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THE OXFORD INSTITUTE FOR ENERGY STUDIES

The Energy Transition and Oil Companies' Hard Choices

I. Introduction

In this Energy Insight, we explore the challenges of the energy transition for international oil companies (IOCs). We argue that energy demand forecasts are inconsistent with meeting Paris Agreement targets using currently available and economic technologies and that, barring a radical change in tendencies, significant volumes of oil and gas will be required well after 2050. However, there will be growing political, societal and financial market pressure to accelerate decarbonization. This poses a major challenge for IOCs, whose current business models and technologies are incompatible with full decarbonization, but whose future depends on them being part of the solution. The paper analyzes a set of investment opportunities that the IOCs are pursuing within the decarbonization space and identifies some of the opportunities and risks they face.

II. The energy transition challenge

Global demand for energy has risen at a 2.8% per annum (pa) CAGR since 1900, and has sustained a similar 2.2% annualised pace of growth so far in the 21st century **(Figure 1)**. Assuming even a lower energy consumption of 1.7% CAGR, by 2050, we estimate global energy consumption will surpass 100,000 TWH (Terawatt Hours) pa. This is will be driven mainly by population growth, rising incomes and decreasing poverty. Thus, unless the world takes a radically different direction, 2050's energy market will surpass 100,000 TWH.

There is a broad energy industry consensus that the expected increase in energy demand by 2050 cannot be met with today's renewable technologies alone and that fossil fuels will continue to play a key role in the energy mix. Our modeling supports this view. Last year wind and solar produced 1,850TWH. Their peak annual growth rates are both around 130-140TWH pa.[1] At a combined rate of around 270TWH pa, they would take around 180-years to ramp up to 50,000 TWH pa, equivalent to around 50% of the 2050 energy market. This is not due lack of investment. The world is currently spending around $300bn[2] pa on wind and solar, placing them second after upstream oil (**Figure 2.**). The figure rises to $400-500bn, including the additional grid investments, which are being made to accommodate renewables' intermittency. Even if the rate of investment could treble overnight, to an unprecedented $1trn per annum, we estimate that it would still take 55-years for wind and solar to ramp up to 50% of the world's energy mix. This forecast seems optimistic to us since it ignores potential cost inflation, grid limitations and demand responses and assumes that profitability is adequate to justify such investment. Our own assumptions in **Figure 1** incorporate continued productivity gains in wind and solar, so that renewable energy supplies can grow by an average of 550TWH pa each year to 2050, ramping up to around 15% of the global energy mix. We also assume

[1] BP (2018). Statistical Review of World Energy. (plus early estimates from the IEA and IRENA).
[2] International Energy Agency (2019). World Investment Report.

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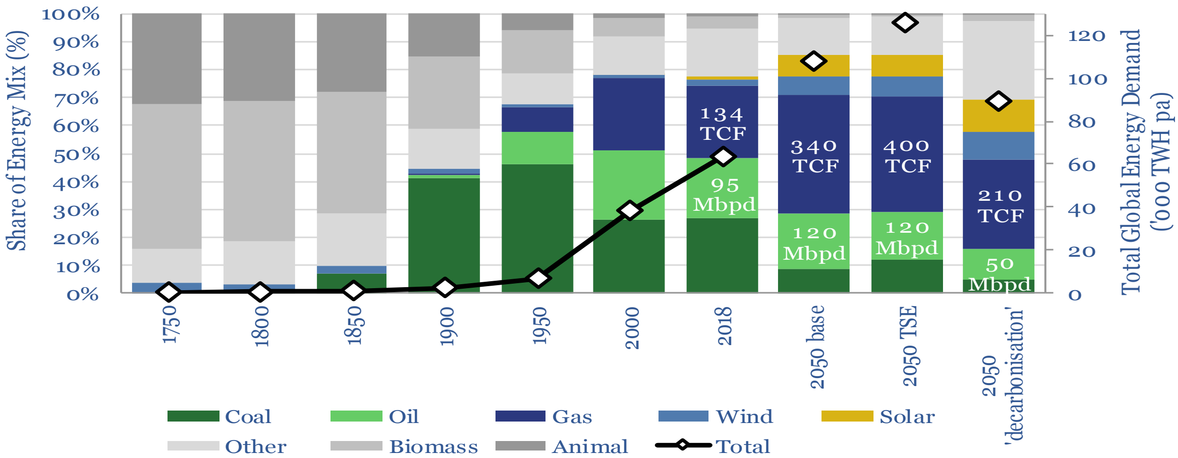
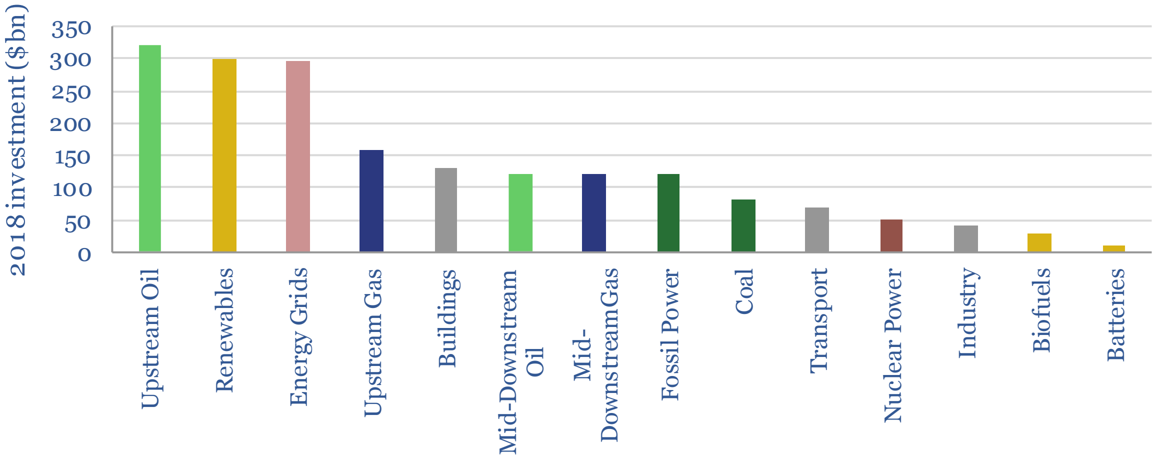
that after remaining flat for 20-years, nuclear energy starts growing again, at 50TWH pa, while hydro power continually grows at its peak annual rate of 180TWH pa. Nevertheless, our model is still left requiring 120 mb/d oil and 400TCF pa of gas to meet the world's energy needs. In this scenario, carbon emissions do not fall.

Figure 1. Oil and gas remain crucial in any realistic model of the 2050 energy mix



Source: TSE Modelling; West, 2018;[3] Fattouh et al, 2018.[4]

Figure 2. Wind and solar are adding around 270TWH pa of new energy each year for $300bn pa of investment; the same as Upstream Oil which adds +2,000TWH pa



Source: IEA, Thunder Said Energy estimates.

Based on our projections that demand for oil and gas will remain robust well after 2050, some commentators may conclude that IOCs and the hydrocarbon rich countries and their national oil companies (NOCs) with large reserves only need to stand still as demand for their products inexorably grows. This conclusion however is simplistic.

