and the eradication of poverty. The societal challenge is to address climate change risks while also meeting growing global energy demand and supporting economic development. Meeting the challenge of climate change in the context of sustainable development requires action from all parts of society.

The oil and gas industry provides more than half of the world's energy and is an essential partner in sustainable development. Meeting the aims of the Paris Agreement implies a transformation of the energy system over the course of this century. Throughout this transition, oil and gas will continue to be an important part of the broad energy mix needed to deliver affordable, reliable, and modern energy products and services.

There are many possible pathways to a low-emissions future, most of which share three common elements: improving efficiency and saving energy, reducing emissions from power generation, and deploying alternative low-emission options in end-use sectors. According to the Intergovernmental Panel on Climate Change and others, carbon capture and storage (CCS) is a key technology to support this transition.[26]

Governments, business and industry, investors, consumers, and civil society will need to collaborate closely to enable the transition to a low-emissions future.

Energy transition in the context of sustainable development

The current nationally determined contributions (NDCs) under the Paris Agreement focus on the period to 2025 or 2030. Actions by nations in the near term on these NDCs will be the significant first steps towards a low-emissions path. However, even if all the current NDCs are fully implemented, the aggregate effects will fall well short of the long-term aims of the Paris Agreement. While some NDC submissions target low emissions as an end point, many countries have not yet set out comprehensive pathways to get there. Recognizing the need for greater effort, each country has agreed to review its NDCs at five-year intervals, with the November 2020 UN Climate Change Conference (COP 26) providing the first opportunity.

In 2015, the UN also adopted the 2030 Agenda for Sustainable Development, with its 17 Sustainable Development Goals (SDGs). The goals and targets are designed to stimulate action by governments, businesses, and wider society in areas of critical importance. Two SDGs are particularly important to low-emissions pathways: Goal 7, to ensure access to affordable, reliable, sustainable and modern energy for all; and Goal 13, to take urgent action to combat climate change and its impacts.

Reducing emissions will require substantial changes in the energy system. Oil products currently provide energy for most of the global transportation system. Natural gas is mainly used for power generation (40 per cent of global gas demand), for residential heating, and as the fuel for industrial processes. Along with oil, natural gas plays a major role as feedstock for the chemical industry. Coal is heavily used for power generation (more than 60 per cent of global coal demand) and industrial processes, including metal ore conversion and cement manufacture. Use of renewable sources such as solar and wind is growing at pace in the electricity sector, alongside biofuels in transport. A low-emissions future will look significantly different from the current energy system and will require fundamental changes in how energy is consumed.

Multiple ways to lower emissions

There is no single pathway to a low-emissions future. Finding these pathways is a task for many actors from all sectors of society over the short, medium, and long term. Governmental agencies, consultants, energy companies, NGOs, and academic institutions have published numerous projections of GHG emissions and associated energy demand. Many variables can affect the pace and nature of change in the energy system, and thus the possible pathways to lower emissions.

[26] IPCC summary report Working Group III of AR5, 2014 and IPCC Special report 1.5, 2018.

Uncertainties exist in climate policy (e.g. the timing and scope of policies to achieve NDCs), technology development (e.g. the commercialization of large-scale batteries and CCS), climate response (e.g. climate models), and finance (e.g. the availability, location, and cost of finance). These pathways differ in terms of their assumptions and uncertainties, but most have three elements in common: improving energy efficiency; reducing emissions from electricity generation; and reducing emissions from remaining end-use sectors.

Improving energy efficiency and saving energy

The most cost-effective method of reducing greenhouse gas (GHG) emissions is to save energy. According to analysis by the International Energy Agency (IEA),[27] with potential improvements in production and end-use efficiency, coupled with energy conservation, forecasted energy demand in 2040 may be roughly 12 per cent less than current levels. To maximize energy-saving opportunities, barriers to uptake will need to be addressed, including by increasing the information available to consumers and aligning the motivation of consumers and suppliers to save energy. While efforts to increase efficiency and reduce consumption are critical, these efforts only slow the growth of GHG emissions—they do not stop it.

Reducing emissions from electricity generation

Multiple approaches and technologies can be used to reduce GHG emissions from power generation. In the near term, one of the most cost-effective and impactful steps that society can take is to switch from coal to natural gas. This step could cut emissions in half for every unit of electricity generated. Near-zero emissions options include renewables, principally from solar and wind, and nuclear power. Longer term, the deployment of gas and biomass-based power generation with CCS would enable near-zero-emissions or even negative-emissions electricity. Reducing the GHG intensity of the power sector would enable the electrification of parts of the transport, residential, commercial, and industrial sectors to decrease their GHG intensity.

Reducing emissions from remaining end-use sectors

Alternatives to electrification include hydrogen, biofuels, industrial CCS, and bioenergy with CCS. While these technologies continue to be developed, additional technical breakthroughs will be needed to achieve cost-effectiveness at the scale needed to transform the energy system. Some areas of the economy, such as aviation, require specific energy characteristics, for example energy-dense liquids that remain fluid at low temperature (-40C) that will be likely to require such alternatives.

A variety of processes and services have specific needs for energy density, transportability, and scalability, which is why they run on fossil fuels today. For the same reasons, there is continuing uncertainty as to whether these could run on direct or stored electricity by the end of this century, and they will therefore require alternative solutions. Commercial shipping and aviation currently use hydrocarbon fuels, benefiting from their energy density. Even given advances in battery technology, the fuel-to-weight ratio of electrochemical (battery) storage makes the use of electricity in long-haul aviation a distant option. A more likely alternative might be bio-based jet fuels, which are becoming more available. Heavy goods transport and large-scale construction equipment would likely use liquefied natural gas or potentially biofuels. Heavy industry requires considerable energy input, such as from furnaces powered by metallurgical coal and natural gas. These reach the very high temperatures necessary for processes such as chemical conversion, glassmaking, conversion of limestone to cement, and refining of ores to metals.

Economy of scale is also critical: delivering large amounts of energy into a relatively small space is important. In the metallurgical industries, carbon (usually from coal) is also needed as a reducing agent to convert the ore to a refined metal.

Carbon capture and storage – a key technology

CCS will likely be key to the final two pathways to lower emissions, decarbonizing electricity generation and remaining end-use sectors. Without large-scale commercial deployment of this technology, lowering emissions will be much more difficult and costly. The Intergovernmental Panel on Climate Change has attached considerable importance to CCS deployment because without it, the cost of achieving atmospheric CO_2 stabilization levels would be much higher. CCS would enable low-carbon fuels and electricity to be used in transport, homes, and industry.

CO_2-emitting industrial processes such as hydrogen production and cement and steel manufacture will almost certainly continue throughout this century. In addition, continued dispersed emissions of GHGs are inescapable in some sectors, notably in

[27] IEA World Energy Outlook 2019 and IEA Energy Efficiency Outlook 2018.

agriculture. In the longer term, to offset dispersed emissions that cannot otherwise be controlled, direct air capture of CO_2 with CCS or the use of biomass as an energy source with CCS provide options. It may take some time, however, for these technologies to be cost-effectively proven at scale.

Large-scale CCS is a reality today, even though deployment remains limited. Deployment of CCS on a scale that makes a material contribution to reducing CO_2 emissions requires addressing current barriers, including cost, complexity along the value chain, regulatory and policy uncertainty, public acceptance, large-scale storage sites, and long-term liability issues. However, the key barrier for CCS is the lack of policies to incentivize and underpin its deployment, creating a level playing field with other technologies.

Critical enablers of emissions reduction

Lowering emissions requires many enabling factors, especially greater collaboration, supportive policies such as market-oriented solutions, and adequate finance.

Collaboration

While the Paris Agreement is based on a concept of global participation and collaboration by signatory parties, governments alone cannot provide all of the solutions. Public and private entities at the national, subnational, regional, local, and city levels will all need to engage with each other, academia, civil society, and private industry. The oil and gas industry has a long history of working with partners of different sizes and nationalities, and with other private companies, NGOs, and governments to reduce and mitigate risk.

Supportive policies

An effective policy environment would enable markets to drive technology innovation, development, and deployment, as well as the infrastructure necessary to transform the energy system at least cost. To support both short- and long-term action, policies should encourage global participation; let markets drive the selection of solutions at lowest cost, while supporting the development of pre-commercial, low-GHG-emissions technologies; recognize the long-term nature of addressing the risks of climate change; provide long-term signals and market certainty, but remain flexible in response to the latest science and technology; be transparent to all stakeholders while minimizing complexity and administrative costs; and address both mitigation and adaptation.

Market-oriented solutions

Countries are increasingly choosing market-based systems and crediting mechanisms to place a price on carbon and to support their efforts to reduce emissions, including regional and international cooperation. Countries at different stages of development and with different states of energy independence will decide how best to design climate and energy policy to pursue sustainable development. Article 6 of the Paris Agreement recognizes the concept of voluntary cooperative approaches, including market-based and non-market-based mechanisms.

Success in reducing emissions will depend on how effective governments are at creating a policy environment that uses market forces to enable low-GHG innovation and deployment. Market-based approaches (such as carbon taxes, emissions trading systems, and tradable permits or standards) can generally be designed to be more economically efficient than most industry-specific regulations, technology mandates, or non-tradable performance standards.

Market-based approaches could have many designs. The most effective will be those that apply to all GHG emissions and provide a transparent price signal; apply the costs of GHG emissions to the emitter to incentivize action; prevent or minimize carbon leakage; provide for linkages with other systems; return revenue generated from the system back to the economy in a non-distortionary fashion that encourages economic growth and limits regressive income effects; and provide for accurate and cost-effective GHG emissions measurement, verification, and reporting.

Systems based on these principles will minimize the overall cost to society by allowing markets to determine the most cost-effective solutions.

Adequate finance

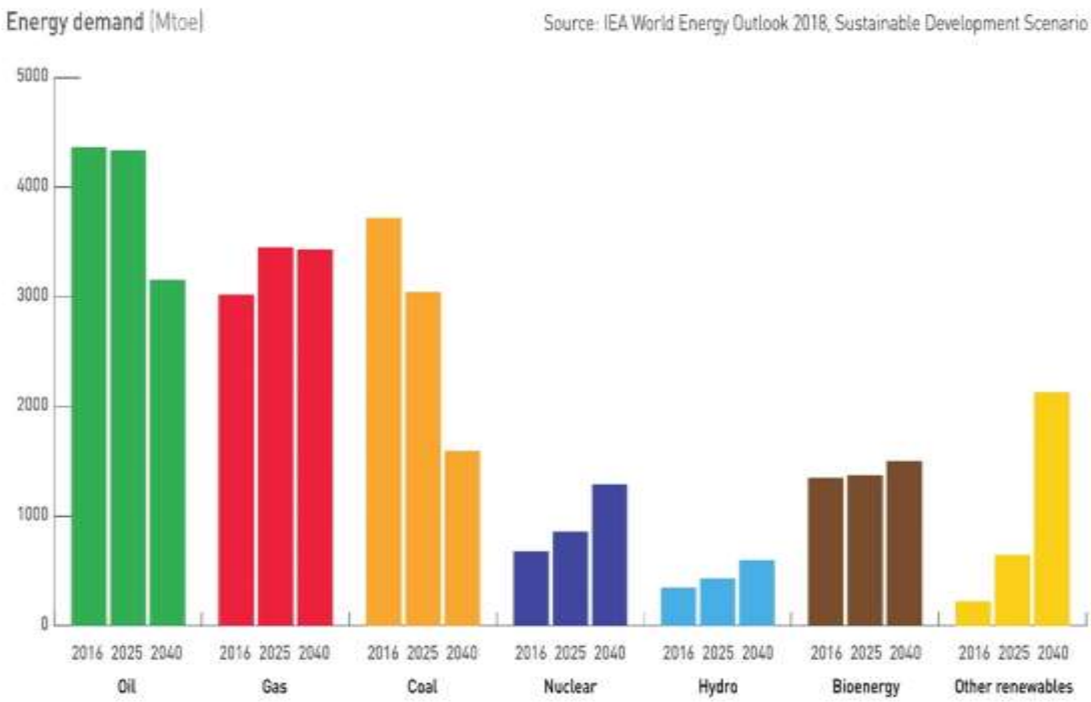
The Paris Agreement provides mechanisms for financial transfers between nations to accomplish the Agreement's long-term goals. Changes to the energy system in line with a low-emissions pathway and increasing demand will require massive shifts in investment flows. In the energy sector, significant investments will be needed over the coming decades to build new infrastructure and replace ageing existing infrastructure. Under its sustainable development scenario (SDS), the IEA estimates that, on average, about $510 billion a year of investment will be needed in the oil and gas sector between now and 2040 to meet anticipated demand.[28]

Achieving the long-term aims of the Paris Agreement will require worldwide action by governments, businesses, and civil society. It will also require the private sector to apply its creativity and innovation to address the world's most urgent societal challenges.

Continuing demand for oil and gas during the energy transition

The number of potential pathways to low emissions make gauging future demand for oil and gas a complex proposition that can generate a range of estimates. The IEA SDS represents one such projection which meets both the Paris Agreement commitments and the UN SDGs. The scenario assumes strong growth in renewables and to an extent nuclear power, but given the scale of the global energy system, it still projects that oil and gas will continue to provide 48 per cent of the world's energy in 2040. Given that producing fields deplete naturally at a rate of around 4–8 per cent a year (depending on field size, maturity, location, geology, and geochemistry), there will be a continuing need to explore for and produce oil and gas during the energy transition. Furthermore, this oil and gas will need to be supplied in a way that minimizes potential adverse social and environmental impacts.

Projected energy demand under the International Energy Agency's sustainable development scenario



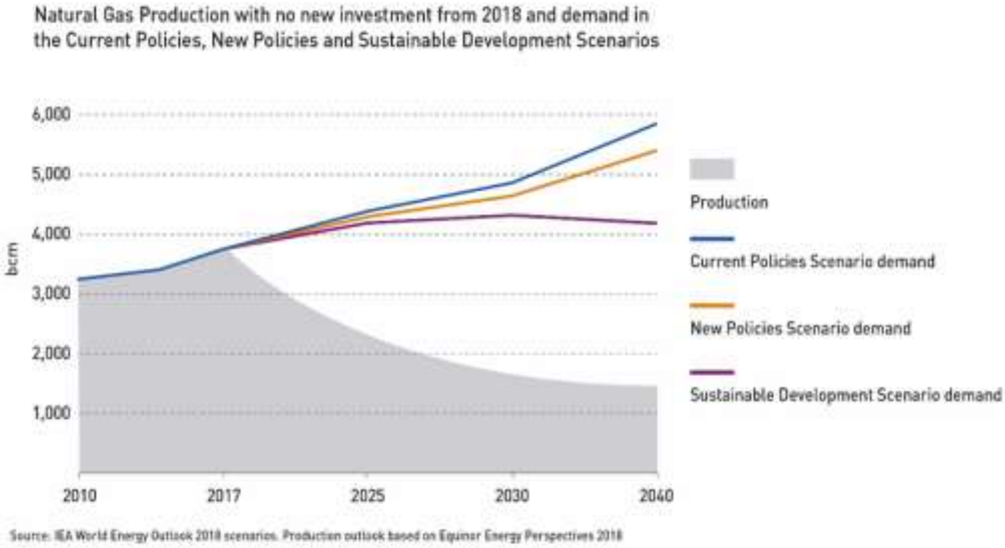
IEA's three key scenarios – Current Policies Scenario, New Policies Scenario and Sustainable Development Scenario – all project a substantial gap between supply and demand if there is no investment in exploration and production.

