Energy Transition Strategy: An Evaluation of the Harder-to-Abate Sectors of International Oil & Gas Companies and the Implications for Net Zero

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ABSTRACT

This research was carried out investigate what energy transition strategies and to what extent the IOCs are addressing the harder-to-abate sectors of shipping, aviation, trucks and petrochemicals; why adopted strategies are ineffective/effective; why the sector is hard-to-abate/neglected, and what fuels have been adopted. Secondary data was collected from IRENA and the seven leading IOCs. Findings were qualitatively and quantitatively analyzed, and show that IOCs have increased their harder-to-abate sector energy transition engagements, compared to previous years. Biofuels and hydrogen are the renewable fuels adopted for this difficult-to-electrify sector, which is not easily directly amenable to other sources of renewable energy. The 'horizontal strategies' of direct/own investments/projects, partnerships, strategic alliances, JV, stake and fuels purchases and outright acquisitions were employed by IOCs to grow their biofuel and hydrogen portfolios, while 'vertical strategies,' entail short and long term strategies. Biofuels represent short term strategy because they are readily deployable fuels requiring little or no engine modifications, while hydrogen represents long term strategy, as engine re-calibration, new distribution and dispensing infrastructures are required. Through the implementation of the horizontal strategy, the vertical strategies are accomplished, leading towards 2050 net-zero target. The IOCs are producing not only grey hydrogen, but also blue (CCS/CCUS-applied) and green hydrogen. Global green hydrogen production entails the electrolysis of water, using enormous amounts of renewable electricity. They now produce, not just bioethanol and biodiesel, but through technological innovation, have developed SAF, Bio-LNG, R-CNG, RNG, LCF and HVO biofuels. While these developments are commendable, they are ineffective, as current sector investments must more than triple, annually, for net zero to be attained, otherwise, it will be an illusion.

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LIST OF ABBREVIATIONS

GHG – Green house gases

IOCs – International Oil and Gas Companies

IRENA – International Renewable Energy Agency

ETC – Energy Transition Commission

IEA – International Energy Agency

ICAO – International Civil Aviation Organization
CCS – Carbon Capture and Storage

CCUS – Carbon Capture, Utilization and Storage

BECCS – Bioenergy, Carbon Capture and Storage

H2/H_2 – Hydrogen

Blue H_2 – Produced with natural gas, while emitted CO_2 is captured, stored or utilized

Green H_2 – Produced by splitting water using electricity from renewable sources

HRS – Hydrogen refueling stations

REDD+ - Reducing Emissions from Deforestation and Degradation of Forests

MPTA – Million Ton per Annum

CO_2 – Carbon dioxide

JV – Joint Venture

MOU – Memorandum of Understanding

TWh - Terawatt-hours

BioF - Biofuel

CO_2, - Carbon dioxide

SF_6 - Sulphur hexafluoride

CH_4 - Methane

HFCs - Hydrofluorocarbons

UNFCCC – United Nations Framework Climate Change Conference

WMO – World Meteorological Organization

IPCC – Inter-governmental Panel on Climate Change

N_2O - Nitrous oxide

PFCs – Perfluorocarbons

UNEP – United Nations Environmental Program

ICE – Internal Combustion Engines

Bpd/kpd – Barrels per day/kilo barrels per day

SAF – Sustainable Aviation Fuel

Bio-LNG – Bio liquefied natural gas

R-CNG – Renewable compressed natural gas

RNG – Renewable natural gas

LCF – Low carbon fuels

LPG/LNG – Liquefied petroleum gas/liquefied natural gas

HVO – Hydrogenated vegetable oil

ATJ – Alcohol to jet fuels
NASA – National Aeronautics and Space Administration

CHAPTER 1

INTRODUCTION

The rising consumption of fossil energy, powered by an expanding global economy is contributing significantly to the current atmospheric GHG buildup (UNFCCC, 2011). Sea level rise, increased cyclones, extreme weather, crop damages, rising flora, fauna and human diseases, and aridity are on the rise, as natural ecosystems are perturbed by climate change especially global warming, and this is "very likely" caused by the emission of GHG (IPCC, 2007a; IPCC, 2007b; IPCC, 2007c and WMO, 2008), which constitutes CO_2, SF_6 , CH_4, HFCs, N_2O, and PFCs (UNFCCC, 2008).

According to an IRENA report, the global energy system, which is based mostly on fossil fuels, is transiting towards renewable energy, both in electricity generation, heating and transportation, which implies that in business decisions, IOCs, should adjust and invest accordingly. As a capital-intensive industry, they could fill the gaps in renewable energy investments in order to achieve net zero climate targets. They need to adapt to the energy transition, support the energy system decarbonization and possibly, lead it (Asmelash and Gorini, 2021).

While part of the global strategy is to adopt renewable energy, CCS/CCUS, as well as energy efficiency measures, the major challenge is the difficult, otherwise known as 'harder-to-abate' sectors such as cement, steel, aluminum and chemical industries as well as transportation fuels (ETC, 2018a,b). For IOCs, this entails aviation, shipping and heavy truck fuels, along with petrochemicals. The latter is projected to account for more than a third of the oil demand growth by 2030, and almost half by 2050, ahead of shipping, aviation and trucks (IEA, 2018), and therefore many biorefineries have to be established by IOCs, and other stakeholders (Maity, 2021).

Since IOCs significantly contributed to GHG emissions (GHG) and global warming, global economy decarbonization in order to prevent dangerous climate change cannot take place without a significant fossil energy business model transformation. In recent times, IOCs have been increasingly engaged in energy transition and decarbonization, by investing in renewable energy. This research evaluates the harder-to-abate sector energy transition strategies of the seven leading IOCs: Chevron, ExxonMobil, BP, Shell, Eni, Equinor and Total, in order to ascertain their adopted renewable fuels, and to what extent they have engaged, what strategies they are using and determine if current engagements and strategies are effective enough for the attainment of net zero target. Using secondary data collected from IRENA and the IOCs, an evaluative analysis of the harder-to-abate sectors energy transition strategies was carried out in order to access their effectiveness. Specifically, IOCs secondary data on renewable shipping, trucking and aviation fuels as well as petrochemicals was collected, along with their strategies, and qualitative and quantitative analyses of the harder-to-abate sectors energy transition strategies was carried out.

A. Research Questions

It is suspected that the harder-to-abate sectors are not receiving the attention they deserve, compared to the 'easier-to-abate' sectors, towards addressing oil and gas GHG emissions. While previous research focused on the broad energy transition efforts and strategies of IOCs and their renewable energy investments/associated technologies, this research intends to answer the following questions:

*What harder-to-abate strategies have been adopted by IOCs, to enable them achieve net zero compliance?

*How and to what extent, are these strategies/efforts, effective in addressing the harder-to-abate sectors and what is the implication for net-zero target?

* What are the adopted energy transition fuels that will effectively address these harder-to-abate sectors?
*Why are these strategies effective or ineffective and why are these sectors harder-to-abate/neglected?

B. Aim

The aim of this study is to investigate the effectiveness of the energy transition efforts/strategies of the seven leading IOCs in addressing the 'harder-to-abate' sectors.

C. Objectives

*To ascertain what efforts/adopted strategies, the leading IOCs are using to tackle energy transition in the harder-to-abate sectors.

* To establish the effectiveness of current strategies/efforts in achieving net zero carbon emission target.

*To determine what the harder-to-abate sector fuels are.

*To establish why adopted strategies are effective/ineffective and why these sectors are harder-to-abate/neglected.

*To provide a research driven justification for policy redirection and strategic efforts aimed at this sector.

CHAPTER 2

LITERATURE REVIEW

While the UNFCCC (1997), defines climate change as "a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which, in addition to natural climate variability, observed over comparable periods of time", the Kyoto protocol (UNFCCC, 2008, 2019), says global warming is the long-term heating of the earth's climate system as observed since pre-industrial times, of about 1° C, between 1850 and 1900 (NASA, 2022). However, from the 20th century it became primarily fossil fuel combustion driven, increasing the concentration of atmospheric heat-trapping GHG like CO_2, CH_4 , N_2O, HFCs, PFCs and SF_6 .

Out of the 55.3 $GtCO_2e$ of 2018 total emitted GHG, fossil fuel CO_2 due to energy production and industrialization, accounted for 37.5 $GtCO_2$ (UNEP, 2019), with fossil energy production leading by 2% increase compared to 1.5% in the past decade for total GHG and fossil fuel CO_2 . At current global temperature level, an increase of 1.5 °C above pre-industrial level, from around 2030 to 2052 is a possible climate target (IPCC, 2018) if GHG emissions are significantly reduced, since 1.5 °C limits compared to 2 °C, will mitigate global warming and induce CO_2 emissions reduction by about 45% between 2010 and 2030 levels, achieving 'net zero' at 2050, whereas, a 2 °C increase would magnify it.

Net zero CO_2 emissions are attained when human-made CO_2 emissions are 'neutralized' globally by the same amount of human-made CO_2 removals over a defined period (IPCC, 2018).

The seven leading IOCs are the focus of this research. They were selected because they greatly influence industry practices and direction, accounting for 12% of global oil and gas reserves, 10% of estimated GHG industry emissions and 15% of production (IEA, 2020). They are also the largest publicly traded IOCs (Asmelash and Gorini, 2021) and all are engaged in the energy transition.

As a result of the climate change induced energy transition, the expected oil and gas demand reduction and global warming concerns, poses significant business risks for oil and gas companies and could lead to substantial globally stranded reservoir assets (McGlade and Ekins, 2015). Expected stranded assets include about 33% of global crude oil reserves, 50% of natural gas reserves and more than 80% of current coal reserves which would be unused between 2010 and 2050 in order to comply with set climate target. Also Arctic resources development and any unconventional oil production increase could be incompatible with average global warming limitation efforts. This also applies to any rapid and complete exploitation of territorial fossil fuels. The implementation of climate policy commitment would equally render unnecessary, continued substantial fossil fuel exploration expenditure, as any new discoveries will not lead to 'increased aggregate production.' While McGlade and Ekins have made these useful predictions on stranded assets, they did not address the 'harder-to-abate' sectors. In any case, it is clear that oil and gas firms need to re-strategize, diversify their portfolios and contribute to global climate change net zero mitigation, by embarking on energy transition to renewable energy (Zhong and Bazilian, 2018) which Hauff *et al* (2014), described as a long-term structural change in energy systems.