First, there are a number of forecasts that would imply a significantly lower demand for hydrocarbons. At one extreme, reflecting the political goals agreed in the Paris Agreement, the Intergovernmental

[3] West, R. (2018). Eternal Flames. Three Centuries of Energy Transition. Redburn 'Thinking Allowed'
[4] Fattouh, B., Poudineh, R. & West, R. (2018). The rise of renewables and energy transition: what adaptation strategy for oil companies and oil-exporting countries? Oxford Institute for Energy Studies

Panel on Climate Change (IPCC) has developed scenarios consistent with zero net carbon emissions by 2050. They assume not only decarbonization of energy sources, but also significant improvements in energy efficiency and, critically, the development of negative carbon emission technologies. Carbon Tracker predicts global demand for fossil fuels to peak in 2023 posing a significant risk to the financial system as trillions of dollars' worth of oil, coal and gas assets could become worthless. [5] Shell has forecast electricity to rise from 20% of the world energy mix today to 50% by 2050; this is a long way from net zero carbon, but does point towards faster decarbonization than our forecasts.

Second, the pressure for decarbonization will increase and is already affecting the IOCs and investment decisions throughout the economy. As we have recently argued,

> 'energy transition risks have often been considered as a long-term issue. This view is misleading, as there is a difference between the timescale within which the transition is completed and the timescale within which the manifestation of its effects on energy markets are felt'. [6]

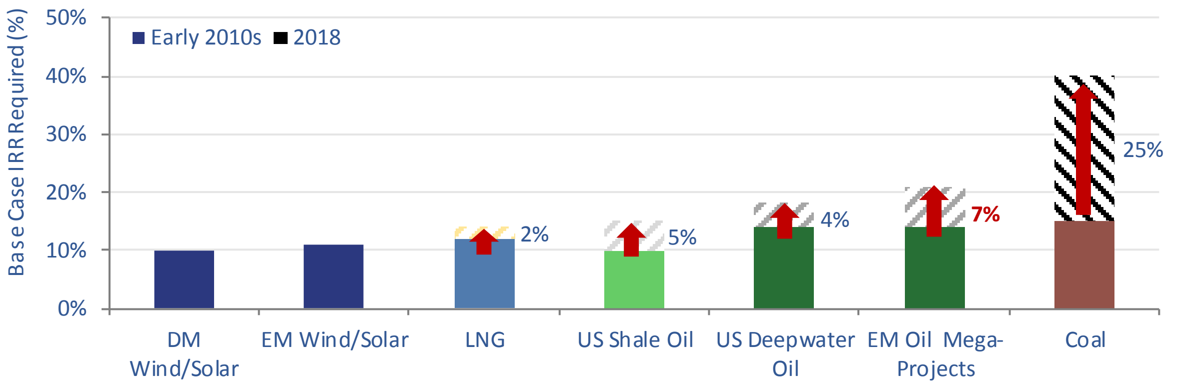
This is echoed in an open letter by the Governor of Bank of England, the Governor of Banque de France and the Chair of the Network for Greening the Financial Services in which they emphasised the importance of reducing carbon emissions and that this would 'require a massive reallocation of capital' and warned that 'if some companies and industries fail to adjust to this new world, they will fail to exist'.[7]

Indeed, there is growing realization that any company that fails to appreciate the changes induced by climate change concerns and societies' desire for cleaner energy could lose its societal license to operate, its competitiveness, its ability to attract and keep talented personnel and even its access to capital. The wheels are already in motion. For example, we conducted a detailed survey last year, capturing institutional investors' decreasing interest in the sector. [8] Fears over the energy transition are escalating costs of capital for investing in coal and new long-term oil projects (**Figure 3.**). Institutions managing over $6trn of capital have agreed to 'divest' from the fossil fuel industry. Oil and gas companies are under increasing pressure from shareholders to reduce emissions from their operations and products and disclose how their strategies can meet the goals of the Paris Climate Agreement. As investors become better organised, these pressures will only intensify. IOCs are also grappling with an increasing number of liability lawsuits brought by counties and cities in the US, which are seeking damages for climate-related problems.[9]

The energy industry is already well into the transition, due to advances in renewables, unconventionals, digital technologies, electrification and the world's growing desire for cleaner, lower-carbon energy. IOCs have been adapting their strategies, increasing investment in low carbon technologies, reducing the carbon intensity of their activities, and adjusting their portfolios for instance to increase the share of gas. IOCs have also been setting targets for greenhouse gas (GHG) emissions reductions and regularly monitoring progress towards achieving these targets with some companies linking executive pay to GHG emission performance. They have also been incorporating climate related risks into their strategies including using an internal carbon price in their investment decisions. However, the pace of change is seen by investors, shareholders, governments, and society in general to be very slow and not enough to confront what some have identified to be 'the great existential challenge of our times'.[10]

[5] See See Adam Vaughan, 'Global demand for fossil fuels will peak in 2023, says thinktank', The Guardian, 11 September 2018.
[6] West, R. (2018). Eternal Flames. Three Centuries of Energy Transition. Redburn 'Thinking Allowed'
[7] Bank of England, Open letter on climate-related financial risks, https://www.bankofengland.co.uk/news/2019/april/open-letter-on-climate-related-financial-risks
[8] Fattouh, B., Poudineh, R. & West, R. (2018). Energy Transition, Uncertainty, and the Implications of Change in the Risk Preferences of Fossil Fuels Investors. Oxford Institute for Energy Studies.
[9] Financial Times, 'Oil majors gear up for wave of climate change liability lawsuits', June 9 2019
[10] Christine Lagarde and Vitor Gaspar (2019), 'Getting Real on Meeting Paris Climate Change Commitments', May, https://blogs.imf.org/2019/05/03/getting-real-on-meeting-paris-climate-change-commitments/

Figure 3. Fears over the energy transition are escalating capital costs for oil and coal



Source: Fattouh et al, 2018.[11]

An accelerated transition though would pose a significant challenge for IOCs, disrupting their business models and undermining their profitability. The dual challenge of an accelerated transition to a decarbonized world without jeopardizing profitability seems insurmountable. As argued above, a key challenge is to attract the capital required to transition a vast, 100,000 TWH industry, which spends $2 trillion per annum. Smaller quantities of capital do not move the needle in this mix. Larger quantities of capital are not going to be available unless they can earn a competitive return. Any decarbonization strategy should be based on firm economic foundations.[12]

Decarbonization and maintaining high returns within the existing set of technologies and business models is not feasible and thus investment in new technologies, particularly in low-carbon energy technologies, that are able to generate higher returns is key for those companies aiming to participate in the energy transition, or to lead it. After reviewing around 3,000 distinct patents across the world's leading oil companies, we find that many oil companies are investing in technologies to improve the efficiency, carbon intensity and economics across their whole portfolios. About 8% of the sector's 2018 patents are in new energies (see **Figure 4**). The remaining 92% are aimed at improving the efficiency of fossil fuels, which indicates that companies remain focused on their traditional activities, which is expected given that this constitutes their core competencies. Companies need to develop projects using these better energy technologies, in all areas of the portfolio: oil, gas, downstream, chemicals, renewables and new energies. Once next-generation technologies have been de-risked, companies need to embrace them, which often require transforming the existing corporate structure to incorporate new businesses with very different business models, consumers and cultures.