Role of the oil and gas industry in the transformation of the energy system

The oil and gas industry plays an important role in providing the energy that is essential for the growth of strong economies. It is working to be part of the solution, helping to ensure these benefits both for today and for future generations, while supporting efforts to reduce emissions.

[28] IEA – the oil and gas industry in energy transitions, 2020.

Projected natural gas supply and demand under three International Energy Agency scenarios, all assuming no new investment in exploration or production



Reducing emissions

The industry has been taking action to reduce GHG emissions from its own operations for many years. An ongoing focus on energy efficiency has resulted in improvements and technological innovations in finding and producing oil and gas, with attendant energy savings.

Natural gas faces some potential challenges, including the impact of methane emissions. The industry has also been taking action to reduce methane emissions and gas flaring. World Bank satellite data show that flaring of associated gas dropped worldwide by 15 per cent from 1996 to 2017, despite an increase in oil production by a third. The IEA methane tracker indicates there are substantial opportunities for further significant reductions in methane emissions across the oil and gas supply chain, from production through transmission and distribution to consumers.

Oil and gas companies are taking independent action to mitigate emissions, as well as participating in collaborative initiatives and voluntary industry groups, including the World Bank Global Gas Flaring Reduction Partnership and its Zero Routine Flaring by 2030 initiative, the Global Methane Initiative, the Methane Guiding Principles, the Climate and Clean Air Coalition Oil and Gas Methane Partnership, and the Oil and Gas Climate Initiative.

Helping consumers reduce emissions

Natural gas, the cleanest-burning fossil fuel, is increasingly accessible, affordable, abundant, and flexible. It has a critical role to play in an energy system transformation that would offer a secure and diverse energy mix. In power generation, combined-cycle gas turbines generate around half the combustion CO_2 emissions of coal-fired power stations. They also have a significantly lower impact on air quality and emit much lower levels of nitrogen oxide and sulphur dioxide (NO_x and SO_2). Natural gas production has been expanding globally, helping to slow the rise in GHG emissions by displacing higher-GHG-emitting fuels. Natural gas can also provide backup to the intermittency of renewables when solar and wind are unable to generate power due to lack of sunlight and wind.

The oil and gas industry works extensively with motor vehicle manufacturers to create products that help increase engine performance. These efforts include participating in vehicle engine research and design to produce gasoline and diesel formulations that increase engine efficiency while lowering emissions. They also include supporting partnerships such as the Global Fuel Economy Initiative, which IPIECA engages with through membership in the UN Environment Programme Partnership for Clean Fuels and Vehicles. Oil and gas companies are also producing new advanced lubricants that reduce engine friction and increase fuel economy.

Heavy-duty vehicles and commercial shipping are two areas that are unlikely to be widely electrified in the near term, although battery and hybrid ferries are entering service. Liquefied natural gas is now being used for heavy-duty vehicles and ships, reducing GHG emissions as well as other pollutants. Many IPIECA members support the advancement of solar and wind power and conduct fundamental research to develop new solutions, such as advanced biofuels and the use of hydrogen as an energy carrier.

Investments are being made in low-carbon businesses, including in the photovoltaic industry, the battery storage industry, advanced biofuels (notably bio-based jet fuels), and in energy consultancy and energy-efficiency services.

Engaging on climate policy

Building balanced energy and climate policy is challenging, and IPIECA recognizes that no one has all of the answers. As economies around the world continue to develop, oil and gas will play an important role in meeting the growing demand for energy. Reducing emissions while providing adequate, affordable, and reliable energy will require financial investments, skilled people, technical innovation, and responsible stewardship from policymakers, energy producers, and consumers.

AN ALTERNATIVE ENERGY TRANSITION PATHWAY ENABLED BY THE OIL AND GAS INDUSTRY

Ahmad O. Al Khowaiter and Yasser M. Mufti

The ways societies use energy for their own specific economic and lifestyle purposes have evolved over the course of history. Long-term changes, or energy transitions, are shaped by socio-economic development, technological innovation, and policies, among other factors. At present, there is a spectrum of diverse energy transition visions, some focusing on energy alone and others extending to sustainability transitions.[29]

For an energy transition scenario to be consistent with the Paris Agreement, which ‘aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty,’[30] it will need to consider sustainability and growth on an equal footing with combating climate change. Hence, we envision energy transitions driven by three interdependent values (sometimes called the 3Es):

- *Economic growth.* This is an overarching priority for developing countries to eradicate poverty and enhance human well-being. Developing nations will not transition to a low-carbon energy system unless it is aligned with their national development goals, including large-scale and rapid poverty reduction.
- *Energy access*. To attain all the United Nations Sustainable Development Goals, the global economy and energy demand must both grow substantially. Further access should be affordable, reliable, and sustainable.
- *Environmental conservation*. The global economy is built on a carbon-based energy system that has been the foundation of modern industrial development but requires more sustainable emissions reductions to address climate change and other environmental concerns.

With improving living standards and the global economy expected to almost double over the next three decades, energy intensity – the amount of energy used per unit of GDP – will likely rise. The International Energy Agency’s (IEA’s) *World Energy Outlook 2019* projects that energy consumption in developed countries will decline, but that total primary energy consumption will increase, led by developing countries. However, global energy intensity is firmly on a long-term downward trend and, according to the IEA, intensity in 2040 will be about 60 per cent of that in 2018. This will reflect improved efficiency in the use of energy, as well as improvements across the economy.

To fulfil the global sustainability challenges represented by the 3Es, the pace of transitions in mobility and advanced materials needs to be synchronized with the pace of the energy transition. This requires an all-fuels-all-technologies approach, where all sectors of society are partners in developing the global narrative, including the oil and gas industry.

[29] F.W. Geels, F. Berkhout, and D.P. van Vuuren (2016), ‘Bridging analytical approaches for low-carbon transitions’, Nature Climate Change 6 (2016), pp 576-583, DOI: https://doi.org/10.1038/nclimate2980 , 1–8; N. Longhurst and J. Chilvers, ‘Mapping diverse visions of energy transitions: co-producing sociotechnical imaginaries’, *Sustainability Science*, 14, no. 4 (2019), 973–90, https://doi.org/10.1007/s11625-019-00702-y;
J. Markard, R. Raven, and B. Truffer, ‘Sustainability transitions: an emerging field of research and its prospects’, *Research Policy*, 41, no. 6 (2012), 955–67.
[30] Paris Agreement, Article 2, https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

Sustainable economic development requires technological breakthroughs where advanced materials and chemistry will be core in accelerating transition across many sectors, including automotive, construction, renewables, and packaging. The oil and gas industry, with a focus on low-carbon-intensity crude and the technological path for crude-to-chemicals, will be a key player in enabling this transition, both economically and with the lowest-possible emission route.

Plastics will remain a considerable market for chemicals and will create the advanced materials needed for the products of tomorrow, including light-weight vehicles, wind turbines, and most consumer durable goods, calling for scaled-up measures to eliminate single-use plastic waste. In particular, recycling will not be the only path to achieve circularity, as, with substantial expertise, oil and gas can scale up the waste-to-power/water conversions, as well as converting waste plastics into useful fuels for transportation and as feedstock for the petrochemical industry, which will dramatically decarbonize the transportation fleet, enabling production of advanced, non-metallic materials.

Oil and gas research, innovation, and technology will advance a high-efficiency internal combustion engine to further reduce the transportation carbon footprint by reducing scope-3 emissions. This becomes critical to address the potential pace gap between the energy and mobility transitions that could drive carbon emissions upward as a result of electric vehicle market penetration.

On another front, in countries where energy poverty exists, oil and gas can be part of the solution to create energy access at scale by providing an economical energy mix that complements gas and renewables. Oil and gas energy solutions can be used to capitalize on plastics waste in those countries, while meeting social objectives, promoting economic development, and creating skilled and non-skilled jobs.

Along these lines, we present the circular carbon economy (CCE) as an alternative pathway for the energy transition, together with key technologies and solutions under a 4Rs (reduction, reuse, recycling, and removal) framework.

The circular carbon economy

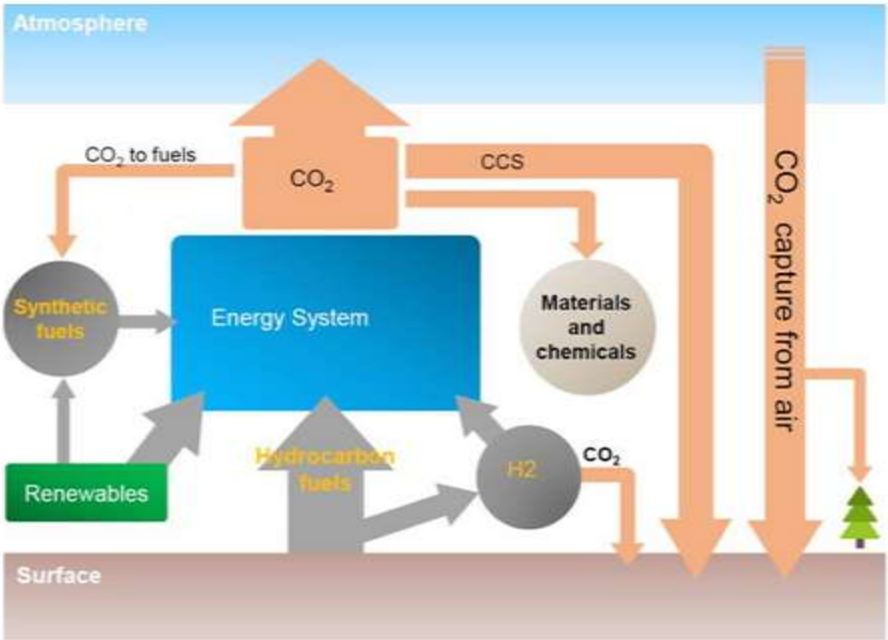
The circular economy concept emphasizes the non-linear nature of the relationship among society, economic/material flows, and the environment. It originated with Boulding's idea of a 'spaceship economy'.[31] This concept has featured in United Nations summits on sustainable development since 1992, to enable the pursuit of sustainable patterns of production and consumption.

The CCE is a framework in which emissions of carbon from all sectors are managed in a way that allows the carbon to move in a closed-loop system, much like the natural carbon cycle. This circularity has the advantage of allowing maximum utilization of existing infrastructure while addressing the emissions challenge, directly and economically and across national circumstances. The CCE cycle has four main pillars:

- *Reduce.* This includes steps towards energy efficiency, zero routine flaring, methane leakage minimization, renewable electricity integration, and switching to low-carbon fuels.
- *Reuse.* This includes CO_2-enhanced oil recovery and supercritical CO_2 applications[32].
- *Recycle.* This includes use of carbon in synthetic fuels, fertilizers/urea, methanol, polymers and other chemicals, and concrete.
- *Remove.* This includes efforts to enhance natural sinks through reforestation, produce bioenergy with carbon capture utilization and storage (BCCS), direct air capture and storage (DACS) as well as other forms of carbon capture, utilization and storage (CCUS).

[31]. Boulding, K. E. 1966. The economics of the coming Spaceship Earth. *Environmental Quality in a Growing Economy: Essays from the Sixth RFF Forum*. H. Jarrett. Baltimore, John Hopkins University Press.
[32] Supercritical CO_2 application is the use of CO_2 in near-liquid state which has superior properties as a process or heat transfer fluid in a variety of industries.

The circular carbon economy



Reduce

Prioritize resources with low-carbon intensity and low operational GHG emissions

A recent study published in *Science* estimated the global carbon intensity of the upstream oil sector[33]. The study analysed approximately 9,000 oilfields in 91 countries, which represented 98 per cent of global oil production in 2015. There is a wide variation in the carbon intensities of upstream oil operations worldwide. The country volume-weighted average carbon intensity ranges from ~3 to 20 grams of CO_2 equivalent (gCO_2e) per megajoule (MJ) of crude oil delivered to the refinery gate, with a global average carbon intensity of ~10 gCO_2eq/MJ. Saudi Arabia has the second-lowest carbon intensity worldwide with an average of ~4.5 gCO_2e/MJ, making it representative of best-in-class industry practice in carbon management.

In a scenario where the global upstream crude oil carbon intensity matches that of Saudi Arabia, the consequential greenhouse gas (GHG) emissions saving is estimated at ~1 Giga tons of CO_2 equivalent '$GtCO_2e$' per year. This is equivalent to any one of the following:

- displacement of 250 million petrol passenger cars by 100 per cent renewable-powered electric vehicles
- removal of 200 million petrol passenger cars from the global fleet
- development of 650 CCUS facilities worldwide
- restoration of 1.5 billion trees per year.

The global reduction in upstream carbon intensity is achievable through a combination of gas management (e.g., flare and methane leakage minimization) and low-GHG technologies (e.g., solar-integrated oil production and gas processing). For example, Saudi Aramco has pioneered gas flaring reduction through the deployment of the Master Gas System[34] and the development of innovative flare recovery systems. The company is committed to achieving zero routine flaring and sharing best practices to accelerate global flare minimization. In addition, Saudi Aramco reservoir management practices over the years, including application of advanced technologies (such as geo-steering, multilateral wells with smart completion, and peripheral water flooding), have reduced water production per barrel (or water cut) relative to the depletion stage of the reservoir. This substantially reduces the energy requirements to process and recycle water, and consequently reduces CO_2 emissions.

[33] Masnadi M.S. et. al., "Global carbon intensity of crude oil production," Science 361, 851 (2018).
[34] Master Gas System is an extensive network of pipelines and processing facilities connecting key gas production sites with demand centres through the Kingdom of Saudi Arabia.

Effective climate policies should recognize the different climate impacts of different crude oils and reward improved production practices with clear per-barrel incentives for the lowest-carbon-intensity producers.

Increase Transport efficiency

Oil continues to be the primary fuel for passenger and freight transportation around the world, and the growing demand for transport calls for a sustainable transition. Disruptive emerging business models for on-road vehicles such as ride-hailing and autonomous vehicles help reduce emissions. At the same time, advanced technology hardware and fuels continue to be introduced to the global market, including more efficient internal combustion engines and alternative fuels, as well as partially and fully electrified powertrains. Saudi Aramco is collaborating with automotive engine manufacturers to re-engineer the internal combustion engine and advance game-changing transportation technologies that could significantly reduce emissions and improve fuel efficiency.

