Unconventional Fossil Fuels: Stranded in a Climate-Constrained World?

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Energy & Sustainable Development


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INTRODUCTION

UNCONVENTIONAL FOSSIL FUELS: STRANDED IN A CLIMATE-CONSTRAINED WORLD?

'Unconventional' fossil fuels cover an extensive range of resource types (heavy oil and oil sands, shale/tight hydrocarbons, gas hydrates), some commercially competitive today, others a long way from viability.

The resource base is huge and will be a large contributor to production up to 2050. How will unconventional fossil fuels develop worldwide? Will environmental policies block their adoption?

Energy Industry Report

This research paper is part of a 12-month series published by The Al-Attiyah Foundation every year. Each in-depth research paper focuses on a prevalent energy topic that is of interest to The Foundation's members and partners. The 12 technical papers are distributed in hard copy to members, partners, and universities, as well as made available online to all Foundation members.

EXECUTIVE SUMMARY

- North America is the long-running centre of unconventional development; other regions are advancing, such as Argentina, China, Russia, and the Middle East.
- Unconventionals have a large spread in costs and environmental impact. At oil prices of $50-60/bbl, oil sands expansion is unlikely, but existing operations are viable; deepwater developments can be highly attractive. United States (US) shale output will be steady but probably not grow significantly.
- Environmental issues include local effects on land, water, air, and greenhouse gas (GHG) emissions. Oil sands have particularly high GHG emissions, which is likely to constrain their expansion. High levels of gas flaring from US shale output weaken its environmental credentials and may constrain exports.
- Continued technological and environmental improvements and the conventional resource base's maturity will lead to an expanded role for unconventionals. However, community, NGO, and government opposition will prevent growth in many promising areas.

IMPLICATIONS FOR MAJOR OIL AND GAS PRODUCERS

- The substantial unconventional resource base far exceeds likely demand to 2050 and beyond. Most unconventional resources will not be produced. Developers will have to concentrate on cost reductions, effective business and investment models, project management, and technology improvements.
- The competitive pressure from unconventionals means that OPEC and other large conventional oil producers have to avoid prices rising too high and losing market share.
- Unconventional gas offers improved self-sufficiency to key countries such as China, parts of the Gulf Cooperation Council (GCC), and possibly Ukraine. Unconventional gas-to-LNG is a competitive threat to Russian gas exports to Europe.
- Coal-to-liquids will probably not expand further outside China, and gas-to-liquids will only grow in niche areas. Oil shale (kerogen) has limited applicability because of high costs and environmental impact. Gas hydrates are a huge resource but technically very immature and of questionable feasibility as yet.
- Unconventional producers will invest in reducing their environmental impact, particularly GHG emissions. Eventually, this will have to focus mostly on non-emitting uses, such as hydrogen production or combustion with carbon capture and storage (CCS).

UNCONVENTIONAL FOSSIL FUELS COVER A WIDE RANGE OF TYPES

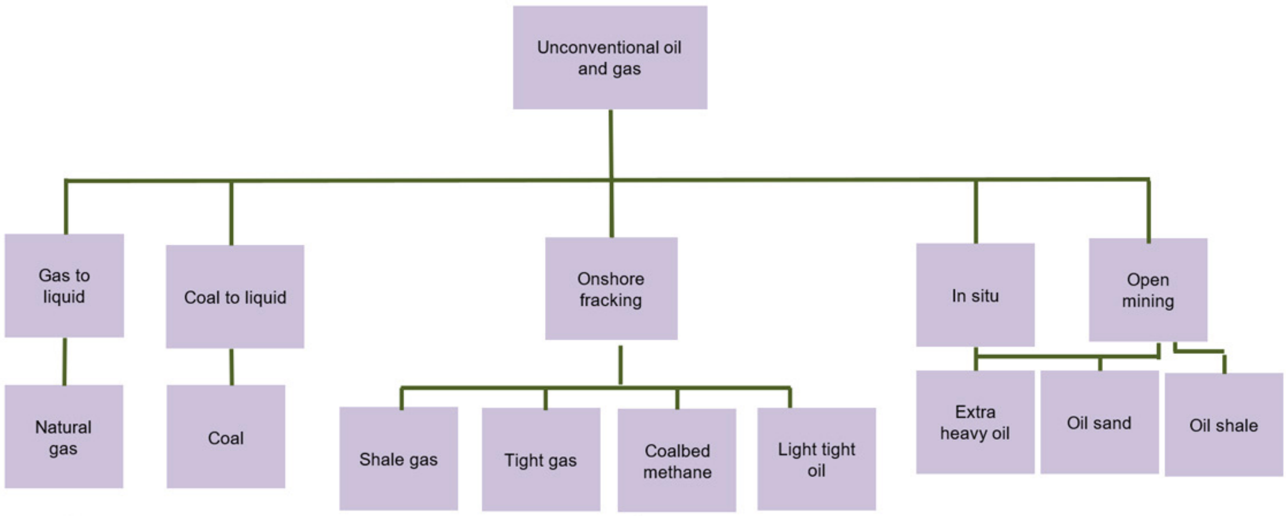
Unconventional hydrocarbons can broadly be divided into three categories:

- Synthetic fuels (made from biomass, coal or natural gas);
- Tight reservoirs (low-permeability sandstones and carbonates, shales, coalbeds, and gas hydrates); and
- Immature or low-quality oils (oil sands, heavy and extra-heavy oil, and oil shale.

Some classifications might also consider oil in difficult geographies (deepwater, Arctic), or contaminated/sour gas (high hydrogen sulphide or carbon dioxide) as unconventional.

The extraction and processing of unconventional oil are typically more difficult and expensive than conventional oil. However, shale oil/tight oil requires a lower sunk cost than conventional oil, with a much shorter lag between initial investment and production – contributing to shorter and limited oil price cycles.

Figure 1 Unconventional oil and gas technologies and sources



UNCONVENTIONAL FOSSIL FUELS

According to IEA estimates, technically recoverable global tight oil resources amount to 420 billion barrels (bbl), 10% of the world total (Figure 2). These are located mainly in the US, Argentina, Russia, Australia, Chad, China, and the UAE. Oil sands' high viscosity, high density, and high concentrations of nitrogen, oxygen, sulphur, and heavy metals make the costs of extraction, transportation, and refining very high. These resources are regarded as reliable long-term flows of liquid hydrocarbons from politically stable jurisdictions with substantial payoffs for any recovery improvements. In Canada, oil sands production reached 2.9 Mbbl/d in 2019, compared to 1.7 Mbbl/d of conventional oil.

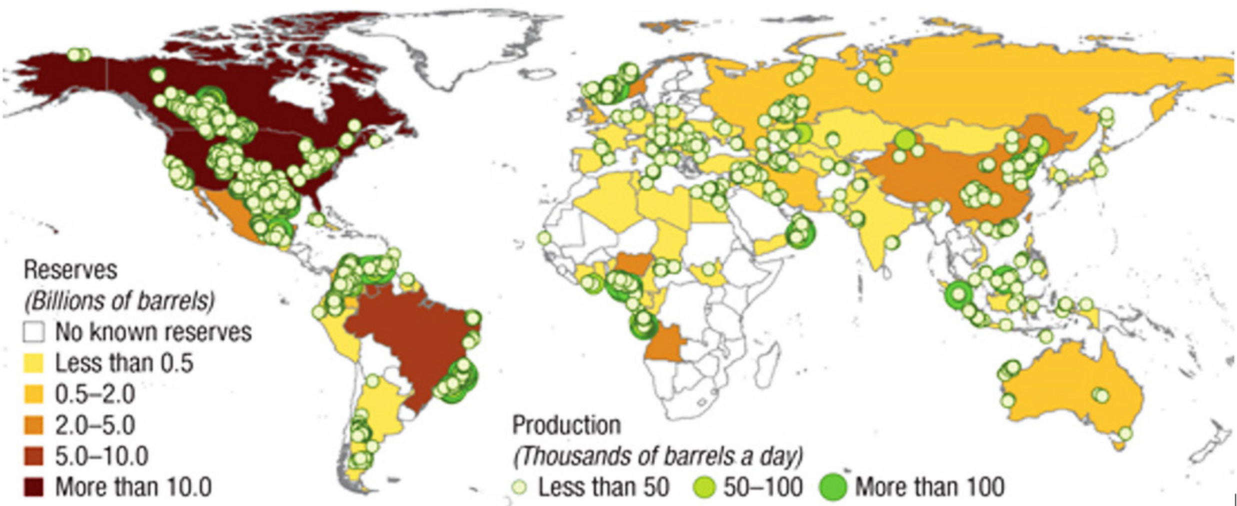
Improvements[i] in drilling techniques enabled drilling in much greater water-depths, allowing deepwater and ultra-deepwater oil extraction. Definitions have moved on with time, but deepwater could be considered deeper than 300 metres, and ultra-deepwater is beyond approximately 1,500 metres.