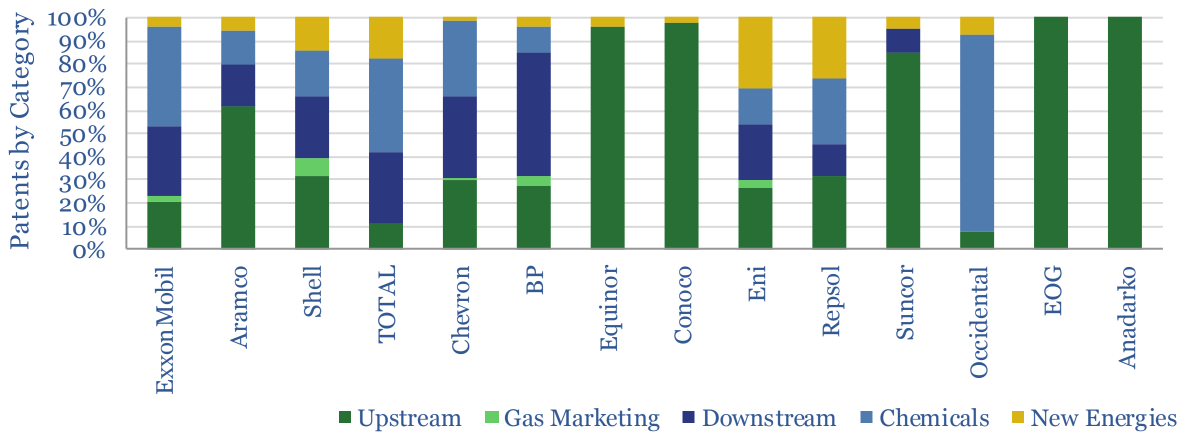
It is important to stress that while investment in low carbon technologies represents a new and an expanded opportunity set, serious questions remain as to whether IOCs will be able to capture these opportunities and develop business models that ensure viability and profitability. One can think of multiple reasons why some of the big international oil and gas companies are well equipped to capture some of these opportunities. IOCs have the capital to scale up some of these technologies. Large-scale projects are key to bringing costs down. In addition to financial strength, they have experience in managing and executing large projects and managing risk. They also have the ability to

[11] Fattouh, B., Poudineh, R. & West, R. (2018). Energy Transition, Uncertainty, and the Implications of Change in the Risk Preferences of Fossil Fuels Investors. Oxford Institute for Energy Studies.

[12] Meeting the investment requirements may not however require double-digit returns that oil companies and their investors are used to. Single digit returns are adequate for most non-oil companies, especially for de-risked investments. So the issue may not be that there will be shortage of capital but that rather oil companies will find it difficult to justify investment in assets with lower returns. Much depends on the extent of competition and governments´ ability or appetite to de-risk decarbonized technologies.

integrate the new technologies with their existing portfolios, infrastructure, and technical expertise. They also desire to remain the world's leading energy companies and not just wither away.

Figure 4: 8% of the leading oil companies' patents are driving advances in renewable energy; the remaining 92% are aimed at improving the efficiency of fossil fuels



Source: Thunder Said Energy Patent Database.

But success is far from guaranteed for instance if decentralised, small-scale solutions are more competitive. Obviously, the ability to capture opportunities will not be uniform across companies. Some may decide that moving aggressively beyond their core business is extremely risky and would lower their profitability and thus would be punished by their shareholders. Others may not have the necessary technical and managerial skills to operate in new markets with completely different regulatory structures and business models. The scale and integration arguments may be convincing for certain technologies that are compatible with IOCs' experience and current business models, corporate structure and capital allocation criteria. However, these advantages do not necessarily apply for technologies and opportunities that are in completely new areas, especially ones that require a different skill set and corporate structure.

Also timing is key when the speed of the energy transition is highly uncertain and not uniform across the globe. As argued previously:

> *'wrong assumptions about uncertainties can lead to misallocation of capital and write-offs. Worse, underinvestment in conventional energy could yield shortages, underpinning shortages of light, heat, power, and mobility – the mainstays of modern civilization. Conversely, a wait-and-watch strategy by postponing investment decisions can create a window of opportunity for competitors. The other side of the coin is that too early investment also limits future options and can lock the company into a suboptimized investment decision'.*[13]

III. The opportunity set in a decarbonizing world

There are many areas in the decarbonization space, which can in principle, present new opportunities for IOCs. The investments being pursued can be divided into two broad categories. The first includes technologies, such as electrification and renewable electricity, which are direct competitors for oil and gas in final markets like transport. For these, we can expect some tensions between the existing business model (and expected returns) and new businesses (with potentially lower returns) that would

[13] Fattouh, B., Poudineh, R. & West, R. (2018). The rise of renewables and energy transition: what adaptation strategy for oil companies and oil-exporting countries? Oxford Institute for Energy Studies

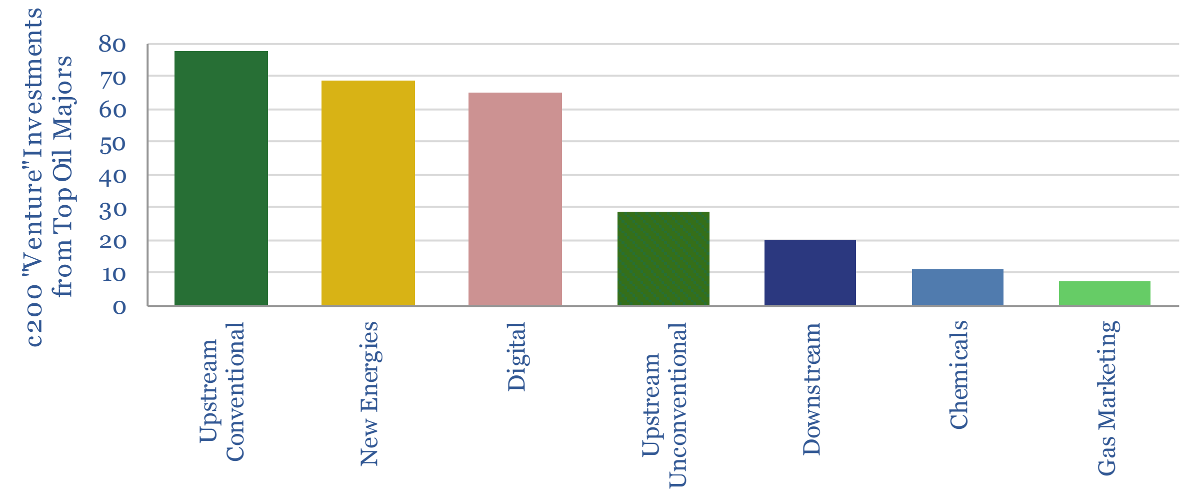
cannibalize the old. The second category includes changes in the mix of fossil fuels, as well as technologies that allow for continued use of oil and gas. For instance, digitization will not solve the CO2 challenge, but will avoid ‘wasting’ carbon budgets and can double project NPVs, generating more capital to fund decarbonization. Carbon capture, utilization and storage (CCUS) would reduce expected emissions and could potentially allow for negative carbon emissions. And blue hydrogen (through steam reforming of methane) would provide a route for the decarbonization of natural gas.[14]

Below, we study a subset of investment opportunities. For the first category mentioned above, we include electrification and the development of next generation wind and solar. For the second category, we include digitizing and deflating oil projects, reusing and recycling fossil fuels, as well as CCUS and increasing the share of gas. We are under no illusion that this list is complete. There are many interesting new ideas in nuclear, algal biofuels or hydrogen. In selecting those studied below, we took into account three factors. First, IOCs are investing in these technologies. Next, the technology must be economic or clearly have the potential to be so. Finally, the technology must be scalable, to make a noticeable difference to the energy transition.