Light-duty electric vehicles (EVs) have made substantial progress in recent years, but their market penetration remains insignificant on the global scale. This transition in mobility must happen simultaneously with transition in the power mix. An EV powered by electricity generated from coal could mean greater emissions on a well-to-wheel basis than an efficient internal combustion engine. Superficial perceptions of EVs today disregard both the upstream (in terms of environmentally harmful mineral extraction practices that will only deteriorate further as demand increases) and the downstream (in terms of battery recycling). Once scaled up, this transition model can seriously jeopardize sustainability.

Managing carbon from marine and air transportation remains a significant challenge. It will require coordinated global efforts to reduce and remove carbon from interconnected ship and aircraft routes globally, including energy efficiency measures, the uptake of lower-carbon-intensity alternative fuels (e.g., synthetic fuels), and revolutionary fuel cell powertrains and onboard carbon capture technologies. Many of these technologies are still nascent and require global collaboration to increase competitiveness.

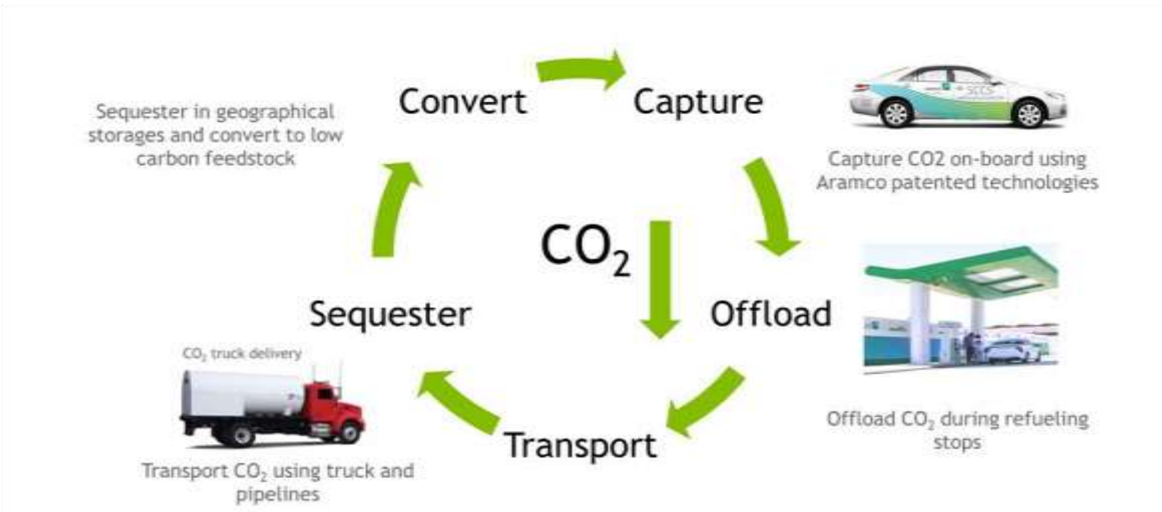
Reuse

Mobile carbon capture technology for transportation

Mobile carbon capture (MCC) is an after-treatment technology that captures and stores carbon onboard the vehicle using a redesigned exhaust system. The core of the technology, much like CCUS applications for point sources, relies on several techniques which separate and compress CO_2 and store it in onboard tanks until it is offloaded during refuelling. A key feature of the technology is the utilization of waste heat available onboard the vehicle, which thus eliminates energy penalties.

MCC technology has potential to significantly reduce the carbon footprint of road and marine transport. In 2018, the International Maritime Organization adopted an initial strategy to reduce GHG emissions from the marine sector by 50 per cent by 2050 compared to the 2008 baseline. This strategy is expected to be regulated by 2023 and will require the shipping sector to adopt significantly more expensive low-carbon fuels to achieve the target. These fuels may not be available at a cost and scale required for the marine sector. Thus, MCC technology is quite well placed to facilitate this target in the near term.

The role of mobile carbon capture in a circular carbon economy



CO_2-enhanced oil recovery

Carbon capture, utilization, and storage (CCUS) technology involves the capture of CO_2 from fuel combustion or industrial processes, its transport via ship or pipeline, and either its use to create valuable products (utilization) or its permanent storage in geological formations (sequestration – discussed in the 'Remove' section below).[35] The reuse of CO_2 to produce valuable products generates a revenue stream through product sale which results in a favourable CCUS economics such as creation of direct jobs plus the multiplier effects. An important reuse technology is CO_2-enhanced oil recovery (EOR), which uses injected CO_2 to extract oil that is otherwise not recoverable.

CO_2-EOR works by injecting CO_2 into the oil field's rock formations where it mobilizes the oil previously trapped in the rock's pore spaces while some becomes immovably trapped in the pore spaces, i.e. sequestered. This process results in emissions abatement on a full life-cycle basis, including emissions from using the oil produced. With the right policy measures, the industry can use this method to store more CO_2 beyond the process optimization requirements.[36]

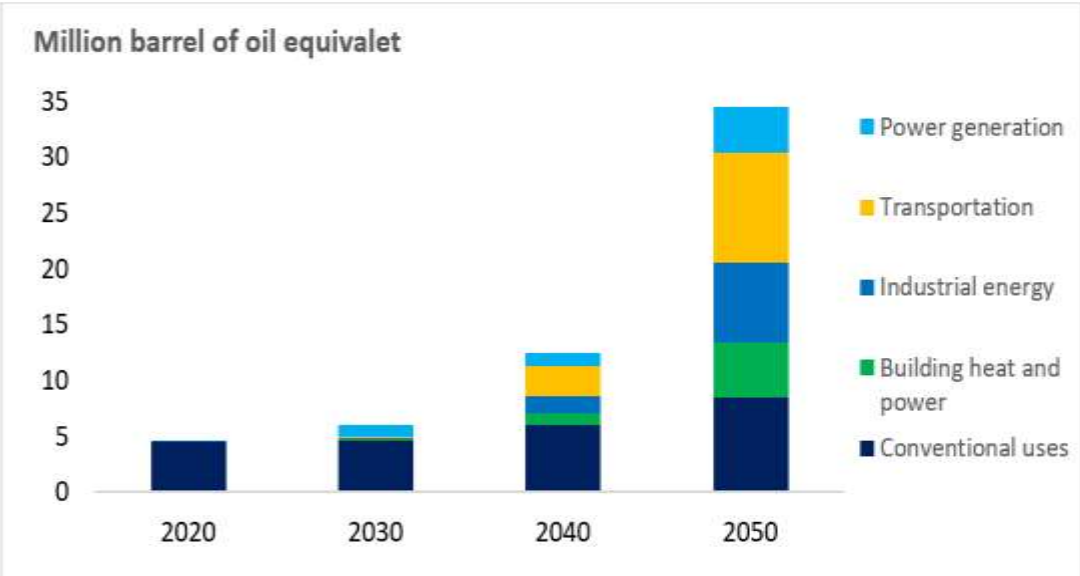
Recycle

Hydrogen

A growing body of evidence suggests that hydrogen is gaining interest around the world, and could become an attractive option due to its versatility. Today, many nations across Asia, Europe, and North America have published national hydrogen strategies that set out ambitious deployment targets by 2050. Future oil refineries will adapt to changing market structure to allow for more production of chemicals and carbon-free hydrogen. This potential energy pathway benefits from process integration and capitalizes on existing infrastructure to provide a uniquely competitive source of hydrogen.

More than 77 per cent of today's hydrogen supply is from natural gas (48 per cent) and crude oil (29 per cent). The rest comes from coal (19 per cent) and renewables (4 per cent).[37] Hydrocarbon feedstock for hydrogen production is the most economical due to its low technology and commercial risks. Low-carbon hydrogen from hydrocarbon feedstock can be produced with CCUS. Significant developments have been made worldwide, but more global policy support, research and development innovations, and scaling up are needed to address the lack of infrastructure, reduce costs, and especially the 'last mile' delivery of hydrogen to end-users.

Global hydrogen demand projections



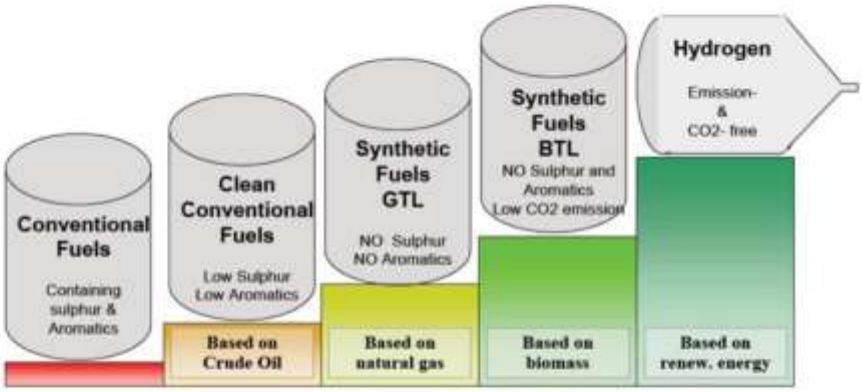
Source: Hydrogen Council, "Hydrogen Scaling Up – A sustainable pathway for the global energy transition" (2018).

[35] International Energy Agency (IEA), "Carbon capture, utilization and storage." https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage
[36] Global CCS Institute, "Global Status of CCS 2019." https://www.globalccsinstitute.com/wp-content/uploads/2019/12/GCC_GLOBAL_STATUS_REPORT_2019.pdf
[37] Air Products website, http://www.airproducts.com/Industries/Energy/Power/Power-Generation/faqs.aspx

Synthetic fuels

The use of hydrogen to recycle CO_2 is crucial in hard-to-decarbonize industries such as cement, steel, and heat and power. In this process, hydrogen produced by water electrolysis using renewable electricity is synthesized with carbon from CO_2 to produce more complex hydrocarbons that can be used as a drop-in fuel in transportation. This is particularly attractive for aviation, which will continue to rely on liquid fuels. Unlike biofuels – which have become controversial due to the GHG emissions resulting from biofuels farming and its competition with food crops – renewable e-fuels have a low environmental risk. In addition, synthetic fuels contain no sulphur and no aromatics and are biologically degradable. Nevertheless, the cost of the full process remains prohibitive in the near term. CCE platforms can achieve economies of scale and offer commercial synergies that reduce the risk of investment.

Steps in the development of future fuels



Source:https://www.bredenoord.com/en/Innovations/gtl-synthetic-diesel/

Remove

There is a growing consensus on the essential role of CCUS in meeting climate targets. The IEA's sustainable development scenario requires CCUS capacities of 350 and 1,488 million tonnes per annum (Mtpa) of CO_2 by 2030 and 2040, respectively[38]. As of 2019, the total capacity of all CCUS facilities worldwide at all stages of development was ~98 Mtpa, up from ~65 Mtpa in 2017.[39] This implies that the current global CCUS annual growth rate needs to be doubled and maintained to 2040 before we can reach the goal of one Giga ton 'Gt' per year capacity.

The perception that CCUS is more expensive than other mitigation technologies is mistaken. The IEA has estimated that as much as 450 Mtpa of CO_2 could be captured, utilized, and stored by deploying available low-cost options.[40] The CCE creates industrial clusters that reduce unit cost, through economies of scale, and accelerate the learning curve.

Conclusion

Various future energy scenarios exist that have different implications for fossil fuel demand and incorporate variable degrees of sustainable energy combined with energy efficiency and decarbonization. Some advocate a future energy system that is homogenous and renewables-based. This is unrealistic and does not balance economic growth, societal needs, and protection of the environment. Others advocate a future energy system that is highly heterogeneous and allows for a market-based low-carbon economy. We see energy transition as a dynamic story, not a static picture, in which the industry will evolve and adapt and make every effort to provide solutions. In that light, we present the CCE – a multi-technology platform that serves all three sustainability objectives, with oil playing the key role as a flexible and versatile energy carrier – as a way to achieve a sustainable energy transition.

[38] International Energy Agency (IEA), "Carbon capture, utilization and storage." https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage
[39] Global CCS Institute, "Global Status of CCS 2019." https://www.globalccsinstitute.com/wp-content/uploads/2019/12/GCC_GLOBAL_STATUS_REPORT_2019.pdf
[40] Global CCS Institute, "Global Status of CCS 2019." https://www.globalccsinstitute.com/wp-content/uploads/2019/12/GCC_GLOBAL_STATUS_REPORT_2019.pdf

MECHANICS OF THE ENERGY TRANSITION

Rob West

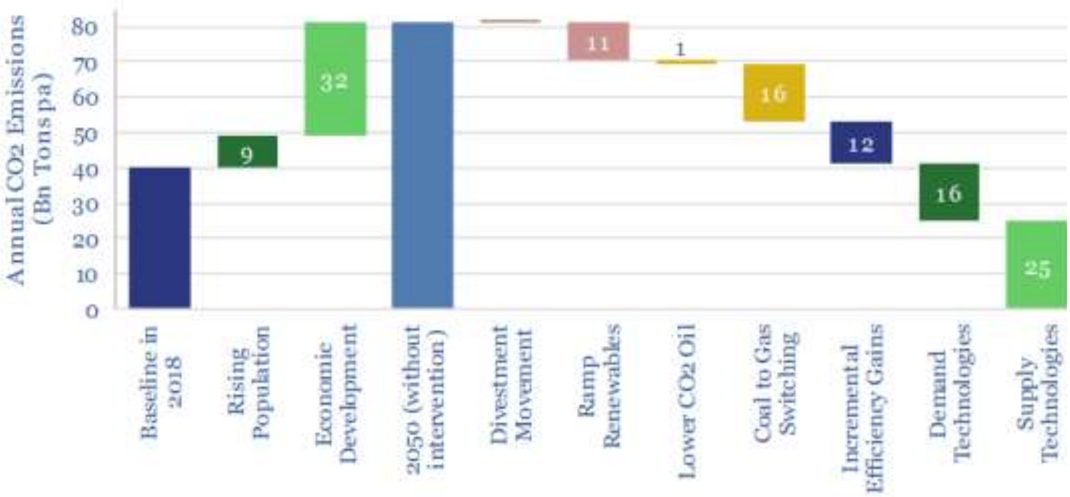
Decarbonization is challenging because of the energy system's sheer size: 63,000 terawatt hours (TWh) of energy was consumed in 2018. For perspective, this is equivalent to a kitchen toaster running constantly, 24 hours per day, 365 days per year, for each of the world's 7.7 billion inhabitants – 22 kilowatt hours (kWh) per person per day.

Most energy consumption is invisible to consumers, but it is nevertheless crucial to their lifestyles. Over half of all the world's CO_2 emissions stem from agriculture, metals, materials, fertilizers, manufacturing, and distribution – the products we consume and the buildings in which we consume them.

Energy consumption is also woefully unequal. The top 1.3 billion in the developed world account for about 60 per cent of global consumption. Another 1 billion lack access to electricity, and 2 billion lack modern cooking fuels. By 2050, emerging-market populations will increase by 25 per cent, and their energy use per capita will rise by 80 per cent, to around 30 per cent of the developed world's per-capita level.

Hence global energy demand is likely to increase to 120,000 TWh per year, doubling CO_2 emissions to around 80 billion tons per year, all else being equal. The new goal of the energy industry should be to meet the world's inherent energy needs, while at the same time decarbonizing the energy system.