The global proved oil reserves were 1.73 trillion barrels as at 2018 (BP, 2019), sufficient for only 50 years production at 2018 levels. Oil demand, expectedly will peak after 2025 at 97 million bpd, declining to 77 million bpd by 2050, while natural gas demand peak comes after 2025 and plateau to 3,850bn cubic meters by 2050. It is therefore crucial that additional, but clean energy alternatives are sought, in order to increase or diversify the global energy mix, which is illustrated in Figure 2.0, and is dominated by fossil fuel with about 82%, while nuclear, hydro, biofuels/waste and others account for 4.9%, 2.5%, 9.3% and 2% respectively (IEA, 2020).

Renewable energy comprises of wind, solar, hydro, geothermal, biomass/waste and marine energy, and are obtained from naturally replenishing sources, yet has limited flow. These resources are virtually inexhaustible in terms of duration, but are limited in available energy per unit time (EIA, 2021). Figure 2.1 illustrates 2020 -2021 renewable electricity generation increases for Solar PV, Hydro, Wind, Bioenergy and others. It indicates that China is in the lead, and that various energy sources are required to meet global energy demand (IEA, 2021).

In general, the global 'harder-to-abate' sectors account for 16Gt of total CO_2 emissions, which comprised of 30% of global energy GHG emissions in 2018 and could rise up to 60% by mid-century due to rising demand and GHG emissions reduction by other sectors. The sector has complex technological and financial challenges as many of these heavy industries employ complex, highly integrated and very high-temperature processes which for now, are only cost-effective, through fossil fuels combustion, as carbon-free processes development are equally complex and expensive, though not impossible, making these sectors very reluctant to engage in energy transition (ETC, 2018a,b); Hydrogen Council, 2017; Ofili, 2021).

Shipping appears to be the most difficult to decarbonize because of low carbon emitting technologies high costs (between S$150 – $350 estimated cost per ton for abated CO_2), emitting about 0.9Gt CO_2, which accounts for nearly 3% of total global emissions and could rise to nearly 1.7Gt by 2050 (ETC, 2018b).

Aviation GHG emissions amount to about 1Gt CO_2 per annum representing almost 3% total global emissions, but it would amount to nearly 1.8Gt by 2050 accounting for about 4% of global emissions and 14% of transport sector emissions, if it is not mitigated. The aviation industry, in 2009, committed to keep flat, total aviation emissions, at the 2005 level, starting from 2020 onwards, and to achieve 50% reduction by 2050. Aviation net-zero-carbon path requires some biofuels and synthetic fuels combination as "drop-in" (readily deployable), low-carbon fuels can significantly enhance the net-zero-carbon aviation transition, since it will not need any substantial new investment in equipment or infrastructure. Globally coordinated regulation, carbon pricing for large scale deployment and cost reductions as well as certifications will be required to guarantee new fuels safety and authentic sustainability (ETC, 2018a; IEA, 2017). The aviation industry has adopted SAF, including ATJ family of processes, which starts with ethanol or butanol, to produce jet biofuel grade, as there are no known practical alternatives to liquid energy carriers. They are the only known option for the transition of any new propulsion technology, even in the next 30 years (ICAO, 2021).

Heavy-duty road transportation which includes goods and heavy road passenger transport account for 2.5Gt of CO_2 annual emissions, representing 7.3% of total global energy system emissions (IEA, 2017). This could increase to 4.6Gt of CO_2 emissions annually by mid-century, if not mitigated, because total road freight volumes will rapidly increase in developing countries by as much as 11.6%, as emissions drop in easier-to-decarbonize sectors like power generation. There has been little focus on decarbonization solutions for road freight transportation compared to the automobile sector (ETC, 2018a). This heavy duty transportation 'little focus', which necessitated this research is shared by other harder-to-abate sectors.

Petrochemicals are derived from oil and gas, and their rising profile makes them the biggest global oil demand driver, as their products demand growth will account for more than one-third of global oil demand growth by 2030, and almost half by 2050, comfortably ahead of aviation, trucking and shipping. They are projected to consume an additional 56 billion cubic meters of natural gas by 2030**.** While many countries' national strategies do not address harder-to-abate sectors, they can be abated by 2050 at the cost of 0.5% of global GDP and with little impact on consumer living standards (ETC., 2018a; IEA, 2018). Yet it is unclear whether the energy transition strategies of IOCs, addresses petrochemicals or provides for alternative raw material feedstock since this global oil consumption driver provides feedstock for plastics, detergents, thermoplastics, synthetic adhesive, synthetic rubber, fertilizers, herbicides, synthetic fiber, cosmetics, insecticides, food grade lubricant, large machine and vehicle lubricants, pharmaceuticals, plexiglas, asphalt road construction surfacing, teflon which is used in cutlery and non-stick pans, cosmetics, nylon, furniture,

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electronics, appliances, wind turbines and solar power panels (Gikunda, A., 2019; J.M.K.C. Donev *et al*., 2020). Although only 3% of petrochemicals are used in pharmaceuticals manufacture, as much as 99% of them contain petrochemical/petrochemical inputs (Zalewski, 2019; Petroleum Service Company, 2018). Petrochemical plastics demand growth will increase their carbon emissions, representing 2Gt annually by mid-century from their production process and 4.2Gt for end-of-life emissions. Plastics production process emits an average 2.5 tons of CO_2 per ton of plastics, whereas the decomposition /incineration of plastics at end-of-life emit about 2.7 tons of CO_2 per tons of plastics.

IOCs know that climate change policies will reduce fossil fuel consumption in the next few decades, yet they are counting on continued hydrocarbon demand, especially for the harder-to-abate sector fossil fuels because electric powertrains cannot ordinarily, compete with the high energy-to-weight ratios of ICE, required for heavy transportation (Raval, 2019).

According to the IEA (2021), if the transformation of the energy system and net zero target will be achieved by 2030 and 2050 respectively, the annual clean energy investment, including biofuels has to more than triple to $4 trillion annual global energy investments through 2030, from the 2017 production levels of 83m tons of oil equivalent, in order to limit global warming to 1.5 °C and close the gap between future supply and demand, caused by diminished fossil fuel production. The IEA points out that, biofuels production growth is not keeping up with this demand. Such threefold output by 2030 requires a 10% combined average annual production growth. Critics say that biofuels are not "carbon-neutral" over their entire life cycle; that they cause land use disruptions, threaten biodiversity and displace food supplies, while proponents affirm that biofuels can offer energy security to non hydrocarbon producing countries, since they are produced mostly from domesticated crops (primary biofuel), wastes (secondary biofuel) and algae (tertiary biofuel), and therefore reduce foreign oil and gas importation that deplete poorer countries' foreign reserves. They are mostly used, currently, to blend hydrocarbons in order to improve their anti-knock and octane rating performance. They enhance air quality benefits when used as pure, unblended or, more commonly, blended with petroleum fuels. Bioenergy/biorefinery plants can combine with BECCS (Figure 2.5) to mitigate emissions and facilitate the removal of CO_2 from the atmosphere **(**Joaquim and Seabra, 2021). Only an annual production growth of 2.5% is forecast over a five year period. The IEA maintains that if technology learning and significant production scale-up fail to reduce costs, current policy support will remain inevitable for their commercial sustainability (Raval, 2019) as they are better suited for harder-to-abate sectors (IEA, 2021). Figure 2.4 illustrates the global biofuel demand, according to region, from 2019, projecting to 2026.

Hydrogen is another potential harder-to-abate sector green fuel, as it is an efficient energy carrier and only emits water, on combustion. Most hydrogen are produced with about 6% of global natural gas and emits about 830 million tons of CO_2 annually (grey hydrogen). Consequently, IOCs are now applying CCS/CCUS to hydrogen production, in order to capture and store or use emitted CO_2 (blue hydrogen). The cleanest hydrogen is made by splitting water molecules using renewable electricity, while emitting only oxygen and this is known as green hydrogen (< 0.1% of global production), but the required electricity input is estimated at 3600 TWh, which is more than EU's annual electricity generation (IEA, 2019). Figures 2.2 and 2.3 shows global hydrogen demand profiles and how CCS/CCUS increases production costs by regions, especially CAPEX.

Li *et al*, (2022) studied the energy transition claims of Chevron, BP, ExxonMobil and Shell and reported that they failed to demonstrate significant transitions away from fossil fuels, to renewable energy as they increased oil and gas reserves and production estimates between 2015 and 2019, leading them to conclude that no IOC is presently on the path to clean energy transition. While recommending greater transparency on actual annual spending, renewables, low-carbon and clean energy, they concluded that the greenwashing accusations against IOCs are well-founded (Green *et al*, 2021; McGreal, 2021). Their conclusion is inconsistent with those of Pickl (2019), and Asmelash and Gorini, (2021).

According to Pickl, (2019), five IOCs issued energy transition strategies and commenced significant investments in renewable energy. A strong relationship exists between IOCs proved reserves and their renewable energy investment strategies. While those with less proved oil reserves are investing faster in renewables, in order to diversify more, and develop less volatile oil portfolios sooner, those with large proven oil reserves, especially US majors with low breakeven assets, are implementing their energy transition strategies at a slower pace. All but two IOCs (Chevron and Equinor), had ongoing biofuel projects, while all seven IOCs had one CCS each. Most of the IOCs had explicit energy transition strategies and renewable energy teams. Shell was rated highest followed by TotalEnergies, BP, Equinor, Eni, Chevron and ExxonMobil, in that order (Pickl, 2019). These findings about US oil majors' energy transition slow pace, in comparison with those of European IOCs, agrees with that of Shojaeddini *et al* (2019). However, Shell and TotalEnergies are European companies, but unlike BP, Eni and Equinor, have huge global proved oil reserves, yet, are investing heavily in renewables (Shell, 2019; Total, 2020).

Asmelash and Gorini, (2021), studied the energy transition strategies of the leading seven IOCs, on behalf of IRENA, and found out that indeed they are progressing in their energy transition which covered a wide range of renewable energy projects, but needs to be scaled up and accelerated. Their finding on US and European IOCs respective slow and faster pace transition is consistent with that of Pickl (2019) and Shojaeddini *et al* (2019).