UNCONVENTIONAL FOSSIL FUELS

Significant demand growth has substantially driven unconventional natural gas (UG) production, with shale gas production fulfilling 69% of the US's expected total dry natural gas demand. UG comes from three main sources: shale gas in low-permeability formation, tight gas in low-permeability sandstone and carbonate reservoirs, and coalbed methane in coal seams. UG is usually found in less permeable deposits rather than discrete reservoirs, using hydraulic fracturing/ fracking, horizontal drilling, multiple drilling, and acidisation. Although several countries began producing it, many global resources have yet to be assessed.

According to the IEA, total production of unconventional gas reached ~700 BCM, 20% of world supply, in 2014, with the US dominating 75% of the total production. UG resources are estimated to account for an approximate 44% of the total technically recoverable gas resources. North America occupied the largest market revenue share in 2019, with the US as the major contributor (Figure 4). Meanwhile, potential shale gas resources in China are attracting significant investments to extract and produce UG.

Figure 2 Unconventional oil, proven reserves, and production, 2016 [i] Over the last decade, unconventional oil and gas have witnessed rapid growth thanks to new technologies unlocking their development potential – previously unreachable and uneconomical using conventional production methods. Their importance is set to continue: according to Rystad Energy, around 30% of the deficit volumes between 2021 and 2050 will come from unconventional global plays.[i] Major unconventional sources include tight gas, shale gas, coalbed methane (CBM), light/extra heavy, tight oil, oil sands, and oil shale (Figure 1). As they become more effective and widely adopted, technology improvements could boost recoverable oil and gas reserves, changing their supply outlook.



Hydrates are an ice-like material formed by water and methane or carbon dioxide at low temperatures or under high pressure. They are found in Arctic areas and under the seabed in deep water. Due to their vast quantities across all regions, gas hydrates are considered "near-future energy resources." In the US, gas hydrates' resource estimates range between 250,000-700,000 Tcf of natural gas compared to 2,829 Tcf of recoverable resources of dry natural gas. These resources could become a major energy source but could exacerbate global warming, as hydrate deposits deep under the oceans or in permafrost may release methane into the atmosphere. Their enormous quantity also could not be used without

Figure 3 Unconventional oil production, 2016

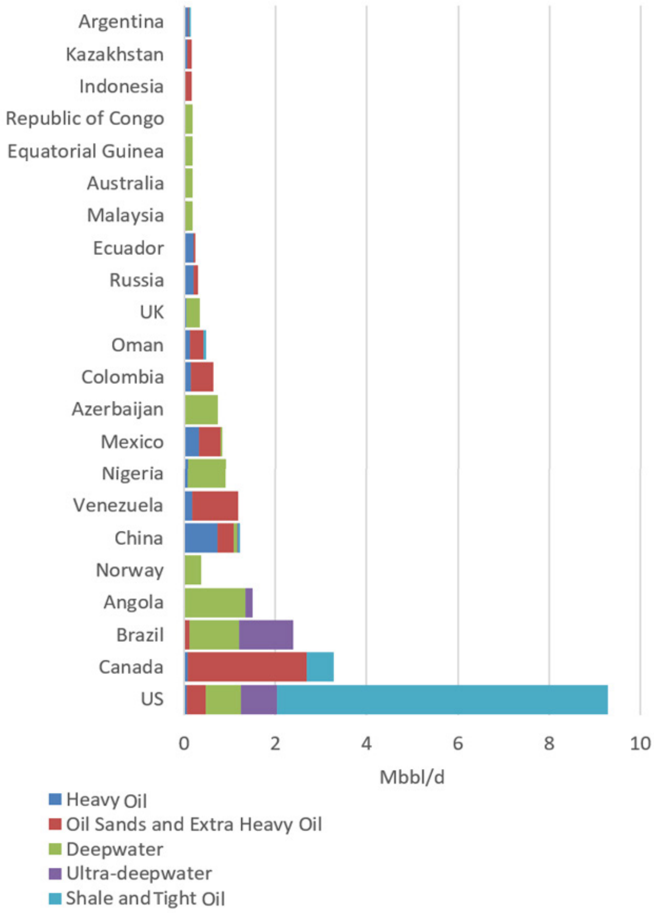
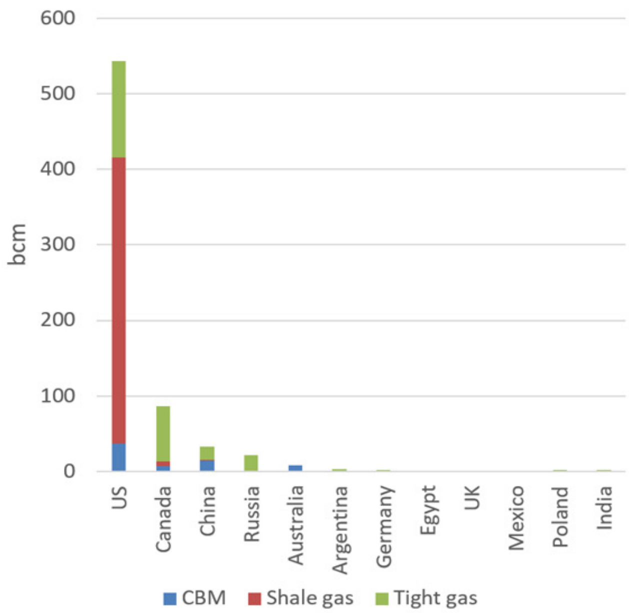
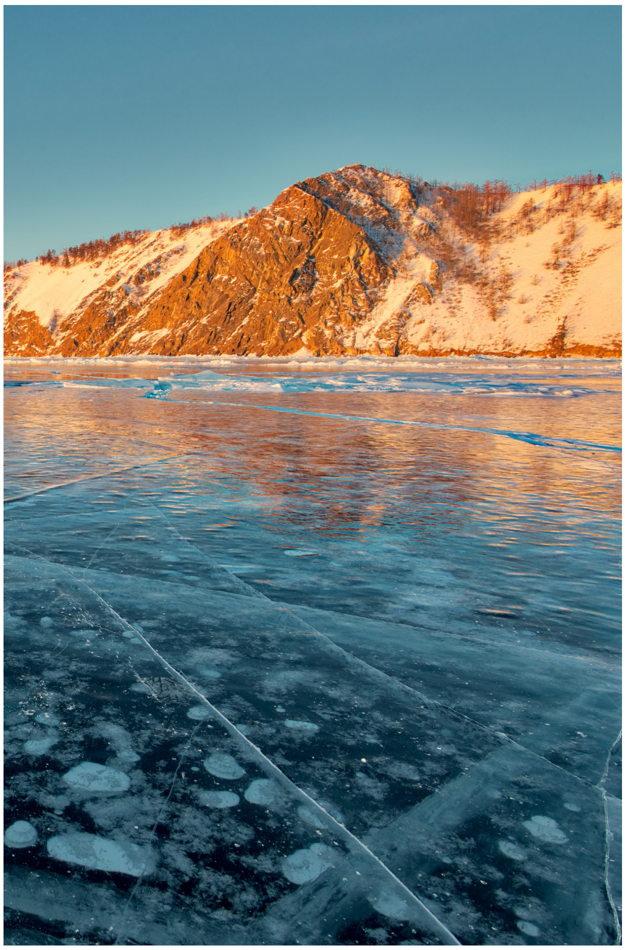


Figure 4 Total unconventional gas production in 2014, by producing country



causing dangerous climate change, unless consumed with non-emitting methods such as CCS or conversion to hydrogen.