Framework for decarbonization of the global energy system by 2050. Without intervention, global CO2 would rise from 40bn to 80bn tons pa, but this can be entirely offset via new technologies

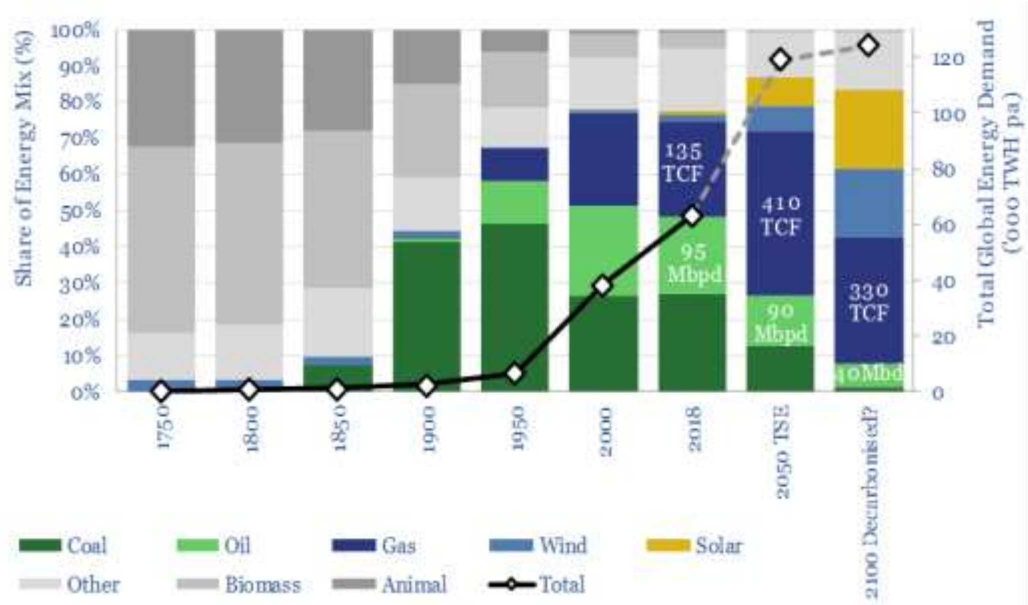


Source: Thunder Said Energy.

The divestment movement is counterproductive to this goal. It aims to restrict investment until the global fossil-fuel supply falls. When supplies fall, prices rise. Thus, potential consumers get priced out, eliminating their demand. Inflicting this outcome on emerging-market consumers could have truly terrible consequences. To achieve an energy transition is likely to require more investment, not less, in order to reshape an industry that currently spends $2 trillion per annum.

Reallocating portfolios into renewable energy is one example, owing to the incredible deflation (around 90 per cent) in renewable energy prices over the past decade – towards levelized costs of 4–6c/kWh, some of the lowest-cost electricity in the world today. But the challenge for renewables is scale. Last year, the world spent $300 billion on wind and solar, which added 270 TWh of new energy supplies. At this pace, it will take about 180 years for renewables to scale up to 50 per cent of the world's energy mix. Renewable investments are likely to double, but wind and solar to reach only 15 per cent of the energy mix by 2050. There are also some types of demand that renewables cannot meet, such as fuel for planes, ships, and trucks; materials production; and industrial heating. Therefore, if we are to achieve decarbonization, we must look more broadly.

Mix of energy sources and total energy demand, from 1750 to 2018, plus Thunder Said Energy's estimates for 2050 and 2100



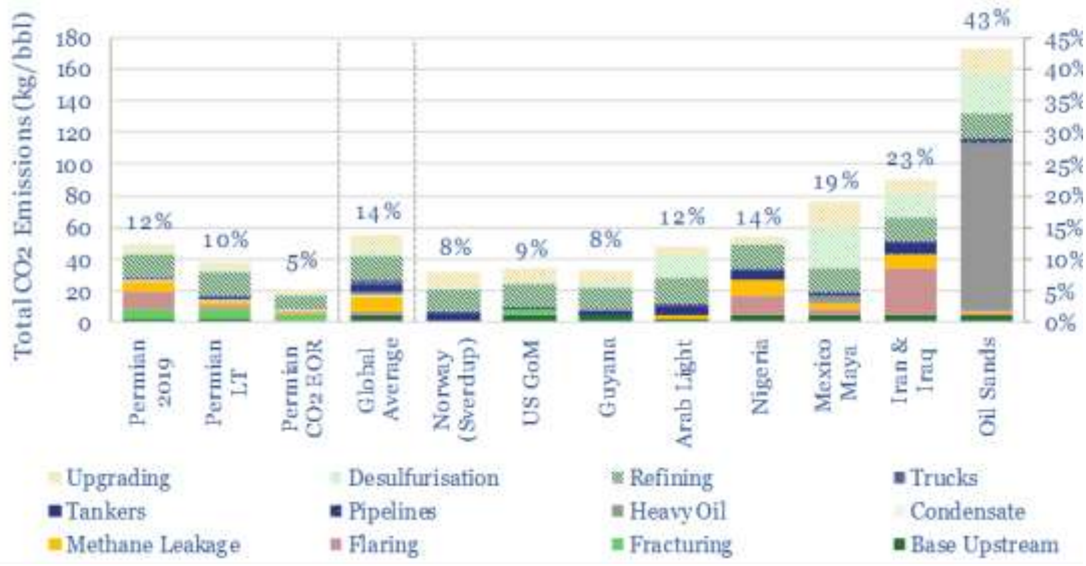
Source: Thunder Said Energy modelling.

Gas should emerge as the leading fossil fuel. Generating 1 megawatt hour (MWh) of power from coal emits 0.85 tons of CO_2, while the same MWh from gas emits just 0.35 tons of CO_2. Hence the projected ascent of gas, shown in the figure above, would yield 20 per cent lower CO_2 emissions in 2050 than if today's market shares of coal, oil, and gas were preserved.

Gas could further extend its lead with new technologies that decarbonize gas-fired power generation. One exciting possibility is oxy-combustion using the Allam Cycle, which is reaching technical maturity. Implementing this zero-carbon gas-power technology should cost less than constructing a new combined-cycle gas turbine.

There is also an opportunity to save about 25 per cent of the oil industry's 2 billion tons of annual CO_2 emissions by reallocating 10 million barrels per day of production away from the most CO_2-intensive resources toward lower-CO_2 oil.

The CO_2 intensity of commercializing oil across resource types screened by Thunder Said Energy



Source: Thunder Said Energy modelling.

Improving upstream CO_2 intensity should be key to achieving the decarbonization goal. Some examples follow.

- *Flaring intensity* has been reduced by 20 per cent across the entire oil industry since the early 1990s. The best antidote to flaring is to develop an industry to monetize the gas. LNG development is 94 per cent correlated with flaring reduction in countries such as Nigeria and Angola. Equatorial Guinea, an LNG producer, has 80 per cent less flaring than its non-LNG-producing neighbour, Gabon.
- *Methane* is a 25–120 times more powerful greenhouse gas than CO_2, depending on the measurement methodology. Between 2 and 3 per cent of all methane produced by the oil and gas industry is leaked, with leakage rates running three to four times higher in remote oil basins than in gas basins. Exciting opportunities to control methane emissions include using drones, satellites, and lower-cost sensors. Leading companies are also phasing out pneumatic devices, which ‘bleed’ methane, replacing them with electronically actuated alternatives, and upgrading valves and seals to minimize leakage rates.
- *Digital optimizations* can save 10–40 per cent of the energy of rod-pumps or Electrical Submersible Pumps, or uplift production rates by 10–20 per cent at mature fields, so that fixed carbon emissions are spread over more barrels, lowering the emissions rate per barrel. Operator efficiencies and CO_2 footprints are usually inversely correlated.
- *Renewable power* is increasingly used to power onshore oil and gas. There is a pipeline of 20 projects, which will generate 10 TWh of solar energy by 2025: about 60 per cent for steam-enhanced oil recovery and about 35 per cent for electrifying onshore operations.
- *Power from shore* is behind the record-low (1 kg per barrel of oil equivalent) upstream CO_2 intensity at the Johan Sverdrup oilfield offshore Norway, allowing such facilities to be electrified via hydropower, cutting out over 70 per cent of the emissions. Similar schemes could extend throughout the North Sea, or in the Gulf of Mexico, powered partly by Texan wind energy.
- *Hybrid industrial engines* have on average 40 per cent greater efficiency. The explanation is that diesel and gas engines are 30–80 per cent less efficient at low loads, where needs can instead be handled by the batteries. The batteries are charged by running the engines at high loads, and/or by regenerative braking. Hybrid engines have been deployed on rigs, platform supply vessels, and even the turbines at one LNG plant.
- *Improved logistics* – carrying fewer materials by truck (70 ton miles per gallon) and more by train (700 ton miles) – can cut 0.2 kg per barrel of oil equivalent for a typical oilfield supply chain.

The downstream oil industry can also improve its CO_2 profile, which matters as refining the average barrel globally emits 30 kg of CO_2, yielding a total of more than 1 billion tons of CO_2 emissions per year. Of refinery CO_2, 50 per cent comes from furnaces and boilers, 20 per cent from associated utilities, and about 15 per cent from refinery hydrogen. The challenge is to decarbonize while improving challenging economics. Power-combustion carbon capture would likely obliterate margins, costing about $2–4/barrel. But more excitingly, a review of 50 recent innovations in refining catalysts found that the thermal intensities of upgrading processes could be reduced by 100–300 °C, saving 5 kg/barrel of CO_2 emissions, while also improving yields and overall economics.

Catalyst development is being transformed from a slow, trial-and-error science to a faster, digitally enhanced one. For example, the BASF subsidiary has recently deployed high-throughput experimentation to help Shell screen hydrocracking catalysts 10 times faster than their prior, 3.5-month process. BASF also started up the chemical industry’s largest supercomputer, Quriosity, in November 2017, for catalyst modelling. Other institutions are following suit, including via advanced computing and machine learning.

If other industries could achieve 15 per cent reductions in their CO_2 emissions (a viable goal for the oil industry), the result would be another 3 billion tons per annum of CO2 saved. Industries that show promise in this regard include agriculture, building materials, e-commerce, plastics, manufacturing, industrial robotics, shipping, and textiles.

Better energy technologies will be required to deliver the rest of the projected decarbonization. Discussing the myriad possibilities is beyond the scope of this article, but there are dozens of potential pathways to economizing energy demand, decarbonizing fossil fuels, and offsetting the remainder of the industry’s CO_2. These range from drone delivery to reforestation to breakthroughs in CO_2 separation and usage.

An energy transition that meets growing global energy needs while decarbonizing global energy is achievable. The most economical approach is to electrify inefficient fossil fuel demand and ramp up renewables as well as possible. This is not a devastating scenario for the oil and gas industry; about 85 million barrels per day of oil and 400 trillion cubic feet per year of gas are still likely to be required by 2050. In order to achieve decarbonization, however, these remaining fossil fuels must be made as efficient and low-carbon as possible, and then their CO_2 must be offset, through next-generation combustion technologies, carbon capture and storage, carbon capture and utilization, and reforestation.

The greatest challenge today is finding investors to back energy technologies. This is the most important component of achieving an energy transition. Yet investing in technology companies requires technical expertise and partnership. Moreover, these companies are early-stage, usually unlisted, and higher risk than established businesses.

Energy majors have already stepped up their venturing activities to support the transition. The year 2019 was a record year, with 40 new investments, of which 65 per cent are in new energy technologies. Progress could be accelerated if leading energy majors allowed public market investors to co-invest in their venture funds, or if more dedicated venture funds launched. De-risk next-generation energy technologies, and the industry can genuinely decarbonize.

Recent venture investments by leading energy majors

Source: Companies, Thunder Said Energy.

CO_2-ENHANCED OIL RECOVERY FOR DECARBONIZATION

Colin Ward

In a future in which the energy system faces dual challenges – addressing carbon concerns and transitioning away from hydrocarbons altogether – reducing the carbon impact of fuels will become a key tool in meeting climate and energy goals. As an example, jet fuel is very difficult to substitute due to the low energy density of batteries and the high cost of alternatives like hydrogen, making an upstream solution the only option until technology and costs evolve. Thus, making the best of the existing energy supply chain through decarbonization is a realistic and cost-effective option for the mid-term and warrants investigation.

Initial efforts to decarbonize oil include shifting portfolios to less intrinsically emissive sources, but further reductions quickly become more difficult. Improved production efficiency – such as reduced flaring and venting, economies of scale, and better operations – can also lead to significant carbon savings; but for large producers, these upgrades have already been implemented as general cost-saving measures. Downstream decarbonization opportunities, where carbon is physically removed from fuels to produce blue hydrogen and other energy carriers, will require time to become truly scalable. As carbon removal from the supply chain and other industries matures, it also creates a new problem concerning CO_2 sequestration. One option that both reduces the carbon intensity of oil and provides CO_2 storage is enhanced oil recovery using CO_2 (CO_2-EOR). The King

Abdullah Petroleum Studies and Research Center (KAPSARC) has examined this promising option in depth and held a workshop in January 2019 with the International Energy Agency to discuss the technology and the opportunities it offers.[41]

Operation and opportunities

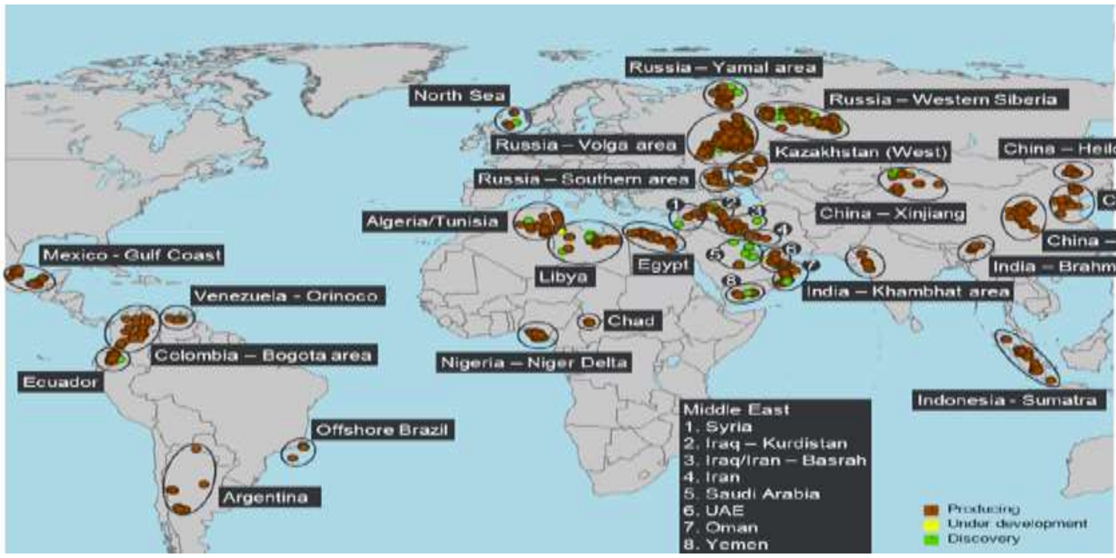
Naturally recoverable oil in a reservoir is typically about 20 percent of the resource available, but injecting CO_2 can reduce the viscosity of the crude and stimulate additional production of up to 13 per cent. Not all reservoirs are suitable for this method, but many do meet its minimum pressure and temperature requirements. Assuming complete separation and reinjection of the CO_2 produced with the crude, the net carbon extracted from the reservoir is lower on a per-barrel basis, avoiding the need for new resources and the emissions associated with developing them.