Strategy involves the analyses of the present situation and making modification or changes, if required, in order to meet desired targets or organizational goals. It is a long term plan and guide for decision making based on several factors or the formulation of basic organizational or industrial long term goals and objectives as well as the implementation of course of actions including the required resource allocation (Drucker, 1954; Ansoff, 1969; Chandler, 1962). It is, therefore, important to strategize the energy transition, in a way that ensures that the harder-to-abate sectors are adequately addressed.

Harder-to-abate sectors neglect has been reported (ETC, 2018a; IEA, 2018) and this will lead to continuous GHG emissions, since they cannot be easily abated through renewable electrification, yet whether the energy transition strategies of IOCs effectively addresses them remain an open question, hence the need for this investigation. This research will establish what the harder-to-abate sector strategies are, evaluate them, find out why they are harder-to-abate/neglected and the energy sources adopted by the sector and provide a research-driven justification for serious attention, which previous studies have not done and therefore fill a very important knowledge gap.

CHAPTER 3

RESEARCH METHODOLOGY/DESIGN

A. Research objectives:

*To ascertain what efforts/adopted strategies, if any, the leading IOCs are using to tackle energy transition in the harder-to-abate sectors.

* To establish the effectiveness of current strategies/efforts in achieving net zero target.

*To determine what the harder-to-abate sector fuels are.

*To establish why adopted strategies are effective/ineffective and why these sectors are harder-to-abate/neglected.

*To provide a research driven justification for policy redirection and strategy aimed at this sector.

B. Research questions

*What harder-to-abate strategies have been adopted by IOCs, to enable them achieve net zero compliance?

*How and to what extent, are these strategies/efforts, effective in addressing the harder-to-abate sectors and what is the implication for net-zero?

* What are the adopted energy transition fuels that will effectively address these harder-to-abate sectors?

*Why are these strategies effective/ineffective and why are these sectors harder-to-abate/neglected?

C. Philosophy

The research question defines the choice of research philosophy (May, 2011). Since one philosophy is not better than another (Podsakoff *et al*., 2012), but justifies the method, which is informed by the nature of observed phenomena. Consequently, this research used deductive approach to develop hypothetical expectations formed from existing data (Saunders *et al*., 2007). Existing theory helps to design research approach (Silverman, 2013). Based on pragmatism and positivism, it seeks acceptable, provable and measurable knowledge (Bryman, 2012).

D. Research design

Research design methods' advantages/disadvantages inform their choice (Cook and Campbell, 1979). Exploratory Studies are flexible, adaptable, provides increased clarity and problem resolution, yet disadvantaged by their directional change from initial objectives due to new insights. Their strength lies in clarifying the understanding of issues or phenomenon, when unsure of their precise nature.

While descriptive research helps to clarify the phenomenon a researcher wishes to study, before actual data collection, data evaluation and idea synthesis skills, enhance descriptive research with explanations. They provide detailed description, accurate profile, attention to details and helps to answer the 'Who,' 'What,' 'Where,' 'When' or 'How' research questions, but are disadvantaged by being often too lengthy, lacking numerical evaluation, ideas synthesis, incomplete and seen as precursors to explanations.

Explanatory studies, helps to resolve the 'Why' or 'How' research questions, while establishing the cause and effect relationships between variables. Their disadvantage is that as they are too focused on resolving the situations or relationships between variables, they might miss new theory opportunities contribution.

Evaluative studies have the advantages of answering the 'How,' or 'To what extent', 'Which,' 'When,' 'Who' or 'Where' research questions and how well a tool, policy, system or strategy works. They also assess the effectiveness of organizational/business strategy, policies and programs including comparisons and performance. They may produce theoretical contributions if emphasis is placed on understanding, not just how effective, but 'why.' Their disadvantage is the over-emphasis on strategy/policy effectiveness, which may result in the neglect of understanding 'why', and possibly missing theoretical contribution opportunities.

Combined studies employs more than one design purpose such as exploratory, descriptive, explanatory and evaluative research or a single method of research design may be used in such way that gives scope to facilitate several purposes and possibly lead to multiple breakthrough discoveries. It is more useful in large scale studies, with enormous data. Their disadvantage is that they are cumbersome, time consuming and expensive

(Creswell and Creswell, 2018; May, 2011 and Saunders *et al*, 2012).

Consequently, combined evaluative/descriptive/explanatory research will be employed to the answer research questions.

E. Research strategies

Experimental research is carried out in order to refute or support a hypothesis or theory, or establish the efficacy/ inefficiency of previously untried methods. They provide insights into cause and effect by demonstrating outcome occurrence when a specific factor is altered. They vary greatly in goal/scale but rely always on procedure repeatability and logical analysis of results and are mostly used in natural science disciplines, but also in the social sciences. It is disadvantaged by limited number of factors and sample size.

Survey is typically used in quantitative research and involves representative population sampling, but can also be used in qualitative research. The data is collected using standard procedures to ensure a level playing field for respondents, who are interviewed through questionnaires. It is an economical strategy that is very useful in business research, mostly deductive and has the advantage of rich, reliable data collection, yet, it is mostly employed for contributing variables observation and limited by its mostly single population focus and sometimes self reporting.

Case study provides insights into various aspects of organizational life, establishing main features, generalizations and enables comparisons. As an in-depth examination, it may involve single or multiple organizations to enable generalizations. Its disadvantage is that it's time consuming and uneconomical. Also, small number of observations makes it difficult to estimate multiple causal effects.

(Saunders et. al., 2007; Bryman and Bell, 2011; Gerring, J., 2007 and Silverman, 2013).

F. Secondary data sources

- Asmelash E. and Gorini, R. (2021). International oil companies and the energy transition https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Feb/IRENA_Oil_Companies_Energy_Transition_2021.pdf
- IOC's websites/reports
- Asmelash and Gorini, (2021) used case study to establish main features and generalizations. Consequently, I adopted qualitative research and case study strategy for secondary data collection to capture expressive information that are not explicit in associated numerical data (Doolan and Froelicher, 2009). Both qualitative and quantitative techniques were used for data analysis.

G. *Ethical issues*

Unlike primary data, secondary data is data collected by someone else. Its advantages include time and cost savings, ease of access and existing data new insights. Its disadvantages include questions about reliability, validity, consistency, outdated data; relevance, differing original purpose and might require permission. Primary data on the other hand is expensive, time consuming, and more complex. Its advantages include relevant and current data collection, own collection methods, and copyright ownership.

Quality threats may affect reliability, that is, the ability to replicate the results consistently. It also includes validity – results analysis accuracy, findings generalisability and adequacy of used methods. The secondary data used in this research causes no harm to persons, while copyright owners allow free access/data use. They are relevant and adequate for answering the research questions and were published in 2021 and 2022. Their copyrights are owned by IRENA and the IOCs, with similar target populations, and they are all reputable international organizations. The constraints include reliance on IOCs data, though this is objectively balanced by IRENA's independent report; time constraint in reviewing/analyzing all seven IOCs websites/IRENA. Data collection and analysis is similar to that of the IRENA report. All sources have been adequately referenced with in-text citations in order to address possible ethical concerns (Hair *et al*., 2011; Smith, 2008 and Dale *et al*, 1988). Tables 3.0 and 3.1 show detailed ethical evaluations.

CHAPTER 4

SECONDARY DATA EVALUATION

A. Findings/Analysis

The harder-to-abate sector/energy transition strategies of IOCs, which are now part of their general business strategies (Figures 4.91- 4.97), include direct/own investments/ expansions/conversions, partnerships, strategic alliances, JV, fuel/stake purchases and companies acquisitions in efforts to attain net zero target. I term this horizontal strategy. The harder-to-abate sector fuels were identified as biofuels and hydrogen. CCS/CCUS is applied for blue hydrogen production. Consequently, these have been used as parameters for evaluation (Asmelash and Gorini, 2021; IOCs websites analysis). While biofuels represent a short term strategy due to its 'readily-deployable' status, hydrogen represents a long term strategic fuel, as it requires engine recalibration, new distribution and retailing infrastructures. Both fuels represent short and long term vertical strategies respectively. The vertical strategy is accomplished through the implementation of the horizontal strategy, while the anticipated profitability and sustainability of the vertical strategy informs the activation of the horizontal strategy (Figure 4.0).

Both fuels are energy dense enough like hydrocarbons, though cost, scale and sustainability remain challenging, as enormous amount of electricity is required for water electrolysis in global green hydrogen production. Biofuels are renewable LCF, and require large amounts of water and biomass for production, while hydrogen emits no CO_2 on combustion. They can promote national/global energy security, as any nation can produce green hydrogen and secondary/tertiary biofuels (SWOT analyses - Figures 4.1 and 4.2)

Shell, TotalEnergies, Eni and BP had ongoing biofuel projects, while Chevron, Equinor and ExxonMobil had no biofuel projects. All IOCs except BP, Chevron and ExxonMobil had hydrogen investments (Table 4.0). Unlike the American IOCs, the European IOCs were engaged in energy transition. BP had 3 three units of sugarcane processing biofuel business in Brazil and intends to increase output from 22,000 bpd to 100,000 bpd (Asmelash and Gorini, 2021).

B. BP

As this website analyses (Table 4.1) show, the recently formed BP Bunge Bioenergia JV has 11 plants/units, increasing its bioenergy portfolio by over 50%. It also acquired a 30% stake in Green Biofuels Ltd, UK's biggest HVO producer, which sold over 55 million liters of biodiesel in 2020 and 2021. BP's Honeywell UOP's Ecorefining technology is planned for renewable diesel and SAF project in Western Australia, in order to convert hydroprocessing equipment to produce approximately 10kbd diesel and RAF. It produced 776 million liters of bioethanol equivalent from sugarcane in 2021.

BP has hydrogen businesses including 1GW of blue hydrogen at Teesside, 60 MW and 250 MW green hydrogen projects in UK and Netherlands respectively and plans to operate 50 heavy duty hydrogen refueling stations by 2030. It's Chevron/Petrobras/Suncor JV is a CCS project.