Currently, there are a few small gas/methane hydrate pilots around the world. Japan will start operations at its first methane hydrate production test, a joint demonstration with the US, on the Alaska North Slope following drilling in 2020-2021. Meanwhile, in March 2020, China extracted 861 cubic meters of natural gas from gas hydrates found in the South China Sea during a month-long trial. The country recently tested gas production from methane hydrate-bearing clayey silts through horizontal drilling for the first time. However, it remains questionable whether hydrates can be extracted at commercial rates over long periods.

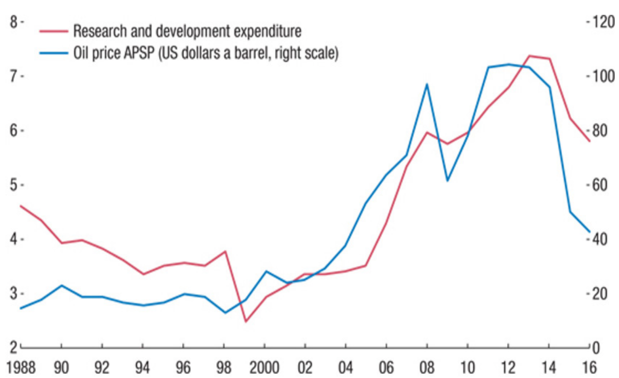


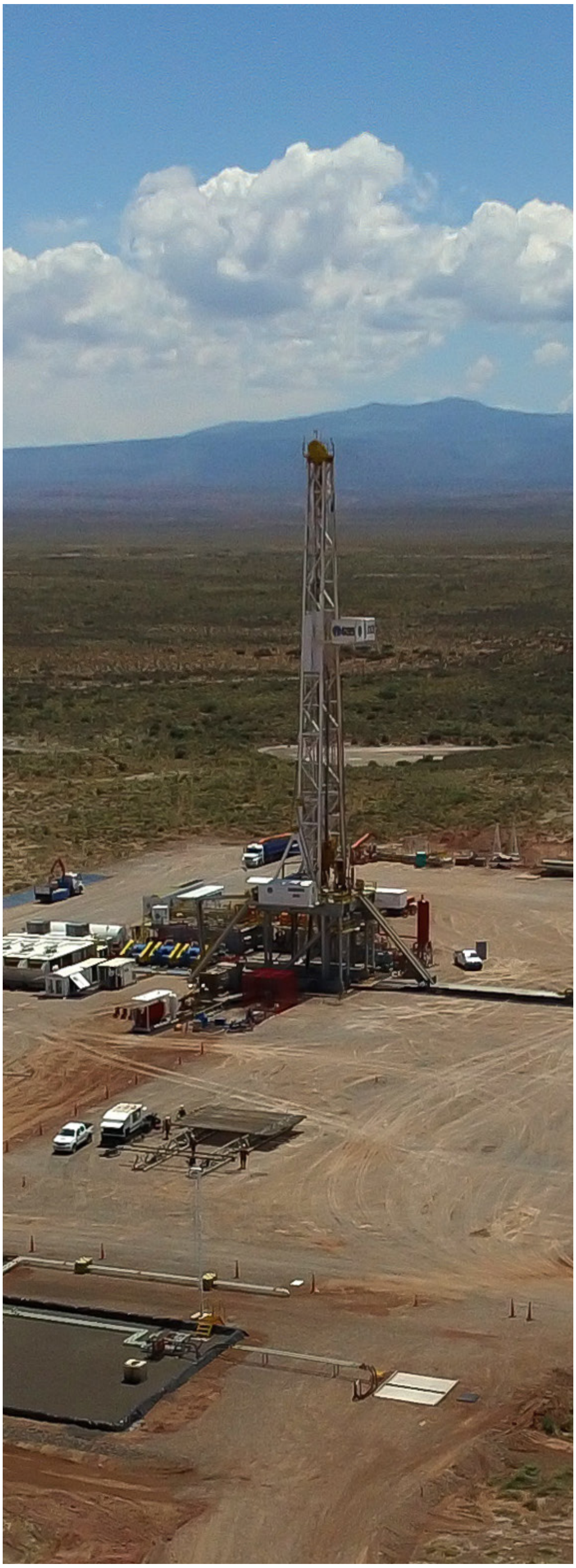
DIFFERENT TECHNOLOGIES ARE USED TO EXTRACT DIFFERENT UNCONVENTIONALS

Hydraulic fracturing/fracking in oil and gas exploration is not new and was first tested in 1947 and applied in the industry around 1949. Subsequently, the technique was used for stimulation of reservoirs and enhanced oil recovery (EOR). The 1970s oil shocks gave impetus to development and trials of hydraulic fracturing. Mitchell Energy was an early pioneer in the Barnett Shale of Texas. However, substantial production did not begin until slick-water (low-viscosity) fracking was combined with horizontal drilling in the early 2000s. From there, shale gas development spread to other basins, notably the Marcellus in the eastern US, and shale/light tight oil formations of the Bakken (North Dakota, Montana and Saskatchewan), Eagle Ford (South Texas) and Permian Basin (West Texas, New Mexico).

Episodes of high prices have been accompanied by substantial increases in R&D expenditures (Figure 5) on the part of major companies mostly. However, the current low-price environment provides little incentive for research into oil-recovery techniques.

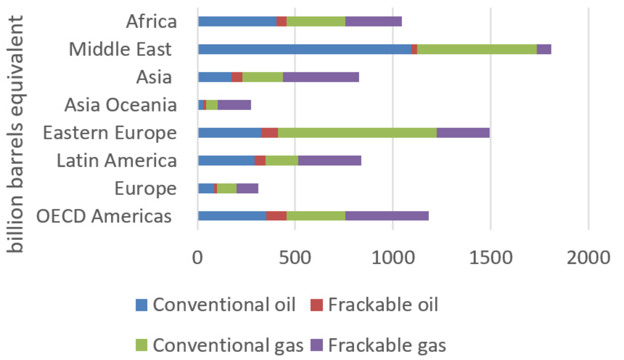
Figure 5 Evolution of R&D expenditure in selected integrated oil and services companies [vii]