In normal CO_2-EOR operations, the amount of CO_2 injected into the reservoir to enhance production is kept to a minimum. CO_2 is a cost, and supply is often limited, so there is little incentive for higher injection rates. However, as more CO_2 becomes available from anthropogenic sources through carbon capture, opportunities to increase these injection levels become viable. Conventional operations use 300 kg of CO_2 per barrel produced, but it is possible to inject 600 kg per barrel if the intention is to maximize both the stored CO_2 and the oil recovered.[1] The impact of injecting 600 kg of CO_2 per barrel means the carbon produced can technically become negative in some fields. This is the case for several of the OPEC producers, including Saudi Arabia and Kuwait, as their crude is relatively easy to produce on a large scale with minimal energy investment.

CO_2-EOR is a common and commercially viable process. It has been used for decades in the North American energy industry, but it can be leveraged into much wider use worldwide. A recent paper published by KAPSARC examined possibilities of using CO_2-EOR to reduce the carbon impact of oil production.[42] The study focused on non-North American resources, because the technique is already well developed in that region but typically relies on geologic CO_2 sources that negate the climate benefits. The results of the study indicate an immediate technical opportunity to store over 40 Gt (gigatonnes) of CO_2 with existing source-sink pairs, and 6 Gt could be stored economically at an oil price as low as \$50. Under less strict criteria, where projects are not limited by local supply of CO_2, the full storage potential jumps to over 200 Gt, in line with estimates produced by others.[43]

The global distribution of reservoirs suitable for CO_2-EOR is robust, with the best locations for development in Russia and China (due to stationary sources near reservoirs) and the highest total storage potential for future development located around the Arabian Gulf.

CO_2-EOR clusters suitable for development



Source: Rystad Energy.

[41] International Energy Agency, *Storing CO2 through Enhanced Oil Recovery* (Paris: IEA, 2015).
[42] Ward, Colin, Wolfgang Heidug, and Nils-Henrik BjurstrØm. 2018. *Enhanced Oil Recovery and CO2 Storage Potential Outside North America: An Economic Assessment*. KS--2018-DP27. Riyadh: KAPSARC. doi: https://doi.org/10.30573/KS--2018-DP27.
[43] International Energy Agency, *Storing CO2 through Enhanced Oil Recovery* (Paris: IEA, 2015).

Encouraging growth

The CO_2 supply is a major constraint on the expansion of CO_2-EOR, and this is primarily due to the limited nature of the available capture and transportation infrastructure. Without using geologic sources there are few high-concentration supplies of CO_2 available. Hydrogen, ammonia, ethanol, natural gas, and urea plants produce waste streams of CO_2 that can be used with minimal processing, but not in the volumes needed to drive mass adoption. Lower-concentration sources like power plants require significant scrubbing but may become key resources in future.

Concerning transportation, building dedicated pipelines for a single source-sink pair often does not make sense economically as the distance and volumes involved are insufficient to justify the costs. For most countries looking to handle captured CO_2, a network approach will be needed to connect several sources and sinks for collection and redistribution. The responsibility for constructing the network remains a question, where it is undetermined if a legal responsibility placed on the emitter, the demand from the oil producer, or an economic incentive for a pipeline operator will drive development. Ultimately, a network of this scale may be treated as a public good or utility and require government backing if private entities are unwilling to invest.

Beyond solving the CO_2 supply constraint, additional factors could increase adoption of CO_2-EOR worldwide. Locally, the tax regime of an oil-producing country can have an influence, by qualifying CO_2 storage as an exempt revenue stream if royalties on oil production are the primary source of government revenue. Direct impacts include the oil price, with revenues from additional production reducing the break-even value for CO_2 to justify an EOR project. A CO_2 price can also drive adoption, under the assumption that emitters are willing to pay more for storage. Lastly, tax credits can be helpful in creating conditions for EOR growth by indirectly incentivizing storage, much like section 45Q in the United States tax code.

Carbon accounting options

The accounting standards for CO_2 emissions and storage may make the idea that crude produced via CO_2-EOR is a reduced-carbon option contentious, due to the CO_2 emitter typically claiming credit for any mitigations. The sequesterer of carbon is often treated as a service provider to the emitter, and not as a full partner in emissions reduction. In this case, the only reward for CO_2-EOR is in the form of payments for the CO_2 stored and additional oil revenues. There are, however, some options that could be more effective in creating favourable conditions with the risk of double-counting the carbon impacts.

First, a novel system to give credit for storage has been proposed that would turn the current thinking about carbon mitigation upside down.[44] Negative-emission technologies will be needed to meet our climate goals, and current reduction schemes make it difficult to extend below zero. By giving credit for verified units of stored CO_2, it is possible to encourage the development of carbon capture, utilization, and storage technology and drive down future costs. CO_2-EOR is an excellent candidate for launching this type of scheme.

Second, in economies that rely on significant hydrocarbon exports for revenue, the value of 'green oil' is a competitive advantage, securing market share and meeting the demands of end markets with established carbon legislation. The ability to extend the lifetime of their primary revenue stream, along with the coincidence of frequent state ownership in emissive industries, indicates that the credit for mitigation could be allocated to the oil producers for export along with their products.

Lastly, if an exporter shifts towards producing blue hydrogen or some other decarbonized energy carrier in the future, then the benefits of CO_2-EOR are compounded. In addition to extending the long-term viability of oil revenues, the challenge of sourcing and transporting CO_2 solves itself, as collocating hydrogen production with crude production makes EOR a self-sustaining system.

Conclusion

While the technology of CO_2-EOR is well established, it has not seen much use outside of North America. Specific conditions concerning the geology, availability of CO_2, economics, and local policy have kept interest in this approach minimal compared to interest in easier and cheaper options. As these factors, and other concerns such as sustainability of supply and carbon impacts, evolve, CO_2-EOR is likely to become a first-line option when transitioning our energy system. Large-scale producers with low costs (such as the United Arab Emirates and Saudi Arabia) are the most likely first adopters, as their margins allow for investment, but other locations with high CO_2 taxes (Norway, Europe), or the need for secure supplies (China) will also play a part in wider growth.

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[44] Paul Zakkour and Wolfgang Heidug, *A Mechanism for CCS in the Post-Paris Era* (Riyadh: KAPSARC, 2019), https://doi.org/10.30573/KS--2019-DP52.

BLUE AND GREEN HYDROGEN IN THE ENERGY TRANSITION

D. Nathan Meehan

Hydrogen is the most abundant atom in the universe; at standard temperature and pressure, it exists as a gas in the molecular form H_2. Hydrogen readily forms molecular bonds with most non-metallic elements and generally exists on earth in organic compounds and water.

Hydrogen can be used as a fuel, as an energy carrier like electricity. Fuel cells use a relatively simple chemical process to convert H_2 or H_2-rich fuel into electricity. Hydrogen-powered gas turbines integrate H_2 combustion as an alternative to natural gas and can be used for stationary power and reduce CO_2 emissions in power generation.

In 2003, then US President George Bush announced an ambitious plan to encourage the use of H_2 for powering vehicles and generating electricity. However, progress has been slow, while $3 trillion dollars of public investment has poured into renewable technologies. Early acceptance of these technologies depended on government subsidies; however, wind, solar, and battery technology costs have dropped by 80 per cent and are routinely competitive with new fossil fuel facilities for power generation. More money is now spent on electricity than on oil and gas supply, and over half of all new electricity generation is from renewables. The pressure for renewable, low-carbon, and even zero-carbon energy is growing from shareholders, financial institutions, and the general public.

Hydrogen is used today to make ammonia for fertilizers, refine metals, and produce methanol for plastics, and the resulting CO_2 emissions are simply vented, increasing greenhouse gas (GHG) emissions. Such H_2 is referred to as 'grey hydrogen', as there are significant GHG emissions associated with its production. New global efforts for H_2 production focus on using fossil fuels coupled with carbon capture. Although biomass, coal, and other hydrocarbon liquids can be gasified to generate H_2, natural gas can be reformed to H_2 using well-established technologies of steam-methane reforming (SMR) or autothermal reforming. Either method makes capture of CO_2 simpler than other methane combustion applications, making it relatively easy to sequester. The SMR process is endothermic and combines high-temperature steam with methane to yield carbon monoxide and H_2:

$$CH_4 + H_2O \text{ (steam)} \rightarrow CO + 3\ H_2$$

The mixture of carbon monoxide and H_2 is called 'syngas' and can be directly used in methanol production. SMR generally uses an excess amount of steam to avoid coke (solid carbon) formation. An additional exothermic step in the process is a water-gas-shift step which converts most of the carbon monoxide to CO_2 and H_2:

$$CO + H_2O \text{ (steam)} \rightarrow CO_2 + H_2$$

Autothermal reforming uses oxygen and CO_2 or steam in reactions with methane to form syngas. The reaction is as follows for CO_2:

$$2\ CH_4 + O_2 + CO_2 \rightarrow 3\ H_2 + 3\ CO + H_2O$$

and for steam:

$$4\ CH_4 + O_2 + 2\ H_2O \rightarrow 10\ H_2 + 4\ CO$$

Syngas can then be further treated to remove most of the carbon monoxide and produce additional H_2. Pressure swing adsorption with molecular sieves can be used to separate carbon oxides from the H_2 product.

Hydrogen generated from fossil fuels coupled with capture and storage of the produced carbon is called 'blue hydrogen'. Methane can also be used to generate H_2 via pyrolysis, leading to solid carbon instead of CO_2 as either carbon black or, potentially, graphene. Natural gas is abundant and relatively inexpensive; some discovered resources may outlast demand.

Advances in electrolysis technology hold the potential to be price competitive with natural gas. When the electrical source has zero GHG emissions (nuclear, solar, wind), the product is referred to as 'green hydrogen'. In electrolysis, low-voltage currents pass through water, with gaseous oxygen and H_2 separating at the anode and cathode, respectively:

$$2\ H_2O \rightarrow 2\ H_2 + O_2$$

The efficiency of this process can be 88–94 per cent.[45]

[45] B. Kruse, S. Grinna, and C. Buch, *Hydrogen Status og Muligheter* (Bellona, 2002) (Hydrogen Status and Opportunities).

In many places solar and wind generate excess power when demand is low, which can be used for H_2 generation. This leads to suboptimal utilization but makes use of essentially free electricity; however, the total cost of green H_2 remains significantly greater than that of blue H_2. Renewables like wind and solar produce difficult-to-store electrons; electrolysis holds the promise to store excess renewable power as molecules.

Hydrogen is a good choice for zero-emissions transportation, where it can refuel vehicles in times comparable to those for liquid fuel and generates no local emissions. European countries are considering H_2 for all segments of the economy and have tested electrolysis techniques extensively. Hydrogen can be used for hard-to-abate energy-intensive industries, including iron and steel, and for specialty chemicals.

Hydrogen fuel cells to generate electricity are scalable and will have significant localized markets. Locally produced H_2 from excess renewables can be readily stored for peak-shaving demands. It is an excellent choice for certain microgrid applications and offers a zero-local-emissions power-generating option.

Fuel cells are extraordinarily clean and require minimal maintenance. With no moving parts, they are also relatively easy to manufacture. Stationary power fuel cells generate electricity cleanly with a small footprint compared to other renewable options. Hydrogen is more attractive than other low-carbon solutions for high- and medium-grade heating, backup power, and highly variable load power. The chemical reaction in a basic fuel cell at the anode is an oxidization of H_2 releasing electrons:

$$H_2 + 2OH^- \rightarrow 2\,H_2O + 2e^-$$

At the cathode the electrons flow through an external circuit and produce hydroxide ions:

$$O_2 + 2\,H_2O + 4e^- \rightarrow 4OH^-$$

The net reaction consumes one oxygen molecule for every two H_2 molecules, resulting in two water molecules along with electricity and heat.

Different fuel cells address different needs and vary in design by operating conditions, the material separating the anodes and cathodes, the types of catalysts required, and the source of H_2:

Alkaline fuel cells, which were developed and used for the Apollo space program, use carbon electrodes with platinum or silver catalysts separated by a liquid caustic solution.

- *Proton-exchange membrane fuel cells* have a polymer membrane (typically a sulfonated tetrafluoroethylene-based fluoropolymer-copolymer) which contains the electrolyte solution separating the anode and cathode.
- *Direct methanol fuel cells* are similar to proton-exchange membrane fuel cells, but draw their H_2 from liquid methanol.
- *Phosphoric acid fuel cells* use liquid phosphoric acid as an electrolyte.
- *Solid oxide fuel cells* operate at high temperatures (1,800 °F) and utilize a dense ceramic material. At high temperatures, platinum catalysts are not required; such fuel cells operate with efficiencies as high as 60 per cent.
- *Molten carbonate fuel cells* are high-temperature fuel cells that use molten carbonate salt mixtures suspended in a chemically inert ceramic matrix. They are less costly and more efficient than phosphoric acid fuel cells.

Phosphoric acid, molten carbonate, and solid oxide fuel cells are used in stationary applications.

The use of H_2-based gas turbines has been demonstrated by several companies. H_2 has a lower energy density than natural gas and requires greater volumetric throughput for the same unit of power generation. H_2 also burns hotter and is more reactive. Less than 100 per cent mixtures of H_2, including syngas and methane-hydrogen mixtures, have shown excellent results.

Hydrogen can be a competitive source of low-carbon energy if there is a developed gas grid and high seasonal loads. A project in northern England (H21) is attempting to convert more than 3.7 million homes plus local industries to H_2 coupled with CO_2 storage in the North Sea. The gas grid in the UK is three times the size of the power grid. No matter how much renewable power is produced, the gas grid has greater capacity to store such power. Many other 100-megawatt scale electrolyser projects are under way in Europe and the United States.

Another near-term use of H_2 is for transportation. It is the preferred fuel for forklifts and other devices used indoors. Japanese and Korean automakers continue to develop excellent H_2 vehicles, and H_2 could be an excellent choice for zero-emissions vehicles. Transportation fuel cells offer the promise of emissions-free transportation with the range and convenience of internal combustion engines. With no massive battery requirements, the vehicles can be less expensive to produce than either electrical or internal-combustion-engine vehicles. Hydrogen-fuel-cell-powered vehicles are electrical vehicles. Fuel-cell vehicles are co-dependent on battery technology. There are only about 15,000 H_2 cars on the road now. New H_2 vehicles stand to benefit from cost-effective developments in battery electric vehicles including improved batteries and the electrification of the power train. H_2 vehicles require a much smaller battery but still benefit from the ability to accelerate quickly and store energy from braking. H_2 fuel cells allow the vehicle to be much lighter and thus able to hold greater payloads and refuel very quickly.