According to BP's CEO, its strategy is to transform from an IOC into an IEC, by hydrocarbon production reduction of more than 40%, new countries exploration avoidance, cut operational emissions by 30-50%, and reduce the GHG emissions in upstream production by 35-40%; use hydrocarbon generated cash to finance (about 40% or more of investment) low carbon electricity and energy and customer convenience and mobility, till 2030, increasing its low carbon investment to around $5 billion a year, that is, a 10-fold increase on the presently invested $500 million; develop about 50GW of net renewable energy generating capacity, which is a 20-fold increase on the current 2.5GW; capture 10% of core hydrogen market share as against small volumes supplies of own operations; produce 100,000 barrels per day of biofuel as against current 22,000 barrel/day; double daily customer interface to 20 million compared to current 10 million; provide 70,000 EV charging points compared to current 7,500; create energy partnerships with 10 to 15 big cities globally and 3 core industries (Looney, 2020).

"If you want to decarbonise, biofuels has a big role to play," says Dev Sanyal, who is responsible for BP's alternative energy business. BP already has one of the world's largest operated biofuels businesses, employing close to 6,000 people in three sugarcane processing units in Brazil. It's traditional biofuel business is commercially attractive and profitable, says Mr Sanyal, but his goal is to make other, more advanced biofuels such as bio jet fuel viable options.

A 2021 signed MOU between BP and NYK Line initiated a collaboration to enable the decarbonization of the harder-to-abate sectors, particularly shipping and heavy duty industry. It will enable them identify opportunities for transitioning to alternatives lower carbon fuels like biofuels, LNG and methanol, and develop ammonia and hydrogen for heavy industry and power generation decarbonization. A similar collaboration with Schneider Electric will explore the latter expertise and consulting skills in the design and decarbonization of energy systems, for heavy duty and shipping.

C. Shell

Shell's long time biofuel investments include the Raizen joint venture in Brazil, which converts sugarcane waste to biofuel, and a Bangalore (India) plant that has advanced biofuel processes that concerts biomass and waste to 'vehicle-ready' fuels for cars, vans and trucks (Shell, 2019). Its German joint venture partners: Air Liquide and Linde, industrial gas manufacturers and Linde, Daimler, car manufacturer and Total and OMV, energy companies are developing a nationwide network of new hydrogen car models for 400 hydrogen refuelling stations by 2023. In 2017, it was the first branded fuel retailer to sell hydrogen at its UK retail sites in 2017; its new Cobham hydrogen refuelling station in London's outskirts was the first of three hydrogen stations Shell hoped to open in southeast England's. It also has two hydrogen stations in Los Angeles and has partnered with Toyota, to further develop the latter's hydrogen refueling network (Shell, 2019).

Shell says it is working with airports, airlines, aircraft manufacturers, major airline users and governments in order to stimulate and accelerate sustainable aviation fuel and plans to increase investments in this sector, as demand grows. It is working with transportation firms, truck manufacturers and policymakers to identify decarbonisation pathways. Increase in the production of low-carbon biofuels remains the short term strategy. It plans to offer biogas and LNG to customer trucks in China, Europe and the USA. The longer term strategy is to increase hydrogen sales for transport. Shell is a member of the H_2 Accelerate consortium, which investigates ways to create the required infrastructure for the generation and supply of clean hydrogen to hydrogen trucks when they become available throughout Europe.

With Rolls-Royce, it is testing the latters engines to evaluate 100% sustainable aviation fuel performance.

The Clean Skies for Tomorrow Coalition is an initiative of the Mission Possible Platform, launched by the World Economic Forum and the Energy Transitions Commission aimed at achieving net-zero carbon emissions by midcentury for the hard-to-abate industry sectors, by making sustainable aviation fuel available and more widely used. It consists of airlines, fuel providers, airports and engine manufacturers.

As one of the world's largest biofuel traders and blenders, Shell blended about 10 billion litres of biofuels, while its renewable compressed natural gas and liquified renewable natural gas (bio-LNG) fuels decarbonised road freights daily.

Its 'harder-to-abate' sectors strategy is intended to help stakeholders find their own net-zero emissions pathways, as it advocates a 3-tiered carbon emissions management, namely avoid, reduce, and offset, and addresses heavy duty transportation. In a Shell survey publication titled "Decarbonising Shipping: All Hands on Deck", interviews with 80 senior executives from the global shipping system, twelve recommendations, such as promoting green shipping demand, global regulatory alignment, funding new fuels R & D, pilot projects scale-up and industry coordination. For aviation, Shell reports that the Clean Skies for Tomorrow initiative, formed by airlines and other industry corporations has called for a set of European policies aimed on support for sustainable aviation fuel growth and use, as this can ensure carbon emissions reduction by as much as 80%. It has signed a number of deals to scale up supply, collaborate with cargo carriers, including the supply of about six million gallons of blended sustainable aviation fuel to Amazon.

As vans and trucks consume about 50% more energy than shipping and aviation put together, Shell says it has commissioned Deloitte to study the sector and provide a roadmap. However, it is collaborating with a US truck company for the building and testing of a hyper-efficient concept truck by using a range of lightweight, energy efficient technologies and materials. Oiled with specially formulated lubricants and equipped with solar panels, it says the Starship truck recorded almost 250% freight tonne efficiency improvement in comparison with average North American trucks. It also introduced specialized of E-Fluids range to truck and bus maker customers, designed to comply with the technology demands of hydrogen commercial and battery electric vehicles. The company is piloting three new California heavy-duty hydrogen trucks refuelling stations. The company is awaiting a heavy duty low carbon demand growth and favourable policy regimes, before making significant strides in this direction. Also, petrochemicals appear to be neglected.

Shell catalysts and technologies formed a global alliance with Arbios Biotech, aimed at using Shell's upgrading technology to develop a low-carbon, circular-economy based biorefinery. Arbios Biotech's hydrothermal liquefaction technology uses forms of wood and post-consumer biomass and near or at supercritical water to produce high quality renewable 'biocrude' and sustainable bio oil for the circular economy. With an 820,000 tons/year biofuel plant, it is developing a biocrude circular-economy biorefinery which is 'upgrade-able' to transportation fuels and chemicals. It is transforming its 14 refineries into 5 biorefineries/chemical parks, reducing hydrocarbon production in 2030 by 55%. It will supply six million gallons of blended SAF to Amazon, increase SAF supply to Neste and will supply Schiphol Airport, Red Rock Biofuels and DHL Express. Along with EuroNet consortium, DISA, Scania, IVECO and Nordsol, it plans to supply customers with net-zero bio-LNG by 2025. It's California R-CNG fuelling site is under construction. Shell's Raízen waste-to-ethanol plant is the world's fourth largest RNG facility; producing 2.5 billion liters of sugarcane ethanol in 2019, while its Rheinland refinery produced as much LCF for over half a million vehicles annually. Shell, Enerkem and others are constructing a LCF plant in Quebec to treat over 200,000 tons of wood waste annually, producing nearly 125 million liters of LCF annually. It's first US RNG facility converted local cow manure and agricultural residues to 2,650 scfm of biogas, and upgraded it to about 736,000 MMBtu a year of RNG.

It has green hydrogen projects of 20 MW in China, 200MW in Rotterdam, 10 MW in Wesseling, 10 MW in Rheinland Germany, 1 GW in Gasunie, Groningen, undisclosed output in Norsk Hydro, Norway, 10 MW in New South Wales, Australia and hydrogen refueling businesses including 3 California heavy-duty hydrogen trucks refueling stations, a new hydrogen car models network development for 400 hydrogen refueling stations by 2023 and Toyota's hydrogen refueling network. It says that sufficient policy interventions are required to drive green fuel investments/consumption.

D. Total Energies

TotalEnergies invested $14 million in a biofuel start-up, Renmatix, in 2016. The start-up uses super-critical water to reduce biomass conversion costs. It converts wood or agricultural waste into cellulosic sugars for biofuels production (Kite-Powell, J., 2016). Total transformed its La Mède refinery into the first French biorefinery in 2017, which has a capacity of 500,000 tons using various types of oils, such as vegetable oils (Total, 2019), to manufacture biodiesel and renewable feedstock. It's hydrotreated vegetable oil (HVO) process produces high quality biodiesel that easily blends with conventional diesel in any proportion, without any negative impacts on fuel quality or engines performance.

Total's transportation fuel strategy for trucks is based on two approaches, natural gas vehicles which come in the forms of CNG and LNG; and improved energy efficiency for diesel trucks.

There are five key players in France's biojet fuel industry project, namely Suez, Air France, Safran, Airbus, and Total. They are presently carrying out a study in order to define the optimal conditions for the production and marketing of clean air transportation fuels.

Their strategy for marine shipping is LNG use. Again, this will not meet the call for clean energy, as natural gas still emits carbon, though, lesser than oil.

TotalEnergies made carbon capture, utilization and storage (CCUS) one of its strategic priorities with the aim of building a new industrial sector such as the trailblazing Northern Lights project.

CCUS will help decarbonize the harder-to-abate sectors, like power plants, cement factories, steel plants and petrochemicals complexes. In order to achieve carbon neutrality in the second half of the century, 750 million tons of CO_2 and 2.4 billion, would have to be captured and stored by 2030 and 2040 respectively, which is in line with the 2040 International Energy Agency's Sustainable Development Scenario projections.

As part of its strategy, TotalEnergies has allocated 10% of its total R&D budget to the development of breakthrough CCUS cost effective and energy efficient solutions, in order to speed up wide-scale deployment as it has geosciences expertise in such areas as for storage reservoir management such as drilling and injection technologies, and gas processing. Other CCUS projects are as follows:

The Net Zero Teesside BP-operated project supported by the Oil & Gas Climate Initiative (OGCI) support, is the first CCUS commercial project in the UK and a global-first and it is designed to capture CO_2 emissions from a new gas-fired power generation plant and from local industrial emitters.

The Acorn project will reuse current oil and gas facilities for the transportation and storage of the CO_2 generated by UK's St. Fergus Gas terminal clean hydrogen production facility.

Aramis is where TotalEnergies intend to convert depleted offshore gas fields to carbon storage sites.