Venturing

It will not always be feasible to develop new technologies in-house. New energies are outside the IOCs and NOCs existing skill sets, fast-evolving and dominated by nimble start-ups. Venturing may therefore provide a better approach, allowing them to deploy their expertise in de-risking, scaling and commercialising others’ technologies. This is already happening. **Figure 5** tabulates around 200 of IOCs’ recent venture investments. Around 70 were in New Energies, focusing particularly on electricity distribution, electric mobility solutions and solar energy. BP, whose ventures fund is most heavily allocated to new energies concepts (**Figure 5**), states that novel technologies *“play a key role in BP's strategy to tackle the dual challenge of meeting the world's need for more energy, while at the same time reducing carbon emissions".*[15] Other oil companies, including TOTAL, Equinor and Repsol have indicated they are also stepping up their renewable venturing.

Figure 5. New Energies are the second most frequent theme in Oil Majors’ venturing



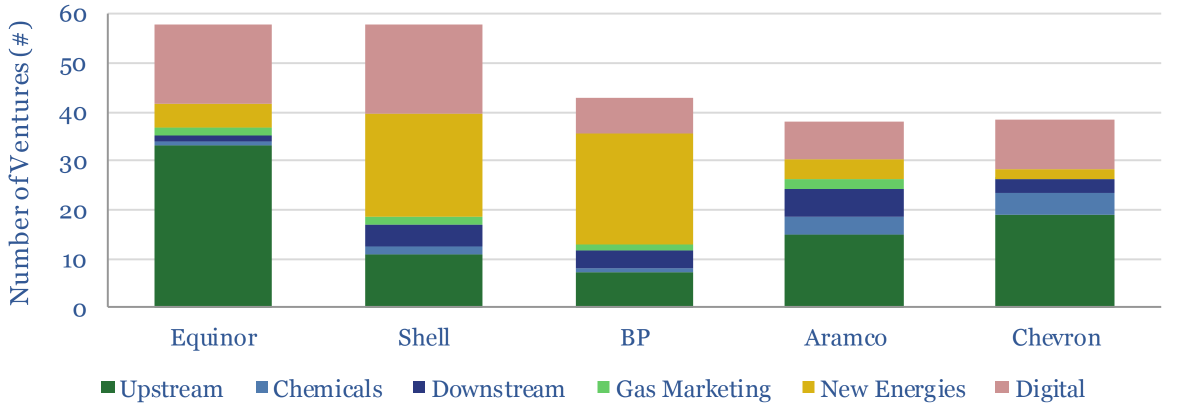
Source: Thunder Said Energy Patent Database

Indeed, the academic literature finds in favor of venturing strategies, when industries are going through periods of rapid change. For instance, Lerner (2013) states that a “corporate VC fund … can move faster, more flexibly, and more cheaply than traditional R&D to help a firm respond to changes in technologies and business models. In some cases, such a fund can even help stimulate demand

[14] Though the first category is sustainable and compatible with full decarbonization, the second is not (with the exception of negative emissions from CCUS).
[15] BP (2019). https://www.bp.com/en/global/corporate/what-we-do/bp-ventures.html

for a company's own products"[16]. Particularly important is that faster disengagement is possible, for "investments that seem to be going nowhere", compared with in-house technologies. Intelligence-gathering from the venture investment can help a company "protect itself from emerging competitive threats".

Figure 6. Venturing activities from five of the leading Oil Majors



Source: Thunder Said Energy Patent Database

Electrification

One area in which oil companies are venturing is that of charging of electric vehicles (EVs). Fast-charging bolts on naturally to the IOCs existing network of service stations and convenience stores. We have already seen Shell acquire fast-charging companies such as, Ionity, Greenlots and NewMotion; and an electricity company, First Utility, which has since been re-named Shell Energy. Likewise, BP has invested in EV charging companies, such as ChargeMaster and StoreDot. TOTAL paid $1.7bn for Direct Energie in 2018. Electrification will help drive the energy transition, and IOCs may find economic opportunities as the market evolves, though this requires developing new business models and adapting to new regulatory structures.

Some commentators may question whether IOCs will find value investing to develop these new businesses, particularly when forays into renewables in the 1980s and 1990s are regarded not to have been successful.

In response, let us consider the recent statement from Shell, justifying its new plans to spend $2-3bn per annum building up its power business: "electricity is expected to become a much bigger part of the primary energy mix, because of changes in consumer energy demand"[17]. Indeed, Shell anticipates electricity being 50% of the energy mix in 2050, compared to 20% now. They are planning that over 30% of their business will be in electricity in the 2030´s.

First, Shell´s plans suggest that an oil company naturally confronts the question whether or not to play a role in the future energy system, as it unfolds, or remains limited to their current activities.

Second, we think the pace of change is going to accelerate, as consumers and politicians focus increasingly on decarbonization. Thus, EV charging should not be considered simply as a minor add-on to an existing IOC business but potentially involve entry into a new decarbonized energy business that could one day dominate. Some oil companies see electric charging as an entry point to decentralized energy systems, not just as a business on its own. It is part of a strategy to become a virtual power producer (VPP) and to optimize the use of distributed energy resources. For instance, the connection between EV charging, distributed energy generation, battery use (V2G) and flexible

[16] Lerner, J. (2013). Corporate Venturing. Harvard Business Review, October 2013
[17] Royal Dutch Shell, Management Day, June-2019

consumption could create a new local energy system to challenge electricity incumbents. This is a key part of the future of the electricity sector and indeed of the future decarbonized energy system. It remains to be seen whether the oil companies will have a comparative advantage in this wider transformation (as opposed to using their service stations for charging).

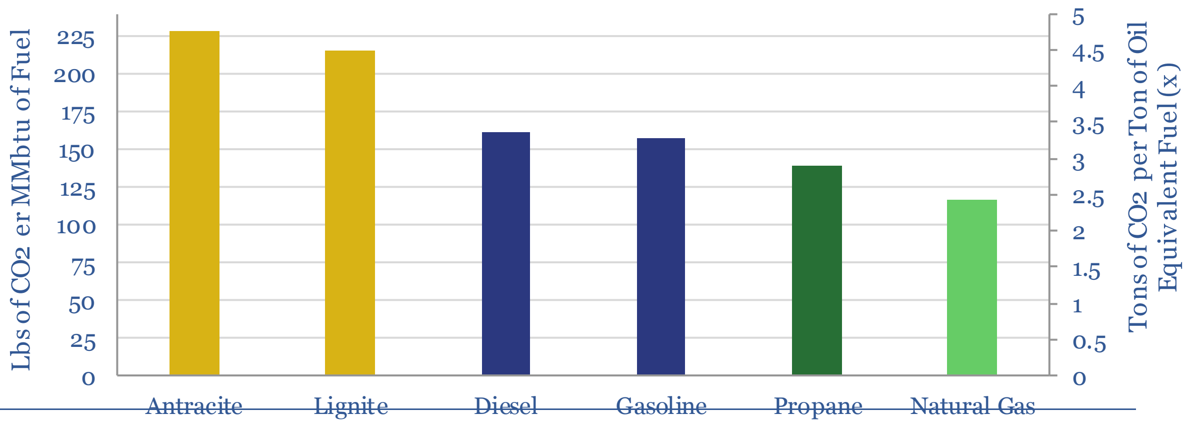
Third, many opportunities to scale up in electricity need to be more economic than they are today, in order to attract the requisite quantities of capital. This view may also be shared by Shell, as Ben van Beurden recently stated

> *“If you think about what the world will have to do, it will probably have to build five more electrical systems of the same size as the one that we have built in the last 135 years... the opportunity that is associated with that is enormous, because we're not going to somehow subsidize four or five more of these things. There will have to be real business behind it, otherwise, it's just not going to happen*”[18].