H_2 vehicles will be preferable to battery electric vehicles when there is a demand for the vehicle to provide heavy-duty service with high payloads for extended periods – like taxis, city buses, and long-distance trucks. Vehicles with intermittent use that could be taken out of service for recharging, like school buses and commuter vehicles, may well be better choices for battery-electric-vehicle applications. Regional trains, buses, taxis, and other fleet vehicles are particularly attractive options which do not require widespread refuelling options. There are also significant opportunities for fuel cell vehicles in heavy-duty mobility with bus, truck, rail, and marine applications. The largest potential impact will be on trucks, as they are the largest source of pollution and carbon emissions in the heavy-duty mobility sector.

The lack of an H_2 distribution infrastructure suggests that fleet vehicles may be the best starting point. While this may seem daunting, the infrastructure demands for widespread electric cars will also be staggering. To reach California's aggressive goals for zero-emissions vehicles would require doubling the state's electrical supply by 2030 and quadrupling it by 2050.

Unmanned aerial vehicles, including drones, are excellent fuel cell applications, with the fuel cells' lower weight allowing greater flight times and ranges than lithium ion batteries can provide for such applications. Uber and other companies are pursuing other aerial applications, including for vertical take-off and landing. Amazon already uses fuel cell drones in its warehouses because of the extended flight times.

Transporting H_2 presents additional challenges. It is possible to blend H_2 in natural gas lines up to about 20 per cent by volume (7 per cent by energy content). Overseas transportation of large volumes of high-pressure H_2 is challenging. While liquid H_2 transportation is possible, conversion of H_2 into relatively stable liquids with high H_2 content, such as ammonia or methyl cyclohexane, currently offers a more economically attractive option. In one case, synthetic ammonia is traditionally produced from H_2 and nitrogen using the Haber-Bosch process. H_2 is recovered at the destination. In the other case, toluene is combined with H_2 to form methyl cyclohexane; recovered toluene can then be reused. Kawasaki Heavy Industries has launched a liquefied H_2 carrier ship designed to transport H_2 from a brown coal facility in Australia to the city of Kobe, Japan.[46] The CO_2 emitted from coal generation will still be vented to the atmosphere, making this a grey H_2 project; however, it should provide insights into the issues associated with transporting liquefied H_2.

Distribution of H_2 for refuelling of fuel cell vehicles has primarily relied on pressurized gas storage. A car might only need 5–10 kg of H_2, and a bus might require 40–50 kg. However, ferries and long-distance heavy-duty trucks might require much more (500 kg) and would stress current technology for storing this amount as a pressurized gas. Improved H_2 compressors should improve such high-pressure storage. Large applications might consider cryogenic applications, but other storage can include liquid organic H_2 carriers for large vehicles and for distribution facilities. Smaller-scale storage can include low-temperature, low-pressure solid adsorption on ceramic materials. The technology associated with these applications is not nearly as mature as fuel cell technology.

The economics of large-scale H_2 will continue to require government subsidies for some time, and numerous technical challenges remain. While H_2 is not as efficient in many applications, it holds greater flexibility and technical and emissions advantages. Hydrogen fuel costs must be at or below parity with diesel to displace other electric applications. There must also be much greater volumes available. Fuel cell buses, in terms of total cost of ownership, will require H_2 costs of less than $10/kg. SMR H_2 delivered straight to a Gulf Coast refining or petrochemical customer is relatively low-cost (about $3–4/kg) and is distributed through a 600 km pipeline running from Texas to Louisiana. This pipeline system has connections to numerous refineries and petrochemical facilities. Blue H_2 delivered to consumers in California costs approximately $14/kg, roughly

[46] Leigh Collins, *World's first liquefied hydrogen carrier launched in Japan*. Rechargenews.com, 11 December 2019. https://www.rechargenews.com/transition/worlds-first-liquefied-hydrogen-carrier-launched-in-japan/2-1-722155

equivalent to $5.60/gallon of gasoline on an energy basis. Green H_2 generation costs for local use vary from $12/kg to more than $15/kg. Green H_2 produced in facilities developed solely for H_2 with a significant scale has the potential to deliver H_2 for under $10/kg.

The Hydrogen Council has forecast rapid decreases in the cost of H_2, based on rapid expansion of and decreasing costs of both green and blue H_2, lower distribution and refuelling costs associated with increased load utilization, and decreased costs for components associated with scale-up in manufacturing.[47] Hydrogen holds the potential to provide a new market for natural gas that will (coupled with carbon capture, utilization, and storage) lower the carbon intensity of the oil and gas industry.

DECARBONIZATION OF GAS

Martin Lambert

When burned, natural gas has the lowest carbon emissions of any fossil fuel. In addition, combined-cycle power plants have higher efficiency than coal-fired power plants. For these reasons, the gas industry has advocated for gas to play an important role to play in lowering carbon emissions from the energy system. Initially, advocacy focused on the benefits of switching from coal to gas, particularly for power generation, and urged that gas-fired power generation play a key role in providing a backup to intermittent renewable generation.

That message did not find widespread acceptance, and the dialogue has now moved on. There are two key aspects to this change.

First, there is a growing awareness that methane leakage from the natural gas supply chain can substantially reduce the greenhouse gas advantages of gas over coal. Methane is a more potent greenhouse gas than CO_2, although its impact lasts for a shorter time. Over a 100-year horizon, methane is estimated to have 25 times the greenhouse gas impact of CO_2. It has also been estimated that if methane emissions along the supply chain exceed around 2–3 per cent, use of natural gas may lead to more climate impacts than burning coal. The gas industry has historically been poor at monitoring methane emissions, and reliable data is difficult to obtain. The industry has responded with initiatives like the Methane Guiding Principles, which were adopted in 2017 by eight energy companies, a number that has now expanded globally to 21. Several players are setting ambitious targets and making strenuous efforts to reduce methane leakage.

Second, even if the issue of methane leakage is tackled effectively, there has been a growing realization that because natural gas, like oil and coal, is a fossil fuel, it will have a limited role to play in a decarbonized energy system. Until recently, targets had envisaged a reduction in CO_2 emissions of around 80 per cent compared to the 1990 baseline. In the last couple of years, policy is increasingly targeting net zero emissions, with countries like the UK and France already committing to net zero by 2050, the EU likely to follow soon, and various other organizations, cities, and states committing to this target, often considerably earlier than 2050. The extent to which policy and the required investments are able to achieve these very ambitious targets remains to be seen, but in a net zero world, it is difficult to see fossil-derived natural gas playing a significant role.

Against this background, it is clear that the natural gas industry faces an existential threat. Renewable power generation is increasing in capacity (expected to reach 50 per cent or more by 2040, according to the International Energy Agency's latest *World Energy Outlook*) and reducing in cost, such that in many places it can already compete with new-build gas-fired power generation, and in some cases can also compete with coal-fired generation. The cost of batteries is also falling, although it is still unlikely that batteries will be able to provide sufficient electricity storage to balance the grid, particularly across seasons. Some studies envisage that the decarbonized energy system will be predominantly electric as gaseous fuels will have little role to play.

Several studies, however, have compared the 'all electric' scenario with a 'balanced' scenario where gaseous fuels continue to play a role, and have concluded that the 'balanced' scenario provides an overall lower-cost solution. This is perhaps not surprising, particularly in those regions where there is significant existing gas infrastructure which is able to transport and store energy in much larger quantities than is possible with the electricity grid. It is recognized that an 'all electric' scenario would

[47] Hydrogen Council, *Path to hydrogen Competitiveness: A cost perspective*., January 2020. https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

require very significant investment to upgrade the electricity transmission and distribution infrastructure. In the 'balanced' scenario, however, it is recognized that gas cannot be unabated fossil-derived natural gas, but will have to be some form of decarbonized gas.

There are broadly two candidates for decarbonized gas:

Methane, with broadly similar properties to natural gas, can be carried without difficulty in the existing gas infrastructure, and its source will be invisible to end users and their gas-burning equipment. This is perhaps comparable to the transition from fossil-fuel power generation to renewables, where the end product (electricity) is identical.

Hydrogen has the advantage that when burned, it does not emit any CO_2, and it can be produced in a variety of ways, including from renewable electricity via electrolysis. It does, however, require significant changes to transmission, distribution, and end-user equipment.

These two alternatives and their production pathways, advantages, and challenges are discussed below.

Renewable methane production

Biogas is a mixture of methane, CO_2, and small quantities of other components, made by anaerobic digestion of wet biomass – typically manure, sewage, agricultural waste, and energy crops. Most biogas is currently used near the point of production in combined heat and power systems. This can reduce demand for natural gas (which otherwise might have provided heat and power generation), but it does not have any other direct impact on the natural gas grid. Biogas can be upgraded to separate the methane (typically around 50 per cent of raw biogas) from the CO_2 and other components, such that the resulting biomethane is of a quality suitable for injection into the natural gas grid.

Production of biogas and biomethane via anaerobic digestion is currently the most mature technology for producing decarbonized gas, but while Europe has been leading the field, total injection of biomethane into the gas grid is less than 1 per cent of current European natural gas demand. At production costs of €50–100 per megawatt-hour (MWh), depending on scale of production and feedstock costs, biomethane is also the lowest-cost route to production of decarbonized gas. Nevertheless, with current wholesale natural gas prices in Europe around €10/MWh, it is clear that expansion of production of biomethane is highly dependent on government policy. This dependence has been demonstrated in several countries (e.g. Germany, Italy, Denmark, and the UK) which have seen rapid investments in new facilities when government incentives were favourable, and a rapid slowdown once policies changed.

In the longer term, a further constraint on the scale of biogas/biomethane production is the availability of sustainable feedstock. Production from biowaste is largely uncontroversial, but if energy crops become a significant feedstock component, the indirect impacts on land use change make the system unsustainable. It is estimated that the maximum sustainable potential for biogas/biomethane production in Europe is between 50 and 100 billion cubic metres (bcm) per year, or around 10–20 per cent of current natural gas demand. Even this level of production would require huge scale-up from the current production level.

An alternative pathway to production of synthetic methane is via thermal gasification of biomass. In this case, feedstocks are typically drier than in the case of anaerobic digestion, for example woodchips and municipal solid waste. The process involves gasification of the feedstock to produce syngas (a mixture of carbon monoxide and hydrogen), which is then processed further to produce methane. This technology has the potential to operate in larger-scale facilities than anaerobic digestion, and a number of demonstration plants have been built (e.g. in Sweden, Austria, France, and the UK). These plants have struggled to establish stable operations, largely on account of variation in feedstock composition impacting the operation of the process catalysts. At this stage it is unclear whether this technology is likely to be developed further. The relatively complex process suggests that direct production of electricity may be a more economically attractive use of feedstocks such as woodchips and municipal solid waste.

Renewable hydrogen production

For production of zero-carbon or low-carbon hydrogen, the main alternatives currently being considered are (1) reforming of methane with carbon capture and storage (sometimes called 'blue' hydrogen), and (2) electrolysis of water using renewable power generation (also known as 'power-to-gas' or 'green hydrogen').

Most hydrogen produced today (estimated to be around 70 million tonnes per year) is manufactured from fossil fuels, and around half is from reforming of methane. These technologies are mature, but also release significant quantities of CO_2, and so are not compatible with a decarbonizing energy system. It is therefore proposed that the addition of carbon capture and storage (CCS) to methane reformation systems will be a source of low-carbon hydrogen. A commercial-scale steam methane reformer with CCS has been in operation at the Port Arthur refinery in Texas since 2013 (with the captured carbon used for enhanced oil recovery). Plans are being developed for methane reformers (probably autothermal reformers, which produce a more concentrated CO_2 stream than steam methane reformers) with CCS, for example in the UK and the Netherlands. The Norwegian company Equinor has experience of CCS in its existing Sleipner and Snovit operations and is playing a key role in promoting hydrogen production from methane reforming with CCS. Costs of hydrogen via this route are estimated to be around €50/MWh, depending on the price of natural gas. Progress on these CCS projects is likely to depend on government support.

Green hydrogen is widely seen, particularly by European Union policymakers, as the desired end-game, because when produced from electrolysis using renewable electricity it is effectively a zero-carbon energy vector. While electrolysis technology has been well known for over a century, the key challenge is that it has not yet been deployed at scale and, partly as a result, it is costly. Several projects are under way with the objective to construct electrolysers around 100 MW scale, but at least 2500 MW of electrolyser capacity is required to produce 1 bcm of natural gas equivalent.

Policymakers also see electrolysis as an important component of 'sector coupling', recognizing that in the decarbonizing energy system it will be important for the gas and electricity systems to operate much more closely than they did in the past. One of the barriers to scaling up power-to-gas systems, however, appears to be the regulatory framework, which has not yet recognized the changes required to promote sector coupling. For example, project developers in Germany point out that, under the current tax regime, the price of electricity used as input to the electrolysis process is the same as the price of electricity for end users, which impairs the economic viability of potential electrolysis projects. There are ambitious targets for the scale of green hydrogen production by 2050 (potentially reaching over 200 bcm natural gas equivalent in Europe), but as yet there is no clear pathway to reach those targets.

Renewable hydrogen is very likely to find a role in the large-scale industrial sector, and probably also in the heavy-duty long-distance transport sector. Less clear is how, and to what extent, gaseous fuels will serve the residential and commercial sectors currently supplied from gas distribution networks, particularly for space heating in buildings. Some consideration is being given to large-scale conversion of end-users to hydrogen (for example in the H21 North of England project), but there are considerable challenges in converting the complex gas system from methane to hydrogen. Some parts (for example, plastic distribution pipes) can be readily converted, but other parts (for example, many metal components and end-user combustion equipment) will need to be examined closely on a case-by-case basis and in many instances replaced. Depending on the costs of these conversions and replacements, and on the evolution of government policy, it may prove more economic to continue to use the existing gas infrastructure to carry decreasing amounts of methane and/or to convert the end-use applications to electricity, where this is a feasible alternative.

Conclusion

There is clearly a case for gaseous fuels to play some role in the decarbonizing energy system. Less clear is the scale and extent of that role, particularly on account of the many uncertainties regarding technology choices, scale up, costs, government policy, and regulations. To safeguard its future role, it is important for the gas industry to build a strategic direction and business cases to make the required investments to reduce those uncertainties, and to demonstrate at scale the role which gaseous fuels can play in a decarbonized system.

EASY AND ECONOMIC SOLUTIONS TO MITIGATING METHANE EMISSIONS

Darcy Spady, Jackson Hegland

Energy transition is a fact of life. How we manage it – through technologies, strategies, and policy – is our choice. In fact, it is not just a choice, it is a well-thought-out decision followed by deliberate actions. The good news is that, on the practical front, many solutions to the energy transition are also good business. One of the key actions we can take, right now, is to reduce fugitive emissions such as methane. For producers, on the business side, keeping methane in the system and monetizing it at the sales meter also make economic sense.