The 3D Project (DMX™ Demonstration in Dunkirk) plans to demonstrate an innovative process effectiveness for CO_2 capture from industrial activities, with the intention of developing the European Dunkirk-North Sea CCS cluster in future.

The company says that bioenergies and hydrogen based fuels are the pathways for the harder-to-abate sectors like aviation and shipping

TotalEnergies, Equinor and Shell, have been partners in the Norway's Northern Lights project since 2017. It is a large scale, project meant to capture, transport and geologically store industrial CO_2 emissions. For demonstration purposes, Phase 1 aims to store nearly 40 million tons of CO2 over 25 years (or 1.5 million tons per year). The goal is to develop a viable, reproducible commercial model that will serve as a template for other large-scale projects worldwide.

TotalEnergies's La mede refinery has a biorefinery of 500,000 ton biodiesel capacity which uses super-critical water to reduce biomass conversion costs, converting them to cellulosic sugars for biofuels (Kite-Powell, 2016). It also has over 100 MW green hydrogen capacity and about 30 hydrogen refueling stations.

E. ExxonMobil

ExxonMobil says it works with over 80 universities, 5 energy centers, and U.S. national laboratories to conduct research into emerging energy technologies in carbon capture and biofuels technologies. It became the first energy company to join the IBM Quantum Network for the exploration of the future quantum computing potential to solve real-world energy problems quicker or more efficiently as against classical computing.

It has been funding a range of leading US universities biofuel research programmes including algae and second generation (non-food) biomass conversion, that is, cell biomass to advanced biofuels (ExxonMobil, 2018). Its 2020 partnership with University of Genova is aimed at fuel cells efficient carbon capture emissions research (Energy Factor, 2020). It is also working with the US-based biotechnology firm, Viridos, for the development of advanced biofuels from algae. Its project objective is to produce 10 000 barrels of algal biofuels daily, by 2025 (ExxonMobil, 2018). A 2020 agreement with Global Clean Energy aims to purchase renewable diesel made from “camelina”, a non-food crop with GHG reduction potential, for road transportation (Energy Factor, 2020).

CCS constitutes a critical part of ExxonMobil’s portfolio and in meeting energy demand while ensuring GHG emission reduction. A 2019 agreement with Mosaic Materials enabled the company explore CCS advancement technology aimed at cost reduction and large-scale deployment (Ali, 2019). Since 1970, the firm has been capturing carbon and says it has captured over 40% of cumulative captured CO_2 and that it presently has one-fifth of the global total carbon capture capacity, with about 7 million tons of carbon annually (LeSage, 2020).

In order to commercialize its diverse low-carbon technology portfolio, ExxonMobil launched a new business, Low Carbon Solutions in 2021, with a $3 billion lower-emission energy solutions investment through 2025, initially focusing on CCS opportunities advancement (ExxonMobil, 2021).

Since heavy-duty transportation requires high energy density fuels such as those provided by liquid hydrocarbons, unlike battery power, which is poorly suited for this sector, algal biofuels have scalable solution potentials that can deliver required liquid energy density form that could reduce GHG emissions by over 50 percent compared to current heavy-duty transportation fuels, ExxonMobil has completed sea trials of its first marine biofuel oil, which could lower CO_2 emissions by as much as 40% compared to hydrocarbon marine fuel.

ExxonMobil and ten other companies have indicated that they will support a large-scale CCS hub in the Houston, hoping that by 2040, it will possibly capture about 100 million metric tons of CO_2 from, chemical plants, refineries and power generation facilities annually – an equivalent of today’s 20 million gasoline-powered passenger vehicles.

The company says it’s scientists and engineers are working towards GHG emission reduction innovative and scalable solutions, focused on, not only the highest-emitting, but also, the most-difficult-to-abate sectors and that predictable, durable and market-driven policies are required in order meet up with the Paris Climate Agreement and produce maximum emissions reductions at the least cost to society.

ExxonMobil has completed sea trials of its algal shipping biofuel; plans a 10,000 bpd algae biodiesel production and has purchase agreement for a non-food crop renewable diesel. Its Imperial Oil affiliate is constructing a 20,000 barrel renewable diesel plant in Edmonton, Canada. It also acquired 49.9% stake in Norwegian Biojet AS.

Equipped with CCS, it produces 1.5 billion cubic feet of hydrogen daily at its Texas Baytown refinery. It is studying blue hydrogen hub feasibility in Southampton/UK and plans a 2030 hydrogen production (4.3 TWh).

F. Chevron

Chevron has invested in the research, innovation and application of technologies that explores GHG emissions reduction, launching a Future Energy Fund initial investment of USD 100 million in 2018, in breakthrough technologies that enhance energy transition to greater diversification of lower carbon emissions sources (Krieger, 2020). Its 2019 CSR Report (Chevron, 2019), commits to address climate change and recognizes three focus areas of action, namely, carbon intensity reduction by 2023; renewable energy increase to support its business through partnerships in biofuels, biomethane and novel renewable-based oil technologies; and future investment focused on breakthrough technologies such as EV charging networks, CCS and CCS.

The company announced in 2021, a tripling of carbon investments to $10 billion in order to reduce carbon emissions footprint through 2028, expand renewable natural gas production to 40 billion BTUs daily, step-up renewable fuels production capacity to, aimed at 100,000 barrels per day renewable diesel and SAF, increase its hydrogen production to 150,000 tons yearly for the power, industrial and heavy duty transport and increase carbon capture and offsets to 25 million tons annually.

Chevron's lower carbon strategy focuses on "harder-to-abate" sectors such as aviation, manufacturing and heavy-duty transportation as they are "much more difficult to electrify than light-duty transportation." Consequently, Chevron New Energies was formed in order to grow hydrogen, carbon capture and offsets.

It plans biogas expansion to 40 billion BTUs daily and biodiesel/biojet fuels increase to 100,000 bpd by 2030; it reports that the harder-to-abate sector 'is more difficult to electrify' as most renewable sources lack the needed fluid energy densities. They partnered Novvi to integrate renewable base oil into lubricant product lines, while its El Segundo, California, refinery is co-processing biofeedstock and producing SAF. Chevron/CalBioGas JV produces biomethane fuel and has announced the first dairy waste RNG. It formed the Chevron/Brightmark JV for dairy RNG and recently acquired 'Renewable Energy Group,' adding 12 US/EU Biorefineries with a combined 500 million gallons of biodiesel/renewable diesel annual production to its portfolio.

Its hydrogen projects include undisclosed outputs of Raven SR waste-to-green hydrogen, Toyota strategic alliance for large scale hydrogen, ACES Delta green hydrogen, Hydrogenous bulk hydrogen storage and transport, Cummins green hydrogen, Starfire ammonium project and Caterpillar rail and marine hydrogen feasibility. Among its eight CCS, include a BECCS.

*G. **Eni***

Eni says its 2021-2024 strategic plan towards zero emissions is strongly committed to key roles in sustainability and innovation. It committed in 2021, to full decarbonization of all their products and processes by 2050. Eni has announced the merger of its renewable and retail businesses so that the resultant larger customer base of 15 million customers will grow in synergy with its renewable energy business. Also, by combining the biorefining and marketing businesses sustainable mobility will be delivered effectively, contributing to the decarbonization of its products. The decarbonization of operations and products will enable it deliver an entirely decarbonized products mix.

For Net Zero emissions at 2050, it introduced new absolute emissions targets of -25% at 2030 vs 2018 and -65% at 2040; new intermediate targets for Net Zero Carbon Intensity by 2050 of -15% at 2030, no longer 2035, with reductions attaining 40% by 2040. As a result of the integration, its retail and renewable energy businesses, bio-products and circular economy will be diversified and expanded. It plans to grow the renewable energy installed capacity to 15GW by 2030.

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It says the full decarbonization of its products and operations will be accomplished by doubling biorefineries capacity to about 2 million tons by 2024, and expanding it five-fold by 2050; greater use of biogas, waste and recycling final products circular economy; use of efficient and digital solutions for operations and customer services; increasing renewable energy capacity to 4GW by 2024, 15GW by 2030 and 60GW by 2050, and fully integrating it with Eni's clients; making use of green and blue hydrogen for it's biorefining system and other hard to abate activities; artificial and natural carbon capture for residual emissions removal; REDD+ projects which offsets over 6MTPA of CO_2 by 2024 and over 40MTPA by 2050; CCS projects' total storage capacity of about 7MTPA by 2030, 50MTPA by 2050. Natural gas will constitute over 90% of Eni's long term production, supporting the energy transition for portfolio balance of intermittent sources.

Eni has developed its decarbonization strategy and integrated it into its business model in line with the Paris Climate Agreement and the 17 UN Sustainable Development Goals. It holds the enviable record of being the world's first to convert a conventional petroleum refinery, in 2014, to a biorefinery which produces green naphtha green diesel, jet fuel, and liquid petroleum gas (Pickl, 2019).

Consequently, it has 2 Biorefineries at Venice (400,000 tons/year) and Gela (750,000 tons/year) which produces green naphtha, green diesel, green jet fuel, and sustainable LPG. It is expanding its annual hydrogen production to 150,000 tons and produces blue and green hydrogen. It plans to double biorefineries capacity to about 2 million tons by 2024, and expand it five-fold by 2050.

H. Equinor

As sustainable oil and gas production remains part of its strategy, it sees electrification as investments in climate and sustainable oil and gas. Transforming producing fields to use electricity rather than gas, is part of its strategy to ensure major emissions reduction in Norway.

Due to electrification, it's Johan Sverdrup field emits 0.67 kg of CO_2 per barrel, compared to, industry global average of 18 kg CO_2. What is unclear is the source of the electricity. If its renewable energy, then that is positive, but if it is from a fossil source, then, its unsustainable.

Among its energy efficiency initiatives include, work processes digitalization, remote operation robotisation, reduced offshore travel, 3D-printing, freight reduction, which together helps Equinor reduce ita carbon footprint.

Equinor bases its harder-to-abate strategy on hydrogen and CCUS. It believes that hydrogen should replace fossil fuels in aluminum, steel and elsewhere. Consequently, it sees a long term role for natural gas, which will be used to produce hydrogen, while emitted CO_2 is captured and stored or utilized.