However, it is worth bearing in mind that oil companies are used to double-digit returns on capital, whereas investors in the power sector are used to lower returns to reflect lower risk. Governments have been comfortable de-risking investment in renewables; an important issue is the extent to which they will do so with electrification.

Finally, the growing role of intermittent renewable electricity is creating a special niche for natural gas. This is because solar and wind power require backup in the absence of storage. Today, natural gas fired plants are the main backup option in most countries. Gas is the lowest-carbon fossil fuel (**Figure 7**), abundant, clean-burning and well suited to provide flexible backup. However, there are important limits. First, the backup role alone does not involve significant volumes of gas. As renewables reduce the running hours of gas-fired plant, the challenge will be to finance new plants that run at very low capacity factors, and to ensure that electricity markets reflect the economic value of flexibility. Second, natural gas competes with other sources of flexibility, increasingly from demand-side response, batteries and hydro. Third, as a hydrocarbon, natural gas will be subject to carbon taxes or other restrictions in a growing number of countries. Looking further down the road, it will compete also with potentially decarbonized flexible generation (e.g. biomass with CCUS, hydrogen).

Figure 7. Natural gas emits c25% less CO2 than oil, and c50% less than coal



Note: Data are shown on a combustion-only basis and do not include methane emissions. Source: Thunder Said Energy Fuel Economy Database

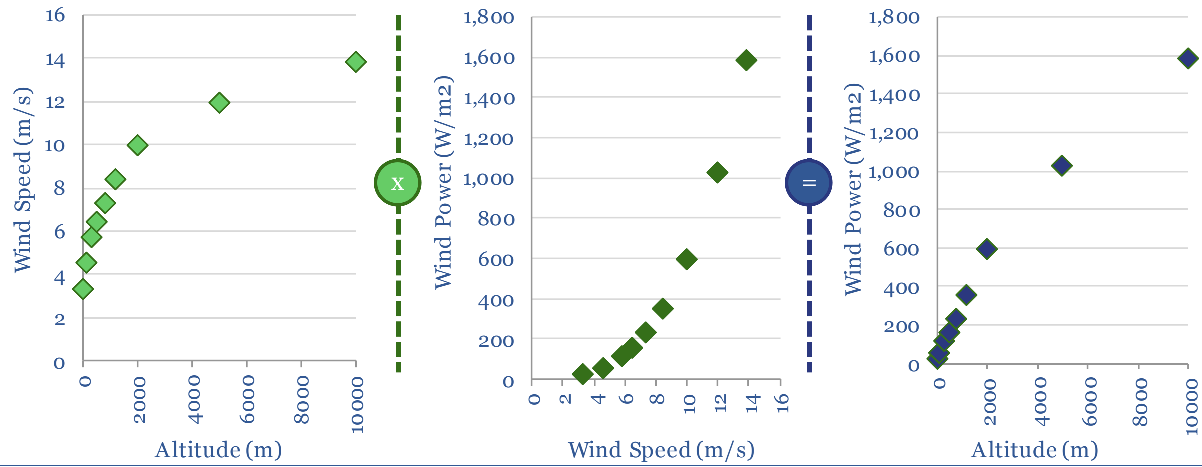
[18] Royal Dutch Shell, 1Q19 Results and Quarterly Conference Call

Next-generation Renewables

IOCs may choose to move further into renewable power, especially where there are opportunities for higher than normal returns because a company has an edge, such as a superior process technology. It remains to be seen whether higher than normal returns can be found in new energy technologies. But as discussed previously, IOCs are investing in new technologies, primarily, using the 'Venture Model'. This gives IOCs flexibility. Moreover, as the energy industry evolves, backing next-generation renewable technologies allows these companies to remain at the leading edge of the industry, improves their reputation with stakeholders and offers opportunities that may integrate with their base portfolios.

If today's renewable technology cannot deliver the energy transition within a reasonable timeframe at a reasonable cost, the world needs to develop renewable technologies that can. IOCs have an opportunity here. In wind, for example, they are actively involved in the race to develop next-generation, airborne wind technology. Power in the earth's atmosphere increases with altitude as shown in **Figure 8**. At 300m, it should be possible to access 2x more power than at 80m. The challenge is how to access these higher wind speeds. The 4,000m foundation and 700T tower already comprise around 35% of a typical, 80m wind-turbine's overall cost. An entire green-tech industry is dedicated to an improvement, "airborne wind", where drones transmit power back down to ground level via a tether. The academic literature estimates costs per-kW could be 10-50% the level of conventional wind turbines. The most famous example is Makani, which tested a 600kW drone in 2017, with the backing of Google. ExxonMobil has filed patents to deploy similar tethered kites offshore, *"opening up a resource system which is four times greater than the electrical generation capacity of the entire United States".*[19] Meanwhile, in February-2019, Shell signed its own partnership with Makani, planning to test the concept offshore Norway later in 2019. Previously, Shell also invested €6M in Kite Power Systems.

Figure 8. Wind speeds, and by extension, power ratings increase with altitude



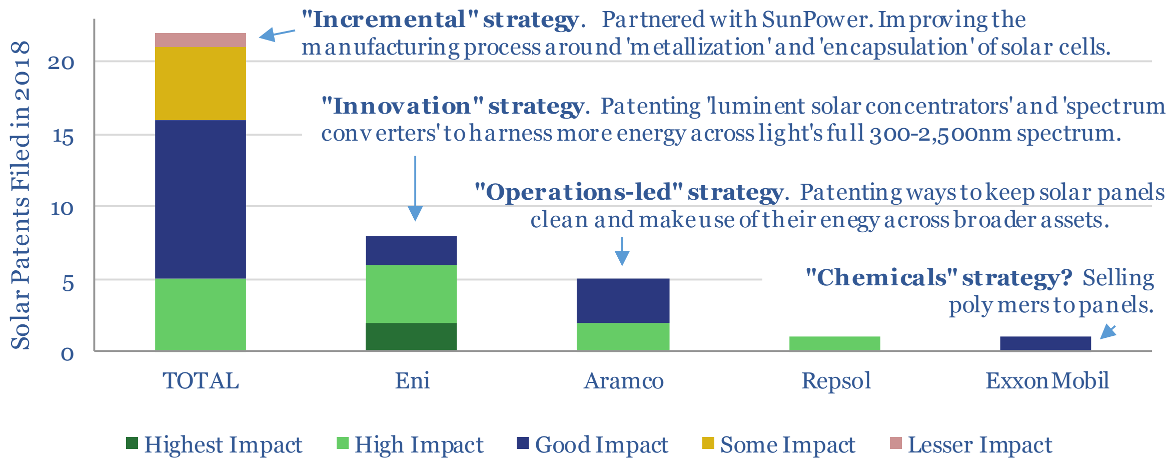
Source: Ragusa et al, 2007.[20]

Likewise, IOCs are funding improved solar technologies, to deliver more energy for lower cost. We reviewed 37 distinct solar patents filed across oil companies in 2018. Three 'leaders' stood out, each pursuing a different strategy (**Figure 9**). Most excitingly, at the cutting edge, Equinor has invested directly in Oxford PV, which is leading the race to develop Perovskite Solar Cells. These crystalline compounds exhibit exceptional opto-electronic properties, low band-gaps and strong conductivities for

[19] Hart, C., & Bushby, D. (2017). Airborne Power Generating Crafts Tethered to a Floating Structure. Patent WO2017218118.
[20] Ragusa, S. M., Lavagno, E & Milanese M. (2007). Valutazioni Energetiche Dell Eolico D'Alta Quota: Kite Gen. Politecnico di Torino.