Shrinkage between the wellhead and the pipeline takes many forms, including accounting losses and processing losses. One key factor is loss to the atmosphere, and even if this represents 1 per cent of sales, 1 per cent can mean a lot on the net profit line.

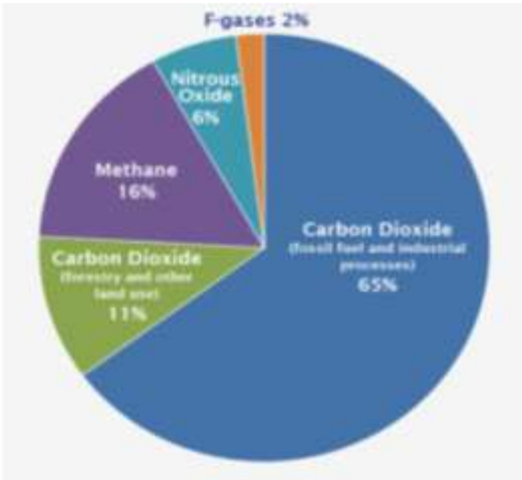
Methane is one of the most powerful contributors to Greenhouse Gasses (GHG), and the commonly accepted Global Warming Potential (GWP) of methane estimated to be a 25 times greater threat to global warming over a 100 year period compared to carbon dioxide. This is very serious, and can be reduced! That is why we want to focus on the methane emissions in this narrative, and specifically the ways that we can effectively measure it and mitigate its release into the atmosphere.

The Paris Climate Accord was a monumental watermark for action on energy transition. It defined a number of specific emission targets that allowed industry, banks, and regulators to focus on defining actions for industry to follow. These Paris targets will not be met by 2040 without action on methane emissions, and that is why the UN Climate and Clean Air Coalition is asking governments to use their NDCs (nationally determined contributions) to significantly reduce methane emissions. The targets proposed are 45 per cent by 2025 and 60–75 per cent by 2030, which would achieve a near-zero methane intensity target. This is achievable, with the help of innovation, the financial sector, and government regulators.

Perhaps as a leading indicator for what was to come in early December 2015 at the UN Climate Change Conference in Paris, the United Nations adopted 17 Sustainable Development Goals in September of that year as a means to integrate social development and environmental protection. Similarly, a trend is now emerging that some might call a leading indicator for emissions management in the oil and gas industry – investor demands. While the Sustainable Development Goals are voluntary measures countries and companies can take to minimize their impact on GHG emissions and GWP, accessing financial capital to execute corporate development objectives is not optional, and therefore this rising tide of investor decisions integrating corporate social and environmental performance becomes critical. Measuring, monitoring, and mitigating methane emissions is clearly a part of this investor matrix.

As is noted above, methane emissions are the second-greatest source of greenhouse gas emissions after carbon dioxide on a mass basis, but has a much more harmful short term effect due to a greater warming effect or GWP. The impact of this is significant and easily misinterpreted - the largest gas by volume is not the most dangerous by GWP.

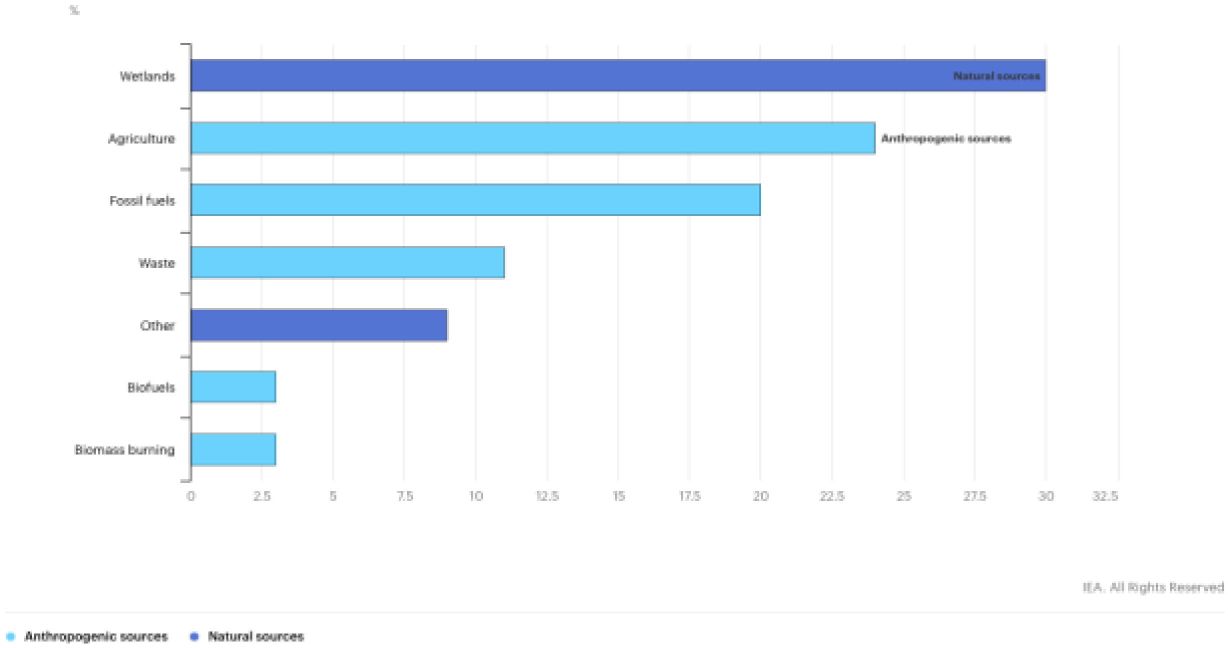
Global greenhouse gas emissions by mass percentage, 2010



Source: Intergovernmental Panel on Climate Change, *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva: IPCC, 2014). Graphically Interpreted by US EPA at https://www.epa.gov/sites/production/files/2016-05/global_emissions_gas_2015.png

There are two types of sources for methane emissions: anthropogenic and naturally occurring. The anthropogenic sources, which account for 61 per cent of the total, are agriculture, fossil fuels, waste (including landfills, sewage treatment & animal waste), biofuels and biomass burning. The natural sources are wetlands, and other naturally occurring sources such as volcanic gasses, termites and many other smaller natural sources. Chart #2 outlines the major anthropogenic and natural sources of methane.

Global methane emissions by source, 2019



Source: IEA, "Sources of methane emissions", IEA, Paris https://www.iea.org/data-and-statistics/charts/sources-of-methane-emissions

The oil and gas sector consistently appears to account for 20 per cent of global methane emissions. A factor we did not discuss is whether this includes the end user or not, which can make a big difference. Let's assume for now we are not including the end user.

The oil and gas industry is obviously a large emitter of methane emissions. As an energy provider, this industry should be leading the way on methane emissions mitigation. In some jurisdictions, this is the case. In the oil and gas industry, there are upstream segments (exploration, drilling, well completions – the process of completing the wellbore with tubulars for permanent use) that find the source and tie it into the grid. This grid, or infrastructure, is known as the midstream segment, which includes (processing, gathering, local and inter-jurisdictional pipelines) that carry out pre-market readiness functions. The final segment is downstream (refining and preparation for final use or local distribution system), which is where the energy is transferred to the consumer.

Of these segments, the leaders in methane measurement and mitigation (MEMM) are midstream functions as well as downstream operations, as in both cases it is possible to document and plan all of the operations in a permanent facility design process. In addition to design documentation and construction of permanent facilities, leaks or escape of methane is relatively easy to measure and mitigate. Upstream, which is all comprised of temporary components, including exploration, has primarily been able to reduce emissions through the replacement or restriction of flaring. Many parts of the upstream value chain have not been addressed, including the temporary procedures of hydraulic fracturing and the 'flowback' post-fracture treatment. This has only recently been addressed. A recent paper on minimizing emissions in sand separators stated:

> For 1 m^3 of sand stopped by each sand separator the vertical geometry would produce 72 per cent of the carbon of the spherical vessel while the horizontal desander would produce 26 per cent of the spherical and the low angle tilt would produce 11 per cent.[48]

This represents a quick reduction of methane venting to atmosphere of 89 per cent just by analysing the geometry of the vessel and moving from spherical to a slightly tilted horizontal vessel. Amazing! – also known as low-hanging fruit.

More readily available are the gains at upstream and midstream facilities, where many innovations and technological changes can replace such things as pneumatically driven devices, various kinetic energy sources using line gas, convert fossil-fuel-

[48] R. Wasfy, D. Spady, K. Hierath, *Fugitive Emissions Study: How to Minimize Emissions While Utilizing Sand Separators* (paper presented at the Society of Petroleum Engineers Annual Technical Conference, Calgary, Canada, 30 September – 2 October 2019, SPE#196142-MS).

powered motors to solar-powered motors and actuators, and switching from line gas to instrument air (compressed air), ideally using a solar-powered source.

A large component of methane emissions is entirely due to leakages, both on the surface and in the subsurface. To find these, leak detection technologies are used. There has been an explosion of available technology for this activity, from the large (via satellite) to the small (valve- or fitting-specific scan). Hand-held optical gas imaging cameras are currently the standard, and will continue to be used in very specific locations on the ground at each valve or fitting, identifying source point leaks.

Other emerging technologies being developed at universities, in government labs, in private workshops, and in the field include drone-mounted sensors, fence-line scanners, mobile equipment that can be moved from site to site, and truck-mounted solutions. This exciting and rapidly emerging space is gaining a lot of attention from industry, government, and environmental non-government organizations (ENGOs) alike. A great example of this is the Canadian Association of Petroleum Producers' Alberta Methane Field Challenge, 'an international competition to test emerging methane detection technologies in a real world setting'.[49]

Venting, in all its forms, is another major source of methane emissions. The difference between fugitive gas (unplanned) and vented (planned but not measured) gas release is simply a matter of design. In an emergency, venting can occur safely to try to bring the pressure situation back into control. When pressure builds too quickly, it must be de-pressured in a safe manner to avoid an explosion, a practise similar to a pressure release valve in a household appliance. Venting is designed to depressure an explosive situation. Many facilities are planned and built to allow de-pressurization in certain situations. This is often categorized as venting, and it is designed to release pressure, but usually not measured. In the example of the flowback of fluids after the conclusion of a hydraulic fracturing treatment, or post-frac flowback as cited above, the objective was that the highly erosive sand would be removed from the flowback process. The pressurized vessel containing the sand, however, is designed to de-pressure by venting or releasing the unwanted gas to the atmosphere before removing the trapped sand. Again, this is gas that can be collected and re-injected into the sales pipeline. The releasing of this gas from the pressure vessel, or venting, harms the environment and loses potential revenue.

Tank vents are arguably the most problematic source of methane emissions. They are difficult to measure (due to health and safety concerns and lack of available equipment) and equally difficult to mitigate given the lack of cost-effective technologies. On the plus side, there are emerging technologies that support the reduction in liquid loading from tanks. While this is a small source of overall methane emissions from the oil and gas supply chain, it is indicative that innovators are focusing on reliable solutions. While measurement may continue to be problematic for these tank-venting sources, it is important to focus on solutions that mitigate the emissions while simultaneously building better emissions measurement solutions.

This leads us to one of the biggest issues limiting rapid uptake of methane-reduction solutions – finding high-quality data on a worldwide scale. Producers are not required to report through a rigorous system, and there are no widely accepted quantification methodologies within a single jurisdiction, let alone any that apply to multiple producing regions. This makes both local and global data sparse. Voluntary schemes and non-robust self-reporting do not always give accurate data.

The lack of high-quality data is a challenge for both regulators and investors, because there is no standard or benchmark that can be used to measure performance. The problem is exacerbated by the fact that there are a multitude of data points that comprise a single company's methane emissions profile. Collecting equipment inventories (e.g. valves, controllers, fittings, and pumps), identifying emissions sources and quantifying the plumes (e.g. intentional and unintentional leaks, blowdowns, and flashing losses), and using reliable emissions quantification methodologies each present challenges in data management. Fortunately, there are a number of well-built emissions data management systems available to the market. Unfortunately, with the lack of standardized databases, methodologies, and regulatory requirements, these data management systems cannot necessarily be compared as apples to apples, which makes benchmarking performance between organizations and jurisdictions difficult.

We have defined the problem and its various manifestations, but what about solutions? What is driving or forcing change in the industry? There are several key stakeholders, each with its own influence over emissions performance. Industry has been pursuing emission reduction for over a decade, largely driven by corporate responsibility initiatives. The public, First Nations

[49] https://www.capp.ca/explore/methane-emissions/

(Aboriginal communities), and ENGOs aim to hold industry accountable by raising awareness of matters that are important to them.

Sustainability concerns and climate change leadership from the investment community is now driving change. The most notable example is the position that BlackRock, a large financial institution, has taken:

> Climate change is driving a profound reassessment of risk and we anticipate a significant reallocation of capital.… BlackRock recently brought on board a leading impact investing team that offers clients alpha through a portfolio of companies chosen on their measurable, positive impact to society.[50]

Finally, and perhaps most critically, governments are driving change through new policies and regulations. Consequently, many regulatory agencies around the globe now understand the issue, and most are planning and reacting to varying degrees.

One of the most proactive jurisdictions is the province of Alberta, Canada. The regulatory body responsible for managing and reducing fugitive emissions is the Alberta Energy Regulator. Recently it has been enforcing a strict measurement guideline, followed by a prescriptive mitigation policy. In 2015, the Government of Alberta directed the Regulator to 'develop requirements to reduce methane emissions from upstream oil and gas operations by 45 per cent (relative to 2014 levels) by 2025.'[51] Given that the oil and gas industry accounts for 70 per cent of the province's methane emissions, it simply had to be done. The work was carried out in a pragmatic two-stage process, using two industry rules: Directive 060, Upstream Petroleum Industry Flaring, Incinerating, and Venting; and Directive 017, Measurement Requirements for Oil and Gas Operations.[52]

Since several Canadian provinces have taken a leading role on this issue, Canada has become one of the leading jurisdictions globally on measuring fugitive methane emissions and mitigating the source of the emission. The practical ability to do this is a very large step past the simple acknowledgement of the need for change or even the building of policy to address the issue. Regulatory or Government Policy must be enforceable and practical, and must reduce methane emissions without restricting the growth of an industry that has globally best-in-class social and environmental standards. This is where technology is playing a leading role.

Innovation in this space is moving at lightning speed. With new jurisdictional direction and enforcement, coupled with the need to prove carbon accounting to financial institutions, new technologies have a fertile space where they can innovate, test, and commercialize their solutions in very short cycle times. The results have been very positive.

There are many practical examples and concrete evidence of solutions ready today for reducing greenhouse gases, and they are measurable. This is an easy win, and it is economic.

In conclusion, when there is commitment from government, regulators, industry, and ENGOs to collaborate and act, the results can be stunning. History will record us as being quick, proactive innovators if we work together to solve a problem. Our efforts in measuring and mitigating methane emissions require all of these pieces working in parallel, not successively. We can do something, and we can do it now.