Equinor has no biofuel plant. It's strategy is based on blue hydrogen; developing a hydrogen power plant in the Netherlands and involved in the Northern England consortium for hydrogen network development. It partnered Engie for blue hydrogen feasibility; RWE, for Shell's NorthH_2 Groningen green hydrogen project (1 GW by 2027; 10 GW by 2040); Open Grid Europe and Thyssenkrupp Steel Europe for 2.7 GW blue hydrogen Duisburg project; Vattenfall and Gasunie for Vattenfall's Magnum gas-fired power plant hydrogen conversion (440 MW); Shell for Rotterdam hydrogen project and the Zero Carbon Humber for the decarbonization of the UK Humber industrial cluster (undisclosed outputs), with a BECCS pilot (website analyses).

Fuel production units/numbers was converted to numerical data (Table 4.2), which informs the graphs and charts (Figures 4.3 – 4.8), that follow. All show that, contrary to Li *et al* (2022), IOCs harder-to-abate plants/unit numbers have increased from the 2021 to 2022 levels, led by Shell (3 to 15 biofuel units; 2 to 10 hydrogen units), followed by BP's biofuel units (3 to 14) and Chevron's hydrogen units (0 to 8 hydrogen). Even TotalEnergies and Eni, which have fewer units/numbers, still had high biofuel (500,000 and 1,150,000 tons) and hydrogen (100 MW green hydrogen and 150,000 tons of blue/green hydrogen) outputs respectively. These improvements aligns with Pickl, (2019) and Asmelash and Gorini, (2021), but differs in that, American IOCs, Chevron and ExxonMobil, are now engaging/increasing their harder-to-abate sector projects.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

To fill a knowledge gap and answer the research questions of how and to what extent, are the energy transition strategies/efforts of the seven major IOCs, effectively addressing the harder-to-abate sectors; the implications for net-zero; adopted fuels, why the sector is harder-to-abate/neglected and adopted strategies effectiveness/ineffectivess, secondary data was collected from IRENA and the seven leading IOCs, followed by qualitative and quantitative analyses.

The 'overall transition strategy' uncovered, consists of both vertical and horizontal strategies. The latter include direct/own investments, JV, partnerships, strategic alliances, company acquisitions, stakes and fuel purchases. The horizontal strategies drive the vertical strategies, which involves biofuels and hydrogen. The vertical strategy consists of short and long term strategies. While biofuels represent a short term strategy due to their readily-deployable status, hydrogen represent a long term strategic fuel as it requires engine re-calibration, new storage facilities, distribution and dispensing infrastructures build-up. These strategies are also applicable to the general energy transition strategies. The latter has been fully integrated into, and greatly influences IOCs general business strategies.

The industry-adopted harder-to-abate sectors renewable fuels were found to be biofuels and hydrogen. IOCs are producing, not only grey, but blue (CCS/CCUS-applied) and green hydrogen, while their biofuels are not just bioethanol and biodiesel, but technologically innovative SAF, Bio-LNG, R-CNG, RNG and LCF. Both fuels are energy dense enough to replace hydrocarbon fuels in the harder-to-abate sectors, though concerns exist about their cost, scale and sustainability, as huge amounts of electricity are required for water electrolysis in global green hydrogen production, while biofuels production consumes huge water quantities and biomass. Biofuels are renewable LCF, while hydrogen emits no CO_2 on combustion. Both fuels will promote global energy security, since any nation can potentially produce green hydrogen and biofuels.

IOCs have increased their number of harder-to-abate fuel projects/outputs, compared to their 2021 performance. Shell leads the pack with more biofuel and hydrogen plants/units, followed by BP and Chevron for biofuels and hydrogen respectively. TotalEnergies and Eni, had the least number of biofuel plants/units, yet had high fuel outputs. Contrary to previous reports, the American IOCs, ExxonMobil and Chevron have fully embraced the energy transition, increasing their harder-to-abate projects. Chevron recently acquired the Renewable Energy Group, instantly becoming one of North America's biggest biofuel producers. Shell, Total Energies and Eni have/are converting their petrochemicals/refineries to biorefineries, while Chevron, Equinor and one Shell JV have one applied-BECC each.

Despite these engagements/increases, the IEA warns that current annual production rates, (within 2.5% annual production growth), are insufficient, and must, more than triple in order to attain net zero target. The global harder-to-abate sector is responsible for about 16Gt of total CO_2 emissions which is 30% of 2018 global energy GHG emissions and could rise up to 60% by mid-century.

These sectors are hard-to-abate because they are difficult to electrify. Unlike other easily-abatable sectors, they are not easily directly amenable to renewable energy. Most of the latter lack the energy-to-weight ratios required by harder-to-abate sector vehicles. Their neglect is therefore due to electrification difficulties, lack of effective policies and infrastructures that enables cost reduction, increased investments and consumption, as they employ complex, highly integrated and very high-temperature processes which, for now, are only cost-effective, through fossil fuels combustion, since LCF development are, though possible, equally complex and expensive, but resulting in harder-to-abate sectors reluctance to significantly engage in energy transition. Yet, without effectively tackling this sector, the global 2050 net-zero efforts will be an illusion, leading to rising global temperature and adverse climate change. It is on this account that these research findings must be taken seriously.

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- *Recommendations*

Since most national energy transition strategies omit the harder-to bate sectors, the IOCs harder-to-abate sector strategies should be incorporated into national/organizational energy transition strategies and energy policies including the use of carbon pricing/policy instruments to re-direct investments towards this sector.

Both fuels should be promoted along with infrastructural build-up, technological/business innovation, cost reduction, scale-up and sustainability.

To attain net zero target, 10% of combined global average annual production growth for the harder-to-abate sector fuels is required as stated by the IEA.

To avoid pressure on food crops, biofuels production should focus on the secondary and tertiary, rather than primary biofuels.

Biofuels and green hydrogen projects should not be located in arid areas with water constraints.

Green hydrogen plants should not be sited in areas with limited renewable electricity.

Grey hydrogen should be replaced with, at least, blue hydrogen production.

More refineries and petrochemical plants should be converted to biorefineries/BECCS.

Further research is recommended to elucidate the strategic importance of the various biofuels (SAF, Bio-LNG, R-CNG, RNG, LCF and HVO) and biorefineries found in this study, in view of the expected increasing long term strategic roles for hydrogen.

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APPENDICES

Tables

Secondary Data Titles	Authors/Dates	Research Questions	Document Types/ Proposed Data Collection Methods	Copyrights?	Permissions?	Supporting Documents?	Type of Organizations
*International oil companies and the energy transition	Asmelash E. and Gorini, R. (2021)	*RQ1	IRENA Research Publication/ Text and Published reports analyses data collection	Yes - IRENA	Yes, says "…may be freely used…" provided authors are credited.	Yes, from IOCs	IRENA: Inter-Governmental Agency
*IOCs Energy Transition Strategies/Business Strategies	IOCs - Regularly updated website/reports (2022).	*** RQ2	IOCs Energy Transition/Business Strategies Reports & updates /website analyses data collection	IOCs	Freely available.	Yes, available online	IOCs

Table 3.0 Sources of secondary data for my research

NB
*RQ1: "What are the strategies and current activities of international oil companies in relation to the energy transition, and how do they compare with what is needed to achieve climate stabilization?"

*** RQ2: Not applicable

Selected Parameters	Asmelash & Gorini (2021)	IOCs Website Analysis (2022)
Organization/ Reputation	IRENA: Very Credible	Credible: Data for Triangulation/update
Copyright?	Yes	Yes
Contacts Availability?	Yes	Yes
Original purpose of Secondary data	IOCs Energy Transition Strategy Research	IOCs Energy Transition Strategy publication
Data Publication Dates	2021	Current
Is data sufficient/suitable for answering research questions/objectives	Yes	Yes
Data Collection Method	Detailed analysis of IOCs energy transition strategies and IRENA report.	Detailed analysis of IOCs harder-to-abate sectors energy transition strategies as published in their websites & reports.
Target Population	The 7 IOC majors; same for my research	The 7 IOC's websites; adequate.
Are there Findings similarities?	Yes – Ongoing, but slow transition	Yes – ongoing transition
Data consistency?	Yes	Yes
Do overall benefits outweigh associated costs of using data?	Yes	Yes

Table 3.1 Secondary data suitability evaluation

Both evaluation Tables adapted from: Hair et al. (2011); Smith (2008); Dale et al. (1988); Stewart and Kamins (1993); Dochartaigh (2012) and Vartanian (2010)

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COMPANIES	EXPANDING BEYOND OIL PRODUCTION TO CLEAN ENERGY TECHNOLOGIES	INTEGRATING LOW-CARBON TECHNOLOGIES IN OIL PRODUCTION	AIMING TO LOWER OPERATIONAL EMISSIONS	RENEWABLE ENERGY TECHNOLOGY MAIN INVESTMENTS	INVESTMENTS IN DOWNSTREAM ELECTRICITY	RENEWABLE ENERGY TARGETS	OTHER ENGAGEMENTS IN LOW-CARBON INITIATIVES (I.E. JOINT VENTURES OR FUNDS)
BP plc	✓	✓		Onshore wind, solar, biofuels, EVs infrastructure, batteries		50 gigawatts (GW) by 2030	Joint ventures with renewable companies
Chevron Corporation		✓	✓	N/A		N/A	Future Energy Fund to invest in breakthrough low-carbon emission technologies
Eni S.p.A	✓	✓		Solar, wind, hydrogen, EVs batteries and chargers, biofuels	✓	15 GW by 2030 and 55 GW by 2050	Venture capital fund for R&D in renewables with universities and research centres
Equinor ASA	✓	✓		Solar, offshore wind, hydrogen, EVs	✓	4-6 GW by 2026 and 12-16 GW by 2035	Joint ventures with renewable companies
ExxonMobil Corporation		✓	✓	N/A		N/A	N/A
Royal Dutch Shell plc	✓	✓		Offshore wind, hydrogen, biofuels, EVs	✓	Invest USD 3 billion in renewable energy (including hydrogen) per year by 2030	Investments in renewable start-ups and innovation hubs
Total SE	✓	✓		Solar, wind, hydrogen, biofuels	✓	35 GW of renewable electricity by 2025	Joint ventures with renewable companies