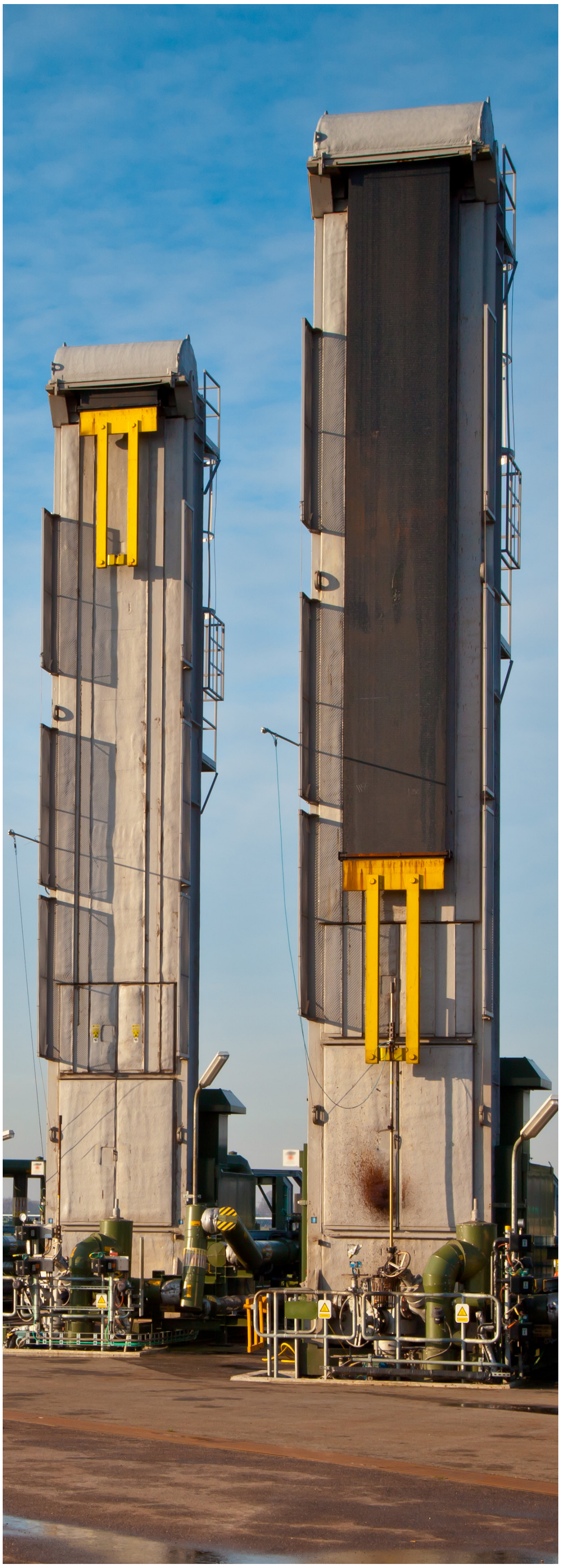


In the first decade of the 2000s, the rapid increase in oil demand, especially from emerging markets like China and India, drove prices up and encouraged investments in tight oil, ultra-deepwater, and extra-heavy oil. The majority of hydraulic fracturing occurs in North America, although large resources exist in the rest of the world, particularly in Asia Pacific (Figure 6).

Figure 6 Geographical distribution of oil and gas resources technically recoverable by conventional methods or fracking [viii]



Oil sands and extra-heavy oil typically require thermal methods for recovery, usually the injection of steam. Where sufficiently shallow, as in parts of Alberta, Canada, the oil sands can be mined from the surface. Otherwise, steam-assisted gravity drainage (SAGD) is used via horizontal wells for in situ recovery. Even though most of the reserves are only accessible through in situ production, 45% of the total 2.4 Mbbl/d of oil produced from oil sands came from open mining in 2016. Most in situ production currently occur in Venezuela and Canada, with 55% of Canada's oil sands production of 2.4 Mbbl/d produced in situ. In December 2019, thermal in situ production from oil sands averaged 1.49 Mbbl/d in Canada, up over 50 kbbl/d from November levels, a new record high for the sector, just before it plummeted in 2020. IHS Markit estimates oil



DIFFERENT TECHNOLOGIES ARE USED TO EXTRACT DIFFERENT UNCONVENTIONALS

sands production to be 175 kbbl/d lower in 2020 compared to 2019's levels, while, at its worst, over 700 kbbl/d of oil sands production may have been temporarily curtailed in the second quarter of 2020. Between January and June 2020, natural gas consumption in the oil sands fell by 22% from 3.2 Bcf/d to 2.5 Bcf/d [ix].

Oil shale is immature kerogen, an oil source rock that has not been buried deep enough to experience the heat and pressure to yield commercial oil. It can be extracted either through surface mining or in situ production.

Although in situ production is the most appropriate way to extract these resources, it is still considered an experimental method and is not commercially developed. Oil shale has been extensively mined for power generation in Estonia, and an oil shale power plant recently began operations in Jordan.

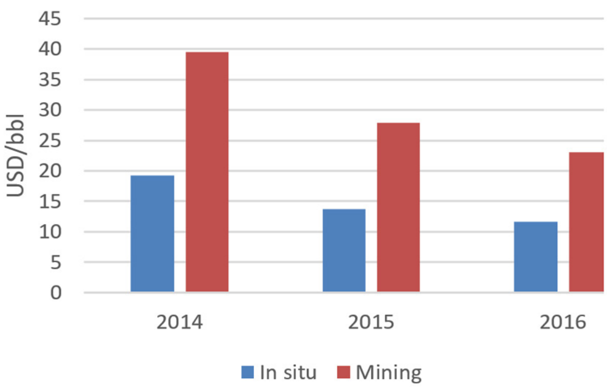
Meanwhile, coal to liquid (CTL) [x] and gas to liquid (GTL) [xi] are produced in small quantities relative to global production, with their technologies still under development. CTL is especially attractive to countries that depend on oil imports and are characterised by large domestic reserves of coal. Coal-derived fuels have been produced in South Africa since 1955. Currently, the country has the largest commercial coal to liquids industry in operation. CTL is used in cars and other vehicles and approved by Sasol to be used in commercial jets. Around 30% of the country's consumed gasoline and diesel are produced from indigenous coal.

The US has been exploring CTL development, though it has limited plans for commercial production. China and Mongolia are also developing the technology, with China opening the world's largest CTL plant in 2016.

GTL is usually seen as an option to reduce gas flaring or reduce the need for imported oil in a gas-rich market. Many small-scale pilots and commercial projects are under development. Qatar is currently having the biggest production facility globally, Shell's Pearl project, at 140 kbbl/d, and the smaller Oryx plant operated by Sasol (34 kbbl/day). Escravos in Nigeria (Chevron/Shell) produces 33 kbbl/d and PetroSA's Mossel Bay facility in South Africa 36 kbbl/d. According to IEA's estimates, total oil production by CTL, GTL, and similar technologies account for an approximate 0.35% of global oil production [xii]. In Canada, synthetic crude production declined to 878 kbbl/d in August 2020, down 88 kbbl/d from July levels, with Suncor and Scotford reporting a decline of 78 kbbl/d and 72 kbbl/d, respectively [xiii]. This shows the repercussions of the Russian-Saudi oil price war and the impact of Covid-19 on oil prices.

In terms of costs, in situ and mining operations witnessed significant Opex reductions, with in situ decreasing from US$ 19.2/bbl in 2014 to US$ 11.6/bbl in 2016, while surface mining fell from US$ 39.5/bbl in 2014 to US$ 23.1/bbl (Figure 7). Further reductions are expected as more R&D expenditures are allocated to optimise these recovery techniques. However, this is not expected to occur soon with the Covid-19-induced economic slump, pushing oil companies to cut their budget and slash their Capex.

Figure 7 Average production cost by extraction method [xiv]



UNCONVENTIONAL RESOURCES ARE GEOPOLITICALLY IMPORTANT

The strategic implication of unconventional energy production begins with the US utilising its domestic shale oil and gas resource to become the largest fossil fuel producer. As the largest producer, the US can achieve energy reductions to boost its domestic manufacturing sector, cut carbon dioxide emissions, develop its domestic natural gas and LNG sector for international exports, and reduce its dependence on imports. The impact of the shale revolution across the US has been profound and has:

- shifted the global energy landscape where the centre of gravity of hydrocarbon production growth has shifted from the Persian Gulf region to the Western Hemisphere;
- provided Europe with an option to diversify its dependence on Russia with the import of LNG from the US, in addition to developing its own indigenous resource;
- led to the US to reconsider its role in guaranteeing the stability and security of vital maritime energy routes;
- diluted OPEC's ability to dictate prices and encouraged it to pivot to Asia-Pacific for increasing conventional energy exports; and
- challenged China to explore its own larger shale gas resource to improve its energy security.