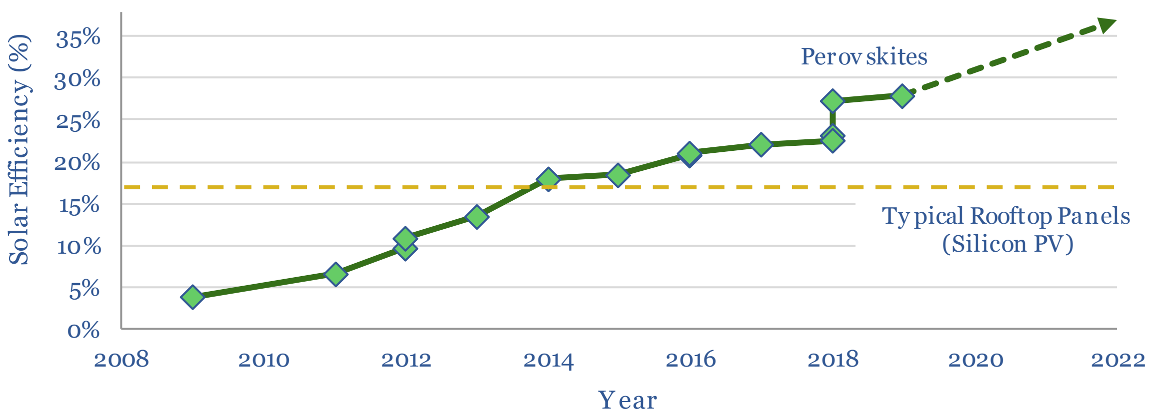
electrical energy. Their efficiency has sky-rocketed from single-digits when they were first invented in the late 2000s, to 28% in Oxford PV's lab in 2019 (**Figure 10**).

Figure 9. The leading Majors are aiming to improve the manufacturing of solar panels, enhance their productivity or deploy them in desert environments



Source: Thunder Said Energy Patent Database.

Figure 10. Efficiency of Perovskite solar cells have reached 28%, with running-room into the 30s%, which would make them 2x more efficient than conventional solar



Source: Technical Papers, Thunder Said Energy

Digitise & deflate: maximise efficiency and improve the economics of fossil fuels

If the world is going to be using fossil fuels for decades, it is necessary for the industry to do everything it can to make fossil fuel projects as efficient and profitable as possible. Making oil projects more efficient is not going to solve the problem of the energy transition. However, it is going to reduce the damage from wasting the world's carbon budgets through methane leakages, flaring and inefficiencies. Improved profitability will also gather more capital to fund decarbonisation.

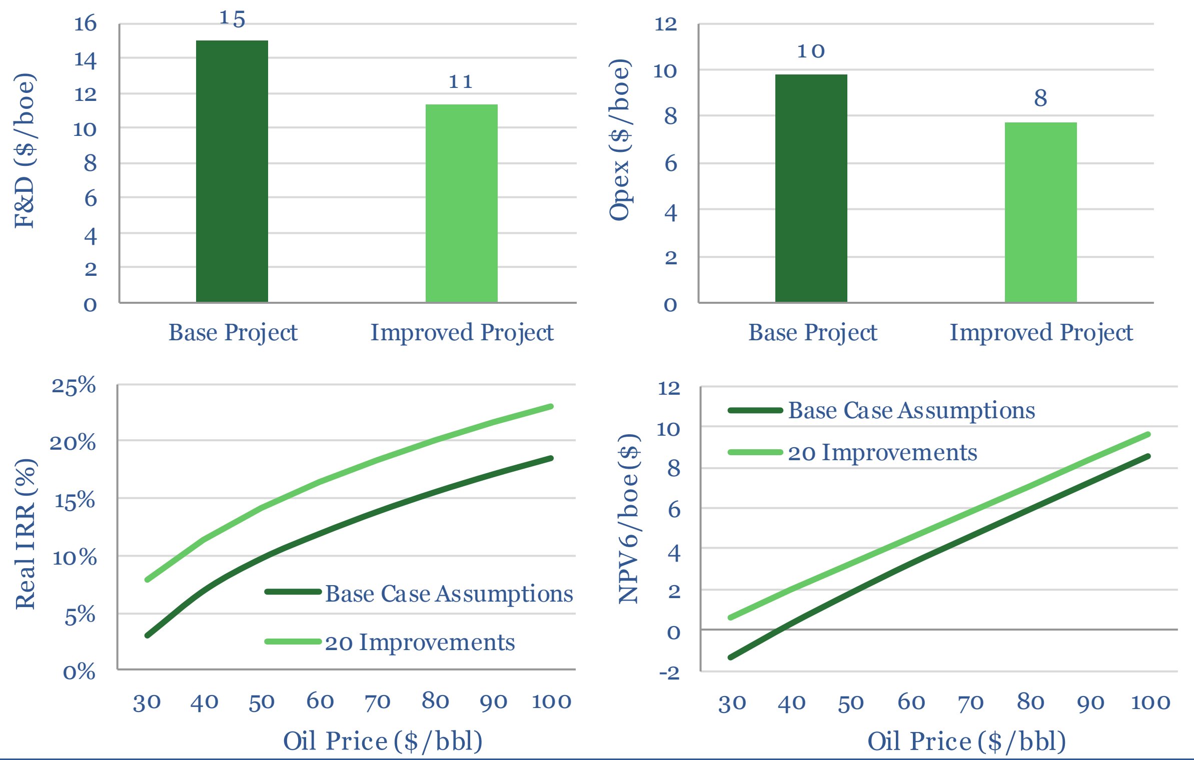
All oil and gas companies have a role to play in ensuring that their operations are efficient. Many IOCs have proposed to halve their carbon footprints by 2050 and cap methane emissions at 0.2% by 2025. Equinor advertises that the current carbon intensity of its portfolio is 10kg/boe, compared to an industry average of 18kg/boe, while its ambition is to reduce CO2 intensity to 8kg/boe by 2030 [21].

[21] https://www.equinor.com/en/how-and-why/climate-change/co2-intensity-goals.html

Actually demonstrating this capability should help secure a societal license to operate and better conditions from the financial community.

Improving efficiency can also be excellent for the economics. As an example, we modelled the economic impacts of the 'top twenty' emerging technologies on a typical offshore project. We calculated the potential to lower F&D costs 25%, lower development capex by $1bn, lower opex by 20%, improve energy efficiency by 25-30%, double the Net Present Value (NPV) from $1bn to $2bn (at $50 oil) and uplift the IRR by 4-5pp at any oil price. This would lower the project's breakeven by $15-20/bbl (**Figure 11**). The most exciting technologies are digital. They yield more oil, simply by optimising existing assets, such as pumps, wells or recovery rates. Higher uptime and greater recovery rates obviate the need to construct additional oil projects.