Table 4.0: Overview of oil companies' engagement with low-carbon technologies

Sources: (Holder, M., 2021), (Equinor, 2021a), (Jewkes, S., 2020a), (Nasralla, S. and Twidale, S., 2020), (Total, 2020a) and companies strategies

Retrieved from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Feb/IRENA_Oil_Companies_Energy_Transition_2021.pdf

IOCs	Harder-to-Abate Strategy	Biofuels	Hydrogen	CCS
BP	Biofuels at core of harder-to-abate Strategy; partnered NYK to study LNG & methanol opportunities & develop NH_3 & H_2	3 Biofuel plants in Brazil, targeted at 100,000 bpd from current 22,000 bpd; one of the biggest biofuel investors	Plans to capture 10% of core H_2 market share. HyGreen H_2 Teesside project targets UK 60MW of Green H_2 production by 2025. Together with proposed 'blue' H_2 project (H_2Teesside), can potentially deliver 30% of the UK's 2030 H_2 production target. Signed JV with HyCC to develop a 250 MW Green H_2 plant in Rotterdam, Netherlands, with 350,000t a year, CO_2 reduction. Signed JV with Aberdeen City Council for Green H_2 hub development. Plans 50 heavy duty H_2 refueling stations by 2030	Involved in Chevron, Petrobras & Suncor CCUS JV
Shell	Has issued Energy Transition Strategy & Harder-to-abate sector publications based on 'avoid, reduce & offset', & help each sub-sector find their net zero pathways. Also commissioned Deloitte to study sector and provide roadmap. Works with Clean Skies for Tomorrow for biojet aviation biofuel. Biofuels, CCU	Longtime biofuel investments include Raizen JV, Brazil that converts sugarcane waste to biofuel; Bangalore, Indian advanced biofuel process that converts biomass/waste to readily usable fuels. Has an EU 820000-tonnes-a-year biofuel facility (sustainable aviation fuel & renewable diesel); blended about 10 billion litres of biofuels; produces renewable CNG & liquefied bio-LNG. Shell/ Arbios Biotech Alliance is developing a circular-economy biorefinery, that uses wood & supercritical	As a member of the H_2 Accelerate consortium, Shell is involved in investigating required infrastructure creation for the production and supply of clean H_2 to H_2 trucks when available throughout EU. It is piloting 3 new California heavy-duty H_2 trucks refuelling stations. Introduced specialized of E-Fluids range to truck and bus makers for H_2 technology & battery electric vehicles demands compliance. Developing with German JV partners a nationwide network of new H_2 car models for 400 H_2 refuelling	Shell is the operator of the world's largest CCS projects – a JV with Chevron & Quest, Canada. Involved in the Northern Lights CCUS project along with TotalEnergies & Equinor, for cement, steel, power plant & petrochemical hard sectors

	& H_2, form the core of its strategy	water to produce biocrude, which can be upgraded to transportation fuels & chemicals. Currently transforming its 14 refineries into 5 biorefineries/chemicals parks in order to reduce hydrocarbon fuels production by 55% in 2030 and provide biofuels for road transportation and aviation, as well as hydrogen. Signed several scale-up supply deals including 6 million gallons sustainable blended aviation fuels supply to Amazon. Testing with Rolls-Royce, Rolls-Royce engines to evaluate 100% sustainable aviation fuel performance. Plans to offer biogas and LNG to trucks in China, EU and USA.	stations by 2023; first in 2017, to sell H_2 at its UK retail sites; its Cobham H_2 London refuelling station was the 1st of 3 H_2 stations Shell planned to open. Has 2 H_2 stations in Los Angeles and is developing Toyota's H_2 refueling network.	
Total	Says that bioenergies and H_2 based fuels are the pathways for harder-to-abate sectors	Invested in a biofuel start-up, Renmatix, in 2016 - uses super-critical water to reduce biomass conversion cost of wood/ agricultural waste to biofuels. Transformed its La Mède refinery into a Biorefinery in 2017, with a 500,000 tons capacity to manufacture biodiesel and renewable feedstock. Involved in the French Biojet project.	5 tons of renewable H_2 produced daily. Has about 30 HRS in Germany, the Netherlands, Belgium and France. Developing many new HRS projects.	Involved in the Northern Lights CCUS project - planned to decarbonize harder-to-abate power plants, cement, steel & petrochemicals complexes; planned a demonstration storage of nearly 40 million tons of CO_2 over 25 years. Involved in Teesside BP-operated CCUS UK project

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				designed to capture CO_2 from a new gas-fired power plant and from local industrial emitters. The Acorn project will reuse current oil and gas facilities for CO_2 transportation and storage, generated by UK's St. Fergus Gas terminal clean hydrogen production facility. Aramis project will convert depleted offshore gas fields to carbon storage sites. The 3D Project will capture CO_2 from industrial activities; will develop the European Dunkirk-North Sea CCS cluster.
ExxonMobil	Has a focus on harder-to-abate sector. Says algal & non-food biofuels are scalable and have required liquid energy density form required for harder-to-abate sectors, just like hydrocarbons. Biofuels, CCS & Research are	Completed sea trials of its 1st shipping biofuel. Plans 10 000 barrels of algal biofuels daily production, by 2025, through Viridos partnership. Has agreement to purchase renewable diesel made from "camelina"- a non-food crop.	SGN MOU will produce initial H_2 of around 4.3 TWh per year by 2030, with government support. Plans to build a "blue" H_2 plant at its Baytown, Texas, refining and petrochemical complex, of 1 billion cubic feet of H_2 per day capacity	Reported it captured over 40% of cumulative CO_2 captured since 1970; has 1/5th of global Carbon Capture capacity; captures about 7 million tonnes of carbon annually. Plans to capture about

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	at the core of Strategy. Research with over 80 universities, 5 energy centers, & U.S. national laboratories.			100 million metric tons of CO_2 from chemical plants, refineries and power generation harder-to-abate sectors annually, by 2040. Signed MOU with SGN, Macquarie's Green Investment for capture of 2 million tonnes of CO_2 per year Bayton H_2 plant CCS to capture and store 100 million metric tons of CO_2 per year by 2040.
Chevron	Its Lower Carbon Strategy specifically addresses "Harder-to-abate" sectors of "aviation, manufacturing and heavy duty transportation"	Targets expansions of Biogas to 40 billion BTUs daily; Biodiesel & Biojet fuels to 100,000 bpd by 2030. Recent Renewable Energy Group acquisition adds 12 US/EU Biorefineries, with combined 500 million gallons of biodiesel & renewable diesel annual production & over 4.2 million metric tons of carbon reduction.	Expansion of H_2 to 150,000 tonnes production annually	2 of the world's largest CCS projects – Shell JV Quest, Canada & Gorgon, Australia (captured & buried 3 million tons of CO_2 in 2020)
Eni	5-fold increase in Biorefineries production by 2050; Biogas for domestic mobility at core of harder-to-abate strategy	Has 2 Biorefineries (Venice: 400,000 & Gela: 750,000 tons/year); produces green naphtha, green diesel, green jet fuel, and sustainable LPG	Use of blue & green H_2 in biorefinery systems & other harder-to-abate sectors	REDD+ projects to offset about 40MTPA & CCS total storage capacity of 7MTPA by 2050.

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Equinor	Bases its harder-to-abate strategy on H_2 and CCUS. Sees H_2 replacing fossil fuels in aluminum, steel industries & elsewhere. Plans for long term natural gas role, for H_2, production while emitted CO_2 is captured and stored.	No biofuel projects	Investing in blue H_2; developing a H_2 power plant in Netherlands with partners also & involved in consortium for H_2 network development in northern England	Uses CCS to address emitted CO_2 during H_2 production

Table 4.1 Harder-to-abate sector fuels/CCS projects – website analysis (2022)

Sources: Shell, TotalEnergies, BP, Eni, Chevron, ExxonMobil & Equinor websites (My Online data collection, March, 2022).

IOCs	2021 Biofuels	2021 Hydrogen /CCS	2022 Biofuels	2022 Hydrogen /CCS
Shell	3	2	15	10
Total Energies	2	1	2	2
Chevron	0	0	7	8
ExxonMobil	0	0	5	3
BP	3	0	14	3
Eni	1	1	2	3
Equinor	0	2	0	7

Table 4.2 Number of IOCs harder-to-abate sector fuel/technologies units for 2021 & 2022

Source: Adapted from Asmelash and Gorini, (2021) and IOCs website analysis (2022).