UNCONVENTIONAL RESOURCES ARE GEOPOLITICALLY IMPORTANT

The US's oil production increased by 8% per year, and natural gas production increased by 5% per year between 2009 – 2019.

As a result, the US currently produces 17 Bbbl/d of petroleum liquids (including natural gas liquids and biofuels), which accounts for 18% of the global supply, and 290 BCM of natural gas per year, which accounts for 23% of the global supply. The country has surpassed both Saudi Arabia and Russia as the largest hydrocarbon producer.

The US's Council of Economic Affairs (CEA) estimates that shale oil and gas exploration initiatives have had a positive effect on domestic energy costs and prices with domestic consumers saving US$ 203bn per year. Furthermore, 80% of the total savings resulted from lower natural gas prices (mainly through electricity tariffs), and 20% from lower oil prices (mainly through transportation fuel costs).

As a result of the price and cost competitiveness, energy-intensive industries such as speciality chemicals, petrochemicals, cement, and steel are undergoing a resurgence with overseas production units relocating back to the US and many European firms establishing new production facilities.

Moreover, shale oil and gas production across the US has reduced energy-related GHG and particulate emissions by 527 Mt per year between 2005 – 2017 by replacing coal in the electricity generation mix with natural gas. This effect, though, may now be running out of steam, with gas becoming a leading source of emissions.

Another geopolitical feature of the US's shale revolution has been the diffusion of fracking technology to develop unconventional fossil fuels in Europe. There are four onshore shale basins across Europe. Estimates of recoverable reserves are unclear as resource assessments are underway, but they appear roughly one-third of US shale reserves' size. However, despite considerable efforts under the Obama administration to study and promote worldwide shale hydrocarbon potential, European shale resources have made very little progress because of high costs and environmental opposition, some of it bankrolled by Russia.

The exception could be Ukraine, if it begins to produce shale gas, helping free itself from Russian pressure and facilitating its integration with the European Union (EU), which also provides the EU with additional leverage to exercise political trade-offs with Russia.

Instead, the additional international supply of natural gas and LNG from the US has diversified natural gas supply options for the EU, away from Russia, and to a smaller extent the Eastern Mediterranean and North Africa.

Although the US has improved its energy self-sufficiency, it is a mistake to assume that it is energy independent. It still has to import medium and heavy crudes to blend with its predominantly light crude for refining. Beyond this issue, the increase in non-OPEC energy production has certainly diluted OPEC's ability to dictate energy prices. Rising US shale output was the primary factor in the 2014 oil price crash, and the OPEC+ grouping, including Russia and other non-OPEC states, have been cautious not to push prices too high and again lose market share to the US. However, the "global market for oil" will continue, where disruptions worldwide will impact prices everywhere.

Nevertheless, growing competition and lower prices have put a strain on the economies of major oil exporters. They have also given the Trump administration the leverage to impose stringent sanctions on Iran and Venezuela, cutting their oil exports to low levels.

On a geopolitical level, the shale revolution across the US has encouraged the Obama, Trump, and the future Biden-administration to rethink the US's role as a security guarantor and the guardian of the vital maritime energy routes across the Strait of Hormuz in the Gulf region and the Straits of Malacca in the Indian Ocean. This guardianship has shaped the respective regions' strategic calculus and global energy landscape for more than half a century. Over time, China is likely to play a larger geopolitical role across the Middle East and possibly the Persian Gulf region, as it already has across Central Asia, supporting its energy interests. If Middle Eastern, OPEC members exercise their strategic leverage across traditional energy markets, it is likely to be with consumers across the Asia-Pacific region.

Since 2000, there has been a long-term trend of a growing Middle East – Asian energy nexus with ~70% of Middle East energy exports dispatched to Asia, mainly China, India, Japan, South Korea, and Southeast Asia. This has led to a burgeoning trade, and an increasing flow of cross investments, such as Saudi Arabia's investments in refineries in China, the UAE's investments in refineries in India, and conversely China's investment in Iraq and Iran.

UNCONVENTIONAL RESOURCES ARE GEOPOLITICALLY IMPORTANT

As China's energy imports from the Middle East rise, so does its desire to achieve a greater degree of energy security. According to some estimates, China has more extensive shale gas resources than the US, albeit trapped under complicated geology, limiting the pace and extraction scope. Despite significant Chinese efforts, only modest progress has been made in developing this resource. China has also not advanced significantly in shale oil, which would be of more value for energy self-sufficiency than gas.

As China is a critical geopolitical rival to the US with its own energy security objectives, unconventional resources are part of Beijing's strategy but have arguably taken a secondary role. Instead, China has emphasised coal-gas conversion, diversifying its imports, including gas and oil pipelines from Russia, central Asia, and Myanmar, and developing renewable and nuclear power and non-oil technologies like electric vehicles.

NEW UNCONVENTIONALS

The production and reserves of unconventional fossil fuels are concentrated across a select group of countries. The US is the largest unconventional energy producer, with 9.3 Mbbl/d produced in 2016, followed by Canada with 3.3 Mbbl/d produced during the same year. For the US, ~78% of the unconventional energy production comes from shale and tight oil with the remainder 22% from heavy oil, oil sands, deepwater, and ultra-deepwater oil.

North America is the unquestionable leader in unconventional energy production. Its success is attributed to its vast resource, access to cutting-edge technologies, extensive supporting infrastructure, technological base and acumen, human resource, the proximity of production sites to end-users, availability of financing, and a liberalised regulatory structure, which have played the major part in the North American "shale revolution".

The remainder of global production and reserves of unconventional fossil fuels is mostly concentrated in Europe, the deepwater and ultra-deepwater oil in North-West Europe, and in various offshore basins across Brazil, West Africa, and the eastern Mediterranean. The Middle East has the highest concentration of conventional resource but has low levels of production of unconventional fossil fuels.

China, Argentina, Australia, and Russia are four of the most promising countries for new shale oil production.

Despite large volumes-in-place, unconventional oil output in China makes up less than 1% of its crude output, due to high break-evens and non-commercial economics. China's shale formations tend to be deeper, more heterogeneous and harder to frac than the US plays – implying higher well costs than in the US. Still, national oil companies (NOCs) have grown their shale oil spending, mainly for energy security. In 2019, China's first shale oil pilot projects were launched in Xinjiang and Dagang, where it is planning to invest US$ 1.5 bn [xv].

Argentina's technically recoverable reserves are estimated to be over 25.5 bbl, mainly concentrated across the giant Vaca Muerta formation.

However, the main factors holding back shale oil and gas production in Argentina are the lack of supporting infrastructure across the production regions, the need to import technology and equipment, and stricter domestic ecological and labour legislation. Hence, shale oil production costs in Argentina are 50% higher than in the US.

Australia has a sizeable, only partly tapped natural gas resource in the form of coalbed methane, known as coal seam gas in Australia, as well as shale gas. The country has 429 Tcf of technically recoverable resources, which could boost natural gas production once developed. Most of the exploration efforts are focused on the Cooper Basin, where most of the country's onshore conventional gas reserves are located. The basin has also attracted international oil and gas companies (IOCs) with financing and technical capacities to develop the shale reserves. Santos, a leading Australian oil and gas independent, drilled the first successful

commercial shale gas flow at its Moomba field in the Cooper basin at the end of 2012. However, reduced capital expenditures resulting from the low oil price environment have significantly decreased Australia's shale gas exploration and development since 2014. In addition to this, the state of Victoria and the Northern Territory have announced a ban on unconventional gas exploration, which the Northern Territory lifted in 2019.

In Russia's case, the tight Bazhenov and Achimov formations of West Siberia and the Domanik Formation of the Volga-Urals basin are key candidates for development with hydraulic fracturing. More resources could probably be discovered in Russia's vast territory, and some estimates suggest 20-25% of its oil production after 2040 could come from shale [xvi]. In comparison, shale gas and coalbed methane are less attractive because of the vast remaining reserves of conventional gas.