Figure 11. Cash flow profile for deep-water investment: 10% IRR at $50 oil



Source: TSE Modelling

Carbon, Capture, Utilization and Storage (CCUS)

There is a growing awareness that, without CCUS being adopted at large scale the prospects of staying well below 2ºC this century are vanishingly small if fossil fuels are going to continue to be used. It is important to distinguish between technologies that capture, store and utilize CO2, thereby lowering emissions (compared to where they would be otherwise), and technologies that are capable of using the CO2 in ways that act as carbon "sinks", creating negative emissions.

CCUS includes a range of technologies. The basic model was originally referred to as CCS, because it involved the capture of carbon and its permanent storage (or sequestration), for instance in used oil or gas fields. However, there is growing interest in the utilization of the carbon, hence the acronym CCUS. Most utilization to date has involved the injection of CO2 into existing reserves for enhance oil (or gas) recovery. New commercial opportunities for utilization are now being studied.

The cost of developing CCUS projects is a major hurdle and largely explains why investment has been significantly below the volume required to make an impact on global emissions. Current technologies for separating CO2 cost >$50/ton, incur a 15-30% energy penalty and have operational drawbacks. Full greenfield CCUS, including new infrastructure, tends to cost $75-100/ton, rising to

$200-400/ton for 'direct air capture'. These projects cannot be scaled up at present because they offer no returns, even with a $20-50/ton carbon price. But next-generation technologies can slash the costs, and could make CCUS economic.

If the world is going to commercialize carbon capture technologies, some IOCs may have a material technology lead, especially from their involvement in LNG, which requires reducing CO2 concentrations in the feed gas down to 50 parts per million. Some also own pipelines and have access to depleted fields where CO2 can be stored. Shell is currently commercializing new solvents, which remove 25% more CO2, for 30% less energy[22]. ExxonMobil has filed over 30-patents improving swing adsorption processes. But next-generation technologies go even further. A first example, Chemical Looping Combustion, burns fuel in a slurry of metal oxide, yielding energy, metal, water and CO2, which can immediately be sequestered. The costs fall to $20/ton, for a mere around 4-10% energy penalty, offering economic returns with a $40/ton carbon price. 40 demonstration plants have been constructed so far. TOTAL is now funding the largest project yet, at 3MW, to start up in China in 2023. Another alternative, Oxycombustion, burns fuel in a pure oxygen atmosphere, outputting pure CO2. Costs are competitive with conventional power. Oxy has invested in NET Power, which started up a 25MW natural gas plant in LaPorte, Texas in May-2018.

Beyond these improvements in capture technology, finding ways to utilize and commercialize CO2 emissions is potentially the game changer. On the one hand, carbon utiliization creates a revenue stream and many more opportunities now exist that do not involve enhanced oil recovery. On the other hand, CCUS has the potential to be a negative emission technology, for instance when it involves biomass. Recent studies estimate that negative emission technologies could absorb between 7-10 GtCO2 at a cost of less than $100/tCO2. That is a significant share of current global energy-related emissions of 37 GtCO2. If these studies proved to be correct, negative-emission CCUS could help to create a cushion for the continued use of hydrocarbons.[23]

Re-use and recycle: opportunities in the circular economy

Another opportunity to lower fuel use is to recycle waste products and plant materials. Numerous companies are pursuing such projects. Most vocally, Eni's "Ecofining" draws on used cooking oils. We have also counted 70 biofuels patents from IOCs in 2018.

We see most potential in plastics. 85% of the world's plastic is currently incinerated, dumped into landfill, or worst of all, ends up in the oceans. The challenge is that conventional, mechanical recycling can only be conducted on pure, PET and HDPE, around 21% of the market. An alternative, Plastic pyrolysis is near to commercialisation. We have assessed twenty technology solutions. The nascent opportunity can turn plastic back into oil, while generating >30% IRRs on investment. This matters because around 9 mb/d of oil demand is currently consumed to make plastics (around 10%), at naphtha crackers in China, Europe and EM Asia. These steam crackers operate at 800-1,000C, consuming 40% of all the energy of the entire petrochemicals industry, with energy comprising 70% of a typical plant's production costs.[24] Demand is on course to reach 23 mb/d by 2060. But it would stagnate if half of the world's plastic can be pyrolyzed (**Figure 12**); and could halve in a more aggressive scenario.

IOCs are exploring this opportunity. OMV's ReOil programme is being trialed at the Schwechat refinery, since 2018. BP noted in 1Q19 that *"we see chemical recycling as a gamechanger for plastics circularity... we are looking to commercialise these technologies by 2025"*[25] TOTAL has filed patents

[22] https://www.shell.com/business-customers/catalysts-technologies/licensed-technologies/gas-processing/natural-gas-purification/natural-gas-processing/amine-gas-treating.html

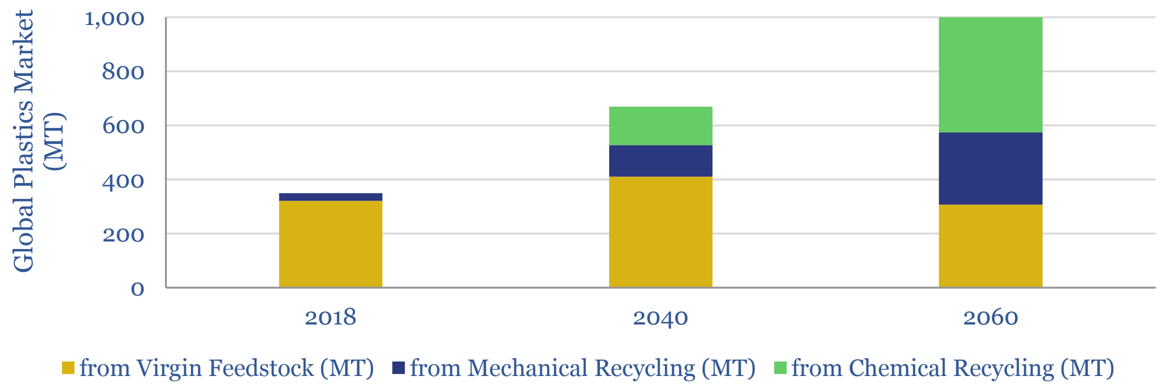
[23] See https://www.bbc.com/news/business-48723049

[24] Al Yami, A. H., et al (2017). Internal Heat Generating Material Coupled Hydrocarbon Cracking. Saudi Aramco patent US20170327750

[25] BP, 4Q18 Results and Strategy Update, February-2019

to recycle pure polyethylene and convert it into *"a polyethylene blend having excellent mechanical properties".*[26] ExxonMobil also filed eight patents in 2018 around pyrolysis.

Figure 12. Pyrolysis could cut oil in plastics by 5% by 2060 even as the market grows



Source: TSE modelling and assumptions

It can make economic sense for IOCs to promote greater re-use of existing fossil fuel products, in order to lower their need to invest in new, greenfield facilities. In turn, this lowers the amount of capital that must be employed, raising future returns on capital employed, and thus pleasing the capital markets, as capital costs are rising for the fossil fuel industry.