GAIA – OIL AND GAS INDUSTRY ACTIVISTS LEADING THE WAY BACK INSIDE PLANETARY BOUNDARIES

Johana Dunlop

Most of my professional life has been devoted to bringing about new ways of conducting business that take account of impacts on society, positive and negative – the so-called externalities that are so rarely integrated in the cost of doing business.

I'm just one of thousands inside the global oil and gas industry, many true pioneers, who work to advance industry understanding of what it means to operate within planetary boundaries and develop sustainably. We challenge the status quo; create tools and processes; engage with our operations colleagues and work alongside them; bring in expertise from social

[50] https://www.blackrock.com/us/individual/blackrock-client-letter
[51] Alberta Energy Regulator, *Methane Reduction* (Calgary: AER, 2020), https://www.aer.ca/providing-information/by-topic/methane-reduction.
[52] Alberta Energy Regulator, *Methane Reduction* (Calgary: AER, 2020), https://www.aer.ca/providing-information/by-topic/methane-reduction.

science, economics, anthropology, environmental science, engineering, and many other disciplines; collaborate to develop best practices to share across the industry; engage with external activists; write technical papers; share our knowledge; drive insightful disclosure practices; drive performance; and work to make sustainability everyone's business.

Professional technical associations have yet to mobilize in relation to sustainable development as it relates to the oil and gas industry. My own professional association is the Society of Petroleum Engineers (SPE), the largest and the only one to date to welcome health, safety, environment, and sustainability professionals on the same footing as their colleagues from the technical disciplines of reservoir engineering, drilling, completions, data science, and production, facilities, and operations.

With 154,000 members in 140 countries, organized into over 500 chapters (including 300 student chapters), the SPE has a footprint that mirrors that of the oil and gas industry. Schlumberger used to say 'where the drill goes, Schlumberger goes'; SPE can make the same bold statement, as it is present in every context in which oil and gas is explored for and developed around the world.

Since 2004 SPE has been a home for Health, Safety & Environment HSE professionals, and in 2010 it became a home for sustainability professionals in the industry. While Greta Thunberg was urging people to 'act like the house is on fire', the sustainability professionals in SPE were doing just that – considering that the scale and the urgency of the challenges facing the planet were reaching a level that merited an acceleration in our efforts. A tipping point in anxiety levels had been reached, possibly a tipping point in key indicators of the health of the planet. The IBHES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) report in May 2019 was a personal tipping point for me.

A group of leaders of the SPE HSE & Sustainability discipline[53] brainstormed about what else we could be doing, what we would wish we had done were we in 2050 looking back, and what other resources we could use to promote sustainable socio-economic development that does not irrevocably push the planet beyond 'the safe operating space for humanity that allows the intrinsic biophysical processes that regulate the stability of the Earth system'.

In collaboration with the American Association of Petroleum Geologists (AAPG), IPIECA (formerly International Petroleum Industry Environmental Conservation Association), International Oil and Gas Producers Association (IOGP), and Oil and Gas Climate Initiative (OGCI), we devised an initiative that we named Gaia, after the ancient Greek earth goddess, to engage and support the members of the oil and gas industry's technical professional societies around the world, starting with the SPE and the AAPG.

Our basic premise was that all hands are needed on deck if oil and gas is to come out on the right side of history – valued for its contributions, yet agile and imaginative enough to evolve with changing expectations of its role in society, demanding as those expectations might be. We wondered what resources were not yet in play and realized that the brainpower and professional experience of tens of thousands of individuals working at the heart of the oil and gas industry were not yet engaged in achieving that goal.

Our initial objective is to reach as many of these individuals as possible. They sit below what I call the sustainability glass floor – running the industry's operations, research and development, and commercial ventures. They are critical to the social and environmental performance of the industry and yet have no direct responsibility for it.

They are individuals, with their own world views, experiences, competencies, talents, sensibilities – and emotions, which are critical to understanding how the increasing polarization between different points of view has come about. Emotions are firing on all cylinders in 2020 and have a tremendous impact no matter where one sits on the fossil fuels and global warming spectrum. They underpin many opinions that bounce around in echo chambers, fuelling mistrust of the agendas and intentions of activists and oil and gas companies. Emotions are important, but they alone do not create the conditions for collaboration and innovation – both essential to a more diverse energy mix, energy access for all, and hydrocarbon use that is net beneficial.

The oil and gas sector's thousands of members find themselves at the heart of societal pressures, pressures that are looking to reconcile a high quality of life with its apparent negative impact on the planet on whose natural services we are dependent. Thanks to their ingenuity in developing hydrocarbons, the members of this sector have enabled the quality of life that most people in the developed countries enjoy. However, this beneficial use of a natural resource provided by the geology of the

[53]Johana Dunlop, Trey Shaffer Flora Moon, Ariane Labadens, Nigel Jenvey, Kamel Ben-Naceur, Josh Etkind Miriam Winsten [AAPG], Judy Kuszweski [Sancroft], Brian Sullivan [IPIECA], Gordan Ballard [IOGP], Peter Day [StarfishTaylor] Julien Perez [OGCI].

planet and thousands of years of its forces at work comes at a price. The very quality of life built on the consumption and combustion of fossil fuels now appears at odds with the balance of our planet. A growing population is generating more waste and encroaching on critical habitat at a rate faster than it can replace itself. Our current consumption models do not appear sustainable, and we cannot account for the externalities of our production activities. No-one is to blame, yet we are all responsible.

For the individuals in the oil and gas industry, the decades of feeling pride that our brainpower was enabling progress are now being replaced with a period in which we continue to feel pride but accusations that engender feelings of defensiveness, even shame, seem to be gaining the upper hand. Yet it is clear from all reliable sources that oil and gas are essential to the future of energy access, key to poverty reduction and even to enabling a more diverse energy mix that includes renewables, which have yet to reach a stage that would support scaling. We are at a complex juncture in history that requires us to engage with stakeholders who want to keep in the ground the energy sources we understand so well.

The ambition of the Gaia Program is to work collaboratively through the professional societies to engage all possible oil and gas industry brainpower and to generate the conversations and conditions inside and outside the industry that encourage constructive multi-stakeholder engagement and encourage the release of capital to fund innovations and solutions that will undoubtedly be built on new business models and new ways of sustaining a high quality of life whilst meeting the world's energy needs. The professional societies are host to conditions that may be unique – participation driven by commitment and domain knowledge, absence of hierarchy, events designed and delivered by these same individuals enabled by professional events staffs, technical journals and repositories, communities of practice, and multi-stakeholder participation, to name a few.

In June 2019, 55 individuals representing eight stakeholder groups convened at the first Gaia Summit, an event designed by industry and non-industry volunteers; silent activists; individuals supported notably by the SPE, AAPG, IPIECA, IOGP, and OGCI; and a few key companies.

Together we worked intensely and non-hierarchically over three days, crystallizing some key ideas as to how we, a nascent movement of individuals, enabled by our professional societies, could contribute uniquely to addressing the tensions between humanity's needs, the balance of the planet's boundaries, and the complex systems and interdependencies that make life possible. Out of this collaborative effort emerged six pathways to action and four principles to guide the actions.

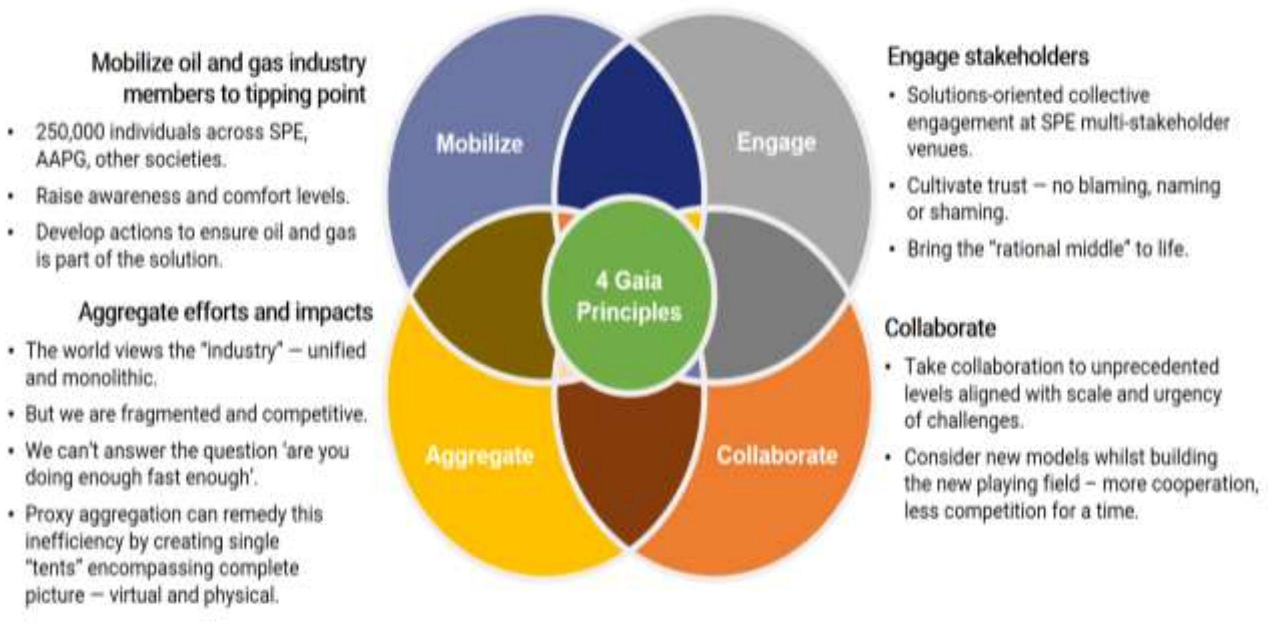
Pathways and principles

The six Gaia pathways indicate the areas in which professional society members could make the greatest contributions through their various venues, governance mechanisms, and communications and technical knowledge-sharing channels. Each pathway has volunteer leaders and is defining and deploying its ambitions through existing and new SPE events and communications channels.

- *Execution* involves ensuring swift and decisive mobilization, aggregation, engagement, and collaboration.
- *Internal industry collaboration* needs to be consistent with the scale and urgency of the challenges.
- *External collaboration* means working with key stakeholders, including academics, activists, policymakers, and start-ups.
- *Measuring what matters most* requires the prioritizing and measuring of of the performance factors that matter most to support decisions, operations, research and development, and commercial activities, by investors and other key stakeholders, that are aligned with sustainable development.
- *Listening and communication* will make it possible to identify the conditions for generating behaviours that are rewarded by the confidence of investors, the loyalty of employees, and the trust of stakeholders, and that allay fears and encourage curiosity and confidence.
- *Innovation* and our best brainpower must be leveraged in service of sustainable socio-economic development.

The four Gaia principles guide what we can do differently, that is unique to our strengths and does not duplicate others' efforts, but rather extends their reach and reinforces them, whilst also catalysing new, even radical, ideas.

- *Mobilization*. Today the oil and gas industry faces an existential threat, yet stands on the brink of a revolution that will see our energy system diversify, decarbonize, and decentralize, with oil and gas still in a pivotal role. There is no road map of sufficient detail or visibility to guide us, and yet we need one so we can plan, prioritize, prove concepts, experiment, fail, try again, raise capital, recruit talent, innovate, design, build, and bring solutions to market. The oil and gas industry is not yet fully mobilized. There is a glass floor below which integration of the UN Sustainable Development Goals is confronted with considerable operational challenges competing with many other priorities and in a form that is not fit-for-decision. We must overcome these barriers and remove these paradoxical injunctions, urgently but thoughtfully, as they are real and require reframing and technique to render them fit-for-performance. Industry societies such as the SPE, AAPG, and others have hundreds of thousands of individual professionals within their reach. We must mobilize them and equip them to be conversant and enable them to integrate sustainability factors into their core objectives – but more importantly, to unleash their creative brainpower in the service of sustainability solutions. We believe the tipping point to be 250,000 individuals.
- *Aggregation.* Today we see a multitude of efforts across the industry going in the right direction and many of great significance, but we are unable to answer the question of just how much are we doing as an industry and whether it is enough and fast enough. We must improve our ability to quantify and measure what matters, but that will take a long time to mature to sufficient reliability. In the meantime, we need proxies – virtual and physical single entry points to the industry that provide a 'good enough' indication of relevance and impact – in context, accountability that generates great confidence, and by extension greater trust that tolerates enough discomfort to produce learning and accommodation of divergent points of view.
- *Engagement.* Conversations must become more solutions-oriented and more encouraging of the kind of engagement Fatih Birol, executive director of the International Energy Agency, called for on numerous occasions last year. Oil and gas industry events can be designed to foster confident collective engagement and increase accountability on all sides, including the industry and external actors and activists.
- *Collaboration.* As an industry we do collaborate very well already, but the scale and urgency of current challenges require a whole other level of collaboration. With regard to sustainability challenges, we are still building the playing field; we should collaborate intensely until it is built, and only then should we compete again. Collaboration doesn't happen overnight; it must proceed through phases to reach levels of collaboration that produce shared goals and shared progress. No collaboration reaches its full potential without near absolute trust, and today the conditions for trust are unstable.



Conclusion

The *2020 Edelman Trust Barometer* asserts that business is a catalyst for change, and individuals look to businesses as agents of change, with the means to carry a higher purpose than simply the profit required to sustain their existence and reward their shareholders and employees, and the potential to enable individuals to become change agents themselves. Edelman also reports that only 24 per cent of a company's measurable trust capital is explained by how good it is at what it is set up to do – design, innovate, plan, build, create teams, find and develop talent, motivate them to work together in the service of the company's mission, and deliver to customers on time, at an expected quality, for an appropriate price – although this is no small feat. The remaining 76 per cent of a company's trust capital is driven by integrity, purpose, and dependability. Businesses are expected to accomplish much – not alone, but in partnership with others, with business as the engine, the most powerful element in the chain of relationships that together can 'move the world to a more trusted state'.[54]

We need to act both quickly and slowly, with urgency and measure, with daring and caution. We need to experiment and evolve new business models, generate excitement, cultivate trust, and collaborate in ways that challenge our competitive mental models. We must find ways to integrate sustainability factors into our business performance metrics to ensure that the business of business is purpose and that this is not incompatible with profit. Sustainability competencies and accountability must mainstream and no longer rely on the tone from the top and the experts on staff. Just as safety was eventually recognized as being everyone's responsibility, so must sustainability be recognized as relevant to each of us. To paraphrase Katherine Hayhoe, the reality is that if we are a human living on planet Earth, then [climate change] [sustainable development] already matters to every single one of us; we just haven't realized it yet.

We are not crossing the road, we are embarking on a game-changing civilization-changing expedition more akin to crossing Antarctica in mid-winter. Now that there is sufficient collective acceptance of the need for action, we need the time to plan and the tenacity, brainpower and capital to create the technologies that will produce the solutions that can restore trust in the oil and gas industry and industry vital to the continued progress of humanity, but within the boundaries of the natural system from which we have become so disconnected. I am personally optimistic that oil and gas can and will lead the way, it must.

[54] *2020 Edelman Trust Barometer report*, page 10. https://www.edelman.com/trustbarometer

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