However, sanctions and lower oil prices have reduced foreign investment in Russia's upstream, especially in Arctic offshore and shale projects, making financing projects more difficult. In 2017, the US enacted new sanctions on Russia, which extended the prohibition on providing technology supporting new deepwater, Arctic offshore, or shale projects.

In recent years, the Russian government has offered special tax rates to encourage investment in difficult-to-develop resources, such as Arctic offshore and low-permeability reservoirs, including shale reservoirs. As a result, many IOCs have entered into partnerships with Russian firms to explore the Arctic and shale resources. In 2012 and 2013, ExxonMobil, Shell, BP, CNPC, and Statoil partnered with Rosneft to explore Arctic fields and shale resources. In 2014, Total agreed to explore shale resources in partnership with Lukoil. However, the IOC halted its involvement later that year, as additional sanctions were announced.

Unconventional fossil fuel production strategies vary between NOCs, large integrated oil and gas companies (supermajors), IOCs, US independents, and diversified independents across North America, Latin America, and Europe. It depends on:

- the variety of resource types, size, and quality available to the company (high-quality conventional resources may be preferred, particularly by NOCs, while shale resources vary widely in producibility);
- access to market (e.g. LNG plants for shale gas export; pipelines for oil sands);
- environmental and community constraints;
- financing availability and shareholder support; and
- technical and organisational skills.

NOCs are increasingly investing in new technologies relating to digitalisation and advanced analytics (e.g., machine learning) to improve the conversation around field optimisation.

In addition, NOCs are partnering with experienced international operators in unconventional and deepwater fossil fuel developments to gain exposure to technologies and operational strategies that could boost cash flow and extend the economic life of their developments. For instance, QP has been active with Total and ENI as preferred partners in exploration in several global deepwater basins, such as South Africa. Bahrain is seeking IOC partners for its Khalij Al Bahrain offshore shale oil and gas play; Total is working with ADNOC in the Diyab shale oil play in Abu Dhabi, and BP has led the Khazzan tight gas development with OQ as a partner in Oman.

In the case of supermajors and other international/integrated oil and gas companies, historically, the focus has been on a diversification strategy geographically and across the midstream and downstream segment, as these segments are more robust during a commodity price downturn. In recent years, the US supermajors, ExxonMobil, Chevron, and large independents such as ConocoPhillips, Hess, Apache, and Occidental have focused their portfolios more on shale and attempted to catch up with shale-focused specialists such as Devon, EOG, Chesapeake, and Continental. The vertically-integrated supermajors have sought to build large contiguous acreage positions, add value via their downstream holdings, and pursue less volatile and price-driven investment patterns than the independents. However, results have been less impressive for ExxonMobil after the expensive acquisition of XTO in 2009, while Chevron appears to have been somewhat more successful by building on legacy positions.

While international independents focus on unconventional energy production as part of their diversification strategy, US independents have typically allocated their capital to scaling up the domestic shale oil resource under a limited scope of operations. Companies such as Marathon Oil produce from several plays; others focus on just one, for instance, Pioneer in the Permian Basin.

However, US independents could expand their operations across the unconventional energy value chain to further diversify their risks. They continue to remain focused primarily on shale oil and to a limited extent, gas (conversely EQT, the US's largest gas producer, concentrates on that rather than oil).

Meanwhile, Canadian firms such as Cenovus and Canadian Natural Resources have focused on the oil sands and expanded by mergers and acquisition of stakes from companies such as Shell, Total, and Statoil (now Equinor). They were seeking to reduce their carbon footprints.

Even if US independents choose to remain shale-focused as part of their long-term strategy, opportunities to invest in water recycling facilities, deploy new drilling technologies, and produce from multiple resources could provide a degree of operational diversification. They have to balance the operational and cost advantages of focusing on a single basin from the diversification of having operations in several areas.

As the oil and gas value chain evolves with a changing unconventional energy resource, reserves, and production strategies, governments and regulators are increasingly revisiting governance structures established for conventional energy.

UNCONVENTIONAL RESOURCES' ENVIRONMENTAL FOOTPRINT IS OFTEN A CHALLENGE

Of all unconventionals, oil sands pose the highest environmental risks, comparable to coal mining. CTL has a high risk too but is only really being deployed in South Africa and China. Oil sands mining entails significant impact on land, water, air quality, public health, and climate. Extra-heavy oil and oil sands have approximately 60-80% higher GHG emissions in production compared to conventional oil. Recovery and bitumen extraction through surface mining and in situ processes result in 3-9 and 9-16 gCO_2eq/MJ bitumen, respectively. Meanwhile, upgrading emissions are an additional 6-17 gCO_2eq/MJ synthetic crude oil (SCO). This compares to an average global upstream carbon intensity of oil production of 10.3 gCO_2eq/MJ, with the best performer, Denmark, at 3.3 gCO_2eq/MJ [xvii]. However, a high degree of variability exists in well-to-wheel emissions due to differences in technologies used, operating conditions, and product characteristics [xviii].

CTL is the most carbon-intensive (six times conventional production) and the emissions from production can be larger than from the fuel use. Although gas can be considered a cleaner fuel than coal, GTL has twice the production emissions than conventional oil [xix]. Both CTL and GTL production emissions could be largely eliminated with CCS.

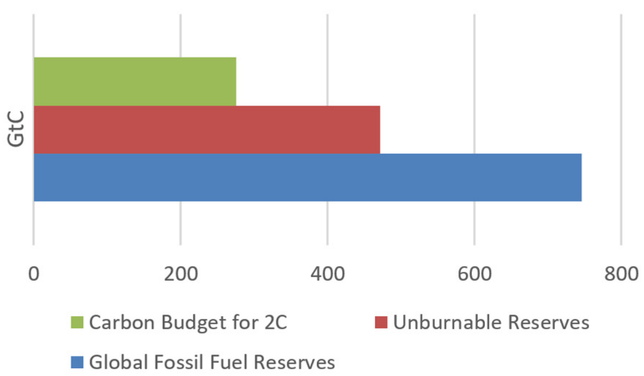
New research points to methane emissions from fossil fuel production, mainly from shale gas operation in the US and gas as the culprit for the methane spike in Earth's atmosphere. A 2015 study led by John Wordem of NASA's Jet Propulsion Laboratory estimated methane leakage of 554,000 tons a year occurs from North Texas' Barnett Shale region. This leakage marks a conservative leakage rate of 1.5%, equivalent to 46 MtCO2e, more than GHG

UNCONVENTIONAL RESOURCES' ENVIRONMENTAL FOOTPRINT IS OFTEN A CHALLENGE

emissions from states such as Nevada or Connecticut [xx]. In April 2020, satellites revealed that fracking had caused increased methane leakage of 3.7%, more than twice that assumed by the US Environmental Protection Agency (EPA), well above the average 1.9% for 11 other major US basins, and higher than that reported by any US oil and gas field before. At high leakage rates, the GHG benefit of gas over coal is severely reduced [xxi]. The International Energy Agency (IEA) has issued a set of recommendations for reducing methane leakage from shale gas operations, including 'green completions', monitoring, replacing pumps and valves, limiting flaring and other measures [xxii].

Unconventional resources have come under challenge because their very large size would overwhelm carbon emissions budgets (Figure 8). However, in the short term, unconventional gas has helped. In the US, it can further help reduce coal use in American LNG exports to Europe, China, and perhaps India.

Figure 8 Global carbon budget for 2°C [xxiii]



Unconventional resources have other environmental impacts beyond GHGs. Oil sands mining is inherently highly water-intensive, leading to water stress, and expensive wastewater treatment. It also poses high risks of significant groundwater contamination because of wastewater leakage. Shale and tight gas production have been accused of contaminating groundwater through gas leakage or fracking chemicals into aquifers. However, gas leakage is natural in most cases, and the main threat of groundwater contamination is from unlined, leaking or over-filled surface pits for wastewater disposal.