Natural gas and decarbonised gas

Many IOCs and NOCs acknowledge their portfolios are slowly shifting from oil to gas. They also stress the case for natural gas to replace coal in the power sector. The ascent of gas in **Figure 1** yields 20% less CO2 than preserving today's shares between coal, oil and gas. This helps to explain their support for a CO2 price to incentivize the switch towards natural gas. However, as argued by Stern[27], in order to increase the share of gas in the energy mix, the industry needs to develop decarbonisation narratives, showing how it will develop commercial scale projects expanding beyond traditional natural gas, also including biogas, biomethane, and blue hydrogen from reformed methane.

IOCs' technologies will be critical as the world depends more heavily upon natural gas. Among the leaders in this space, ExxonMobil and Shell both filed over 60 distinct patents for gas-processing technologies in 2018, followed by Aramco, Chevon and TOTAL. It is easy to under-estimate the complexity, for example, of treating natural gas, which requires removing impurities, such as CO2, H2S acid gases, mercaptans, carbonyl sulfides and carbon disulfides. Furthermore, gas value chains are complex. This creates opportunities for integration along a value chain.

IV. Oil companies in transition: Opportunities and risks

We are under no illusion that our list of energy technologies above is complete. For instance, there are many radical new ideas in nuclear, algal biofuels or hydrogen.[28] This Energy Insight is not the place for a thorough review of all the exciting technologies in the energy space. Rather, it tries to make few points based on the brief review of selected technologies:

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[26] TOTAL (2018). Recycling Of High-Density Polyethylene From Domestic Polymer Waste. Patent Number TR201802343.
[27] Stern, J. (2019), 'Narratives for Natural Gas in Decarbonising European Energy Markets', OIES NG 141, Oxford: OIES. https://www.oxfordenergy.org/publications/narratives-natural-gas-decarbonising-european-energy-markets/?v=79cba1185463

[28] Although, if we did, the point remains: you will find, for instance, Eni at the forefront of nuclear research, ExxonMobil at the forefront of algal biofuels and Shell at the forefront of hydrogen.

- Current technologies are unable to attract the requisite quantities of capital at the pace required for full decarbonisation. The energy transition is pushing and will continue to push investors, including the oil and gas companies, to develop new low-, zero- and negative-carbon technologies. IOCs will seek to maximize the efficiency of their baseline businesses and evolve their portfolios towards natural gas (eventually decarbonized gas) and electrification; some will seek to pioneer next-generation technologies and accelerate the pace of decarbonization. Competition in developing these new technologies and business models has begun and will intensify as the energy transition accelerates.
- IOCs are pursuing different opportunities that are broadly consistent with the decarbonization objective. Some investments would help sustain existing lines of business and lower emissions (compared to business as usual), for instance by improving efficiency, capturing and storing carbon, reducing methane emissions and decarbonizing natural gas. These are areas where the IOCs have comparative advantage. Alongside these, IOCs are investing in areas where decarbonization involves replacing fossil fuels, for instance renewable power and electrification of energy markets. These are also opportunities for IOCs, but the latter will compete with many other players, for instance from the electricity sector and especially the digital world. Furthermore, these are areas which compete with the IOCs current businesses, raising questions about the future of the latter.
- IOCs are backing new technologies under venture models, rather than in-house. This means the technologies can be monitored, the economics can be dispassionately assessed, and the leading ideas can be scaled up when the opportunities are de-risked. Conversely, it can be advantageous to “fail fast” and move on to other opportunities.
- The decarbonization space presents new opportunities, but the question remains whether oil companies are better equipped than others to create successful and sustainable new business models in these and other new energy technologies. Based on their patents and venturing activities, leading IOCs appear to be at the forefront for certain technologies. They seem well placed to capitalize on their deep pockets to scale up technologies and on their existing portfolios to integrate some new technologies. But there are serious risks to an accelerated transition strategy towards low-carbon technologies. This shift can adversely affect their profitability, especially as new business models have not yet been proven. The pace will not be uniform across oil and gas companies and some will simply consider the move beyond the core businesses to be unattractive. As the energy transition advances, we are likely to see more divergence in strategies and approaches across companies.
- The challenge for IOCs companies that invest in low carbon technologies is to show that they are better placed than others to succeed in a decarbonized world. We think IOCs have not made a strong case to financial markets, shareholders and the wider society, if indeed there is such a case to be made. This helps explain why shareholders often reward companies with high dividend and large buyback purchase programmes; they do not believe that IOCs can lead the transition or perhaps even survive it without a major transformation. Yet, we would argue that the IOCs need to attract large amounts of capital and invest heavily in low carbon technologies in on order to move the needle on decarbonisation.
- The transitioning is a multi-decade journey, requiring multi-decade leadership and coherent narrative with a consistent communication strategy. The latter is an area where we think the industry has also not been effective so far. Emphasizing the importance of these new low carbon technologies and how IOCs are playing a leading role in this space can perhaps excite investors and convince the wider society that IOCs are part of the solution and not only part of the problem.

V. Conclusion and future research

First, there is a central question that each IOC needs to address when considering how to adapt to the energy transition: whether we can expect evolutionary change within the existing socio-technical regime, rather than a fundamental change that requires new practices, regulations, values, perceptions and business models, as well as new technologies. A company´s views on this will determine its reaction to the challenges of the energy transition. It is worth studying the experience of other sectors and companies that have recently had to address the same question. In particular, the power sector has been turned upside down by the combination of decarbonization policies and technology change. Markets, regulations, business models, corporate cultures and corporate structures from the last century are completely inappropriate today. Utilities that relied on fossil fuels have seen their market value drop substantially and have undergone corporate restructuring to separate their "bad bank" assets and activities from the more promising ones. Others saw the change earlier or were quicker to adapt when needed. Meanwhile, new entrants are increasingly important, especially in renewables and distributed energy services that are customer facing. These changes go way beyond new investment opportunities; they require a fundamental rethink about energy and society in a decarbonised and digitalized world.

Second, we have emphasized that renewable power technologies and electrification alone will not come close to full decarbonization of the energy sector. Even the European electricity association, Eurelectric, whose goal is full decarbonization of electricity by 2045, recognizes that electricity is unlikely to provide more than 60% of Europe's energy needs by 2050. The IOCs have an opportunity to develop non-electric zero carbon technologies to help fill this gap. Research should not only focus on potential investment in specific technologies, but how they fit into new decarbonized energy systems that combine electricity with decarbonized fossil fuels (as do the current proposals for heat decarbonisation in the UK).

Third, this Insight illustrates the inconsistencies between the Paris Climate targets and most energy industry forecasts, including our own. Existing technologies and incentives for investment are inadequate. Policies should actively promote research into new low, zero and negative-carbon technologies, as well as supporting experimentation with new business models that support decarbonization. This is the time to partner with policy makers, for instance, to press for rising carbon prices and carbon intensity targets across the economy, and for public-private partnerships to promote innovation.

Finally, the focus of IOCs to date has been on diversification and adaptation, which seems a sensible strategy in an environment of high uncertainty about the speed of the energy transition. IOCs should ramp up on technologies where they see real opportunities and they are in a good position to exploit. But it remains very unclear whether these investments are being pursued as part of a long-term vision or as part of an ad-hoc approach. Specifically, what is the long-term future of an IOC in a decarbonized world? Does the IOC see itself morphing into something new that will not be in the oil and gas business but where it has no clear advantage and returns are lower, or can it see a future of oil and gas that is decarbonized and where it has a greater competitive advantage but where the decrabonization technologies are not yet commercial? These are some of the key questions that IOCs will need to confront sooner rather than later.

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