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FIGURES

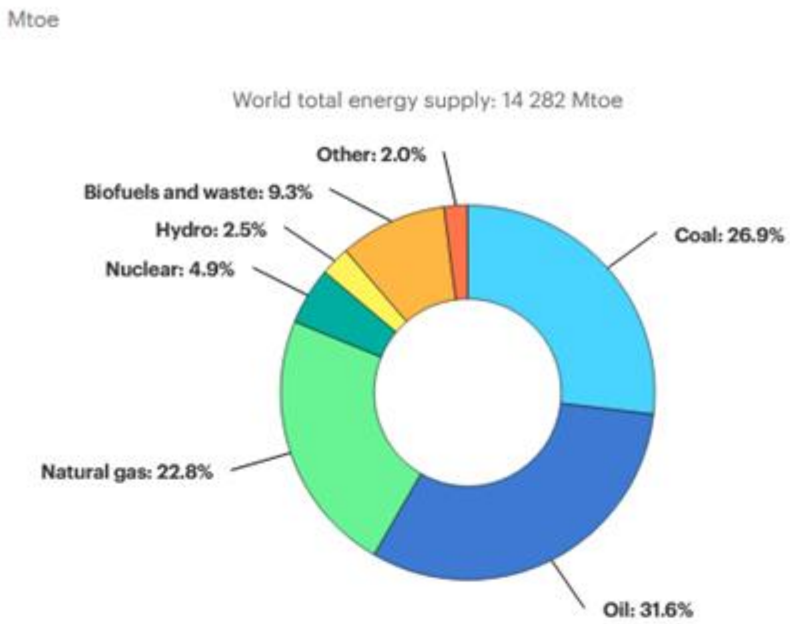

Fig. 2.0 2018 Global energy supply

Retrieved from: https://www.iea.org/reports/key-world-energy-statistics-2020

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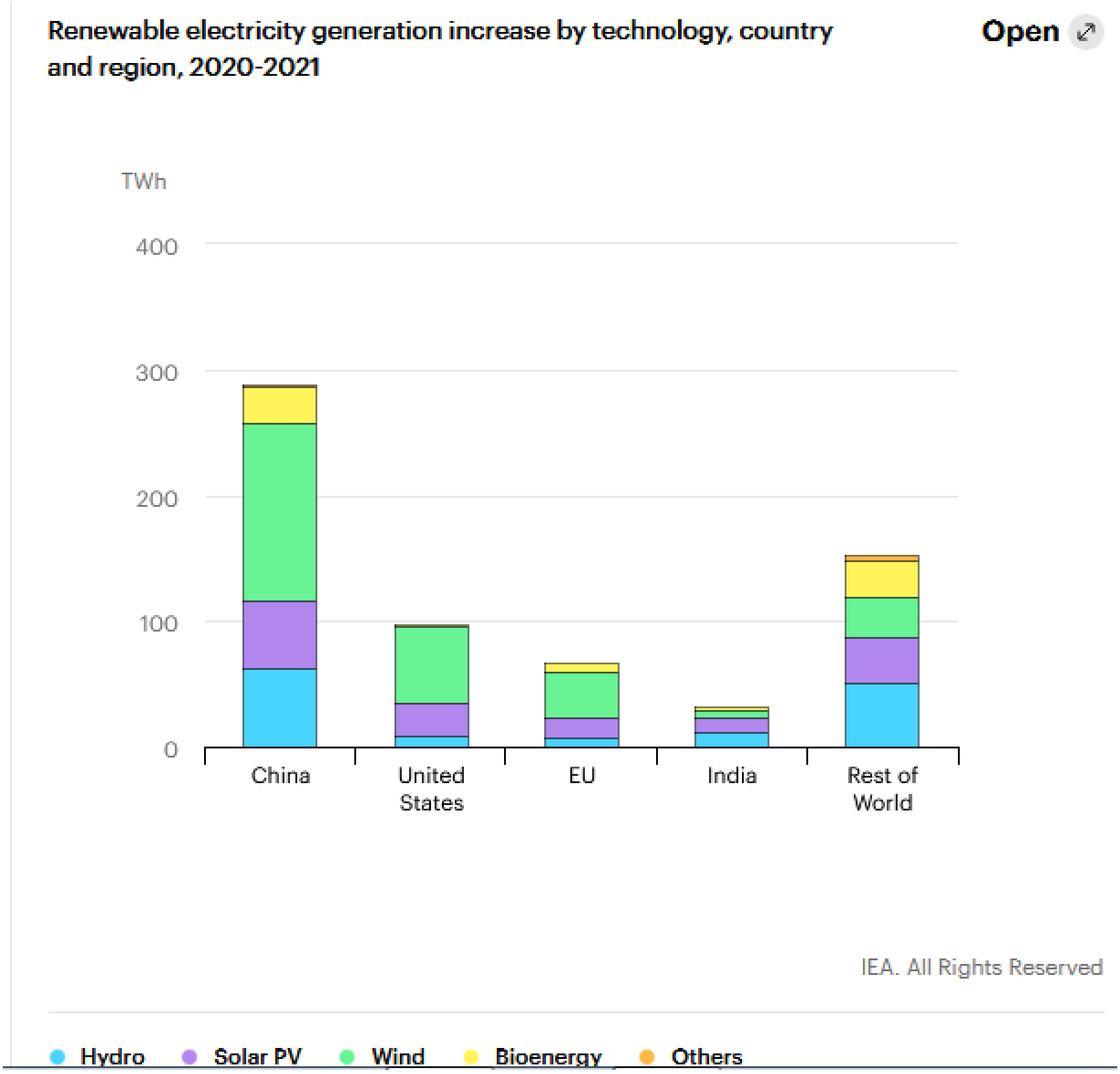

Fig. 2.1: Renewable electricity generation, 2020-2021

Retrieved from: https://www.iea.org/reports/global-energy-review-2021/renewables

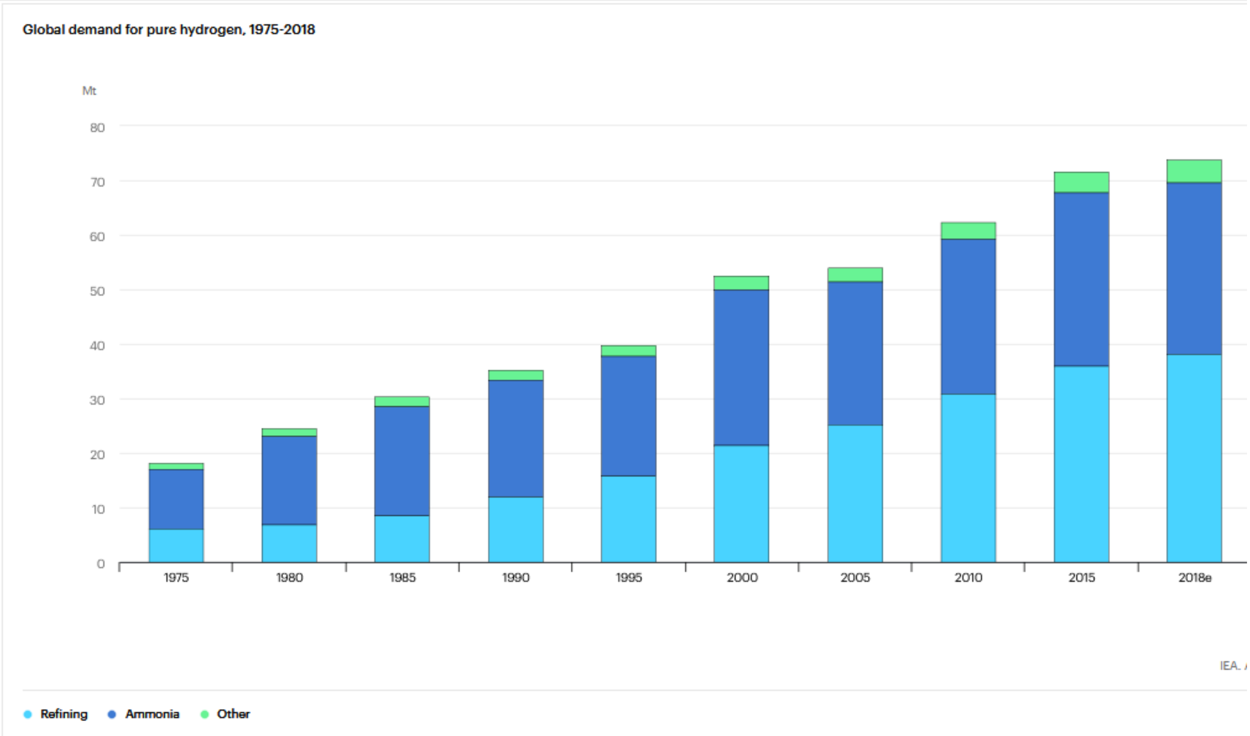

Fig. 2.2: Global Pure H_2 demand 1975 -2018

Retrieved from: https://www.iea.org/reports/the-future-of-hydrogen

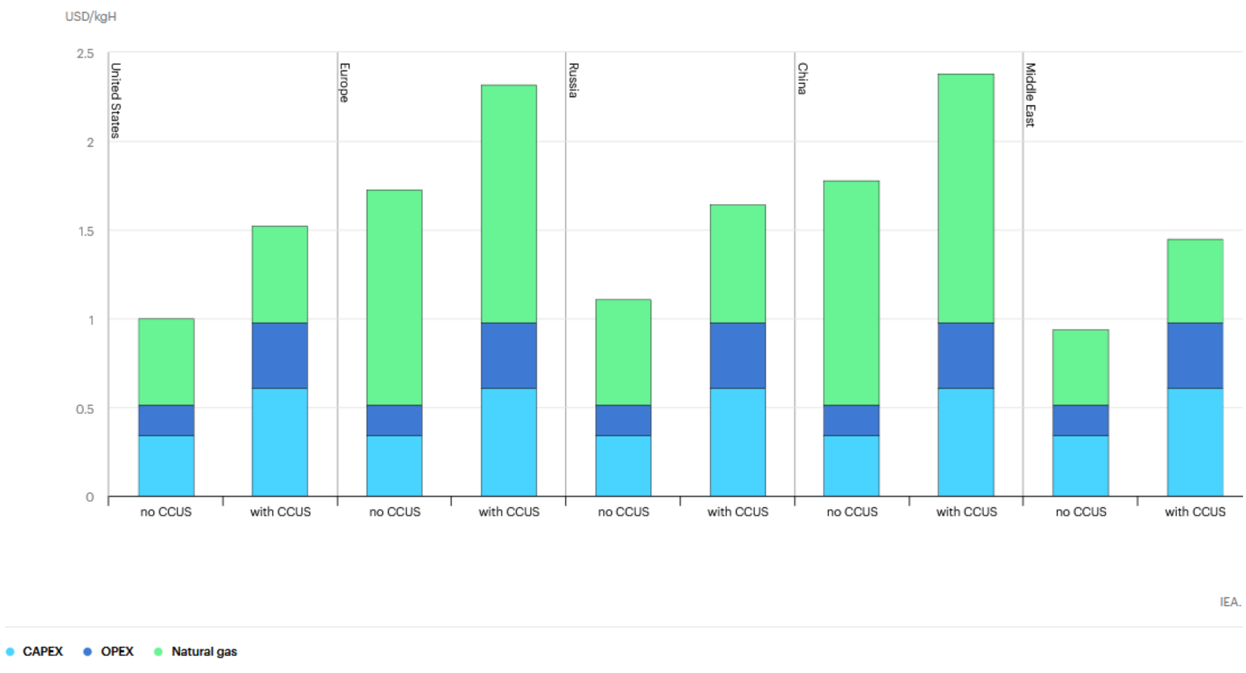

Fig. 2.3: Hydrogen Production Costs using Natural Gas, with/without CCS/CCUS per region

Retrieved from: Retrieved from: https://www.iea.org/reports/the-future-of-hydrogen

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