Induced seismicity can be triggered by fracking operations, as fluids are injected into the ground. However, the EPA has shown that most induced seismicity [xiv] cases are not associated with the actual fracking itself, but with drilling and injection of water into deeper water disposal wells. Still, the risk of induced seismicity from fracking is considered higher than for conventional oil and gas.

These various harmful effects on the environment unleashed strong opposition to unconventionals' production. In the US, public opinion has grown sceptical of fracking. According to Gallup public opinion polling, Americans were evenly split on their support for opposition to fracking in 2015. However, by 2016 Americans opposed it by an 11-point margin, which widened to 18 points in opposition by 2017. The Pew Research Center also documented this trend over the same period. On August 2019, Associated Press-NORC poll found that only 22% of Americans support increasing fracking, while 45% opposed increasing it [xxv]. However, the idea that fracking is environmentally unfriendly is still up for debate among the government and corporations, both of which clash with environmentalists. Meanwhile, in Australia, fracking policies vary widely across Australia's states and territories. While coal seam gas extraction has proceeded in Queensland almost unimpeded, the industry was halted in Victoria[xxvi].

In the UK, fracking was halted as of November 2019 due to eight years of opposition from local communities and major political parties. The Preston New Road was the main point of protest of thousands of activists, leading to the blockade of Cuadrilla's drilling site. In France, fracking was banned in 2011, and lately, France's parliament has completely banned the extraction of oil and gas within any of the country's territories [xxvii].

These environmental campaigns opposing unconventional production constitute additional challenges, intensifying the financial stress, and limited access to capital created by the crash in oil and gas prices in 2014 and the further pandemic-linked slump in 2020. An increasing number of financial institutions refuse to finance the most carbon-intensive resources, such as oil sands. The growing likelihood that the EU will set a carbon standard for fuel imports might also rule out oil or gas produced with high levels of flaring and other emissions.

The environmental footprint of unconventionals, however, could be reduced by a number of processes and initiatives, including:

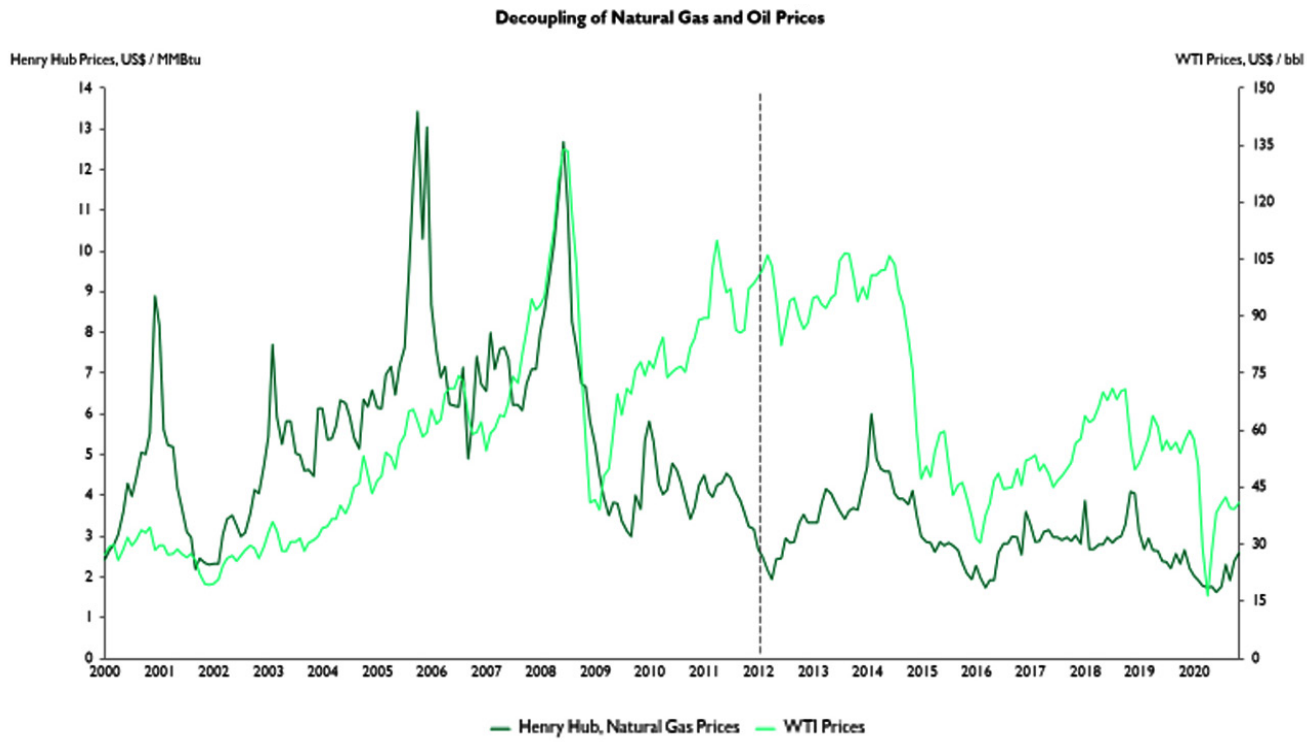
- Stopping flaring and methane leakage;
- Improving energy efficiency and waste heat recovery;
- Sourcing power from renewables;
- Waterless fracking;
- Solvent-enhanced heavy oil extraction;
- Carbon capture and storage;
- Conversion to 'blue' hydrogen; and
- Oil sands mining site remediation.

However, the negative image of fossil fuels in general, and unconventional resources in particular, have acquired will make further development increasingly challenging.

UNCONVENTIONALS WILL BE AN IMPORTANT PART OF FUTURE SUPPLY

The US is now the largest oil and gas producer globally, surpassing Russia and Saudi Arabia. The country's status is attributed to the increasing exploration and production of shale oil and gas, and the global energy markets have accepted that the country's unconventional energy resource will play a significant role across global oil and gas markets, such that:

- Production of shale gas from the US has triggered a decoupling of natural gas prices from oil prices;
- The US is a net exporter of natural gas and liquified natural gas (LNG);
- Reshaped the global natural gas market with increasing developments of technically recoverable unconventional resources across Latin America, Europe, and China;
- Challenged Qatar's position in the global natural markets with shale gas exports from North America; and
- Forced natural gas-short countries like Oman, the UAE, and Saudi Arabia to develop their domestic unconventional gas resource.



In 2012, Henry Hub, natural gas prices decreased to between US$ 1.8 and US$ 3.8/ MMBtu, from between US$ 5.8 and US$ 13.3/ MMBtu in 2008. This decrease represented long-term decoupling of natural gas prices from oil prices, which was previously caused by demand-side shocks and natural disasters that temporarily led to divergent prices.

Natural gas prices across Europe and Asia are usually significantly higher than the US, but decoupling signs exist across the European market.

As of 2020, the US became a net exporter of natural gas, and as of 2016 a net exporter of LNG. Further to this, LNG importers such as

Japan have secured North American shale gas supplies linked to the Henry Hub price.

An additional supply of natural gas and LNG from the US has transformed the global natural market, where a complex and volatile global supply of natural gas has made it difficult to forecast future supply-demand balances for each regional market in terms of supply from unconventional and conventional resources, and supply from cross-border pipelines and LNG imports.

This increased uncertainty has provided additional leverage to natural gas consumers to move away from long-term contracts based on oil-price indexation, and enter into shorter contracts, in addition to capitalising on the LNG spot market that increased to 32% of the overall LNG trade in 2018, compared to 20% in 2017.

The decoupling of natural gas and oil prices has allowed the US to become a net exporter of natural gas and LNG. An increasing spot LNG market has increased LNG capacity and countries across China, Europe, and Latin America to develop their unconventional resource.

Large projects are currently under development to build natural gas import capacity through cross-border pipeline infrastructure that connects gas from Central Asia, Russia, and Myanmar to China. Relevant LNG capacities suggest a strong expectation that China and Asia's demand for natural gas will further increase.

Development of the vast unconventional resource in China, Europe, and Latin America will take at least another 5 – 10 years as

UNCONVENTIONALS WILL BE AN IMPORTANT PART OF FUTURE SUPPLY

exploration and surveys are underway that better understand shale oil and gas formations. New technical expertise and technologies are acquired, supporting midstream infrastructure development, and a supportive regulatory and fiscal environment is enforced.

For example, China has a vast unconventional gas resource, and its supply could cause another major shock that reshapes the entire natural gas market. China recently started assessing and exploring its shale reserves in cooperation with international IOCs. The government has set ambitious targets for shale gas production and is releasing several policies to encourage indigenous unconventional gas development.

In addition to developing its unconventional gas resource, China has taken a major step in forming "PipeChina" to own and build the supporting infrastructure. PipeChina, formally known as China Oil and Gas Pipeline Network, is a merger of oil and gas pipelines and storage assets, mostly from state-owned energy giants PetroChina and Sinopec, in return for cash and equity in the pipeline company.

The establishment of PipeChina aims to provide neutral access to the country's pipeline infrastructure, which was primarily owned by PetroChina, in a bid to help small and non-state-owned companies and encourage investment in the sector.

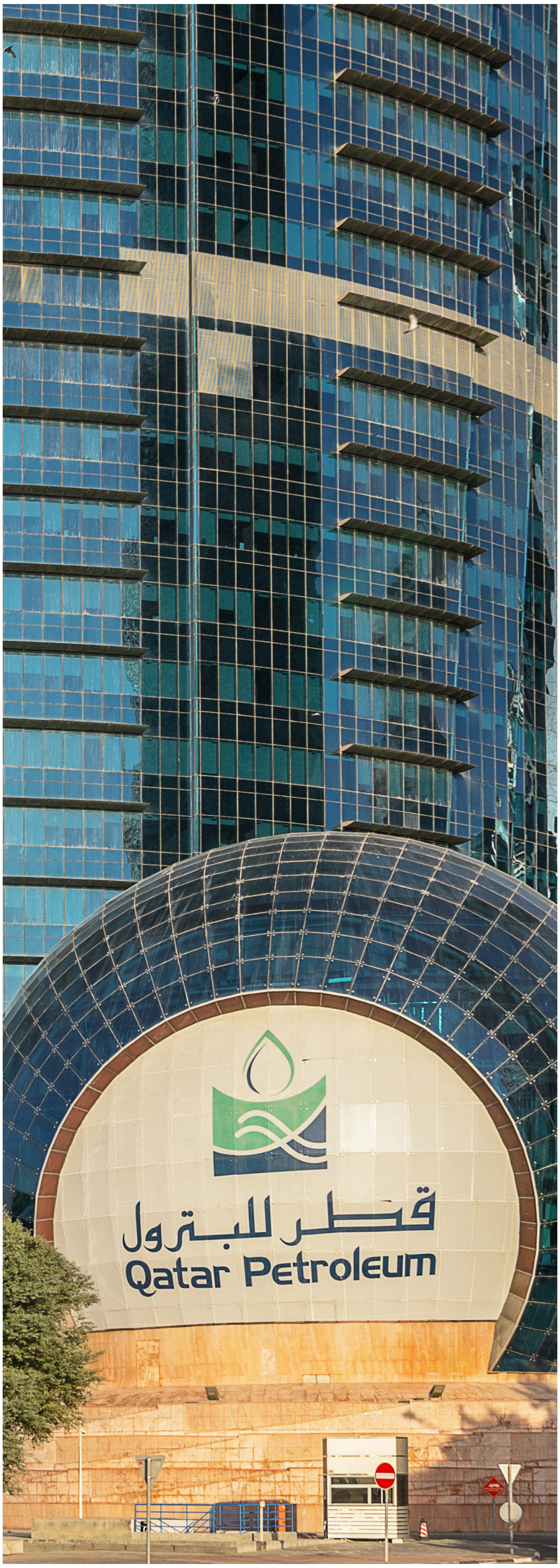
At the end of 2020, the Government of China has subsidised costs and relaxed regulations relating to shale gas exploration to boost its unconventional resource. IOCs are now allowed five years to explore blocks before relinquishing them, compared to three years previously. Earlier in the year, China allowed foreign IOCs to directly explore and develop allocated fields and basins as long as they have a locally registered office.

The impact of shale oil and gas supply from the US on the GCC is mixed. In Qatar's case, LNG exports are mostly based on long-term gas contracts priced on oil indexation. However, the respective contract/price structure is under pressure as customers across Asia are encouraged by alternative natural gas and LNG suppliers to reduce oil-price indexation and seek shorter and flexible agreements. In the long term, Qatar's significant challenges are unconventional gas developments and investments in LNG capacity that result in overcapacity, an increase in exports from North America, and/or shale gas developments across China and other markets, which will significantly decrease global prices.

In contrast to Qatar, Bahrain, Kuwait, and the UAE are net importers of natural gas, buying LNG to cover their peak demand during the summer period, and have developed LNG facilities to meet increasing demand from the domestic power sector. As noted, Bahrain and the UAE, in particular, are looking to develop domestic shale and tight gas. In 2018, Total and ADNOC signed a concession agreement to launch an unconventional gas exploration programme in the high potential Ruwais Diyab play (Jurassic tight carbonate reservoir) that spreads 6,000 km2 across Abu Dhabi. At the end of 2020, the companies announced the first unconventional gas's delivery from the concession.

In early 2020, the UAE announced a major discovery of 80 Tcf of shallow low-permeability gas resources, named Jebel Ali. The resources lie within 5,000 km2 between Saih Al Sidirah in Abu Dhabi and Jebel Ali in Dubai. ADNOC has drilled more than 10 exploration and appraisal wells. The field will have to compete on price with LNG imports, new domestic sour gas developments, and possible renewal of the Dolphin pipeline contract with Qatar after 2032.

Moreover, GCC countries such as Saudi Arabia and the UAE are increasingly assessing their unconventional oil and gas resource. Initial estimates indicate that unconventional gas resources across the GCC could amount to ~700 Tcf with Saudi Arabia accounting for more than 90% of the resource. Saudi Arabia is committed to exploring its large shale gas potential as it intends to free up its domestic consumption of crude oil, which could affect its export capacity and the country's long-term fiscal standing.



CONCLUSIONS

Although the resource base of unconventional fossil fuels is huge, their extraction and development differ from one type to another, requiring the employment of different sets of technologies with varying levels of maturity and commercial viability. Due to increased R&D expenditures, such resources will significantly reshape world supply by 2050. Although most recoverable volumes are currently located in North America, other regions like China, Argentina, Russia, and the Middle East have also increased their investments. Meanwhile, the North American unconventional sector is being reshaped by consolidation, greater capital discipline, slower growth, and a larger role for the supermajors and a few larger specialists such as EOG, Occidental, and EQT, rather than the independents who led the earlier phase of growth.

As economic factors have depressed investment in US shale and Canadian oil sands, and Venezuelan heavy oil output has collapsed, particularly in 2020, some other regions are seeing unconventional growth. Unconventional production outside the Americas remains tiny. Nevertheless, conventional field maturity, technological advances, better resource appraisal, and a drive for domestic self-sufficiency, can advance both unconventional oil and gas in new areas.

However, environmental issues, including land impact, water and air pollution, degradation, GHG emissions, and methane leakage could hamper future investment and limit capital for unconventionals' E&P. This will require extensive technological and environmental advances, to ensure a future role for unconventionals. Eventually, the enormous size of the unconventional resource base means it will have to be produced and used in non-emitting ways, such as with CCUS and hydrogen conversion, to be viable at all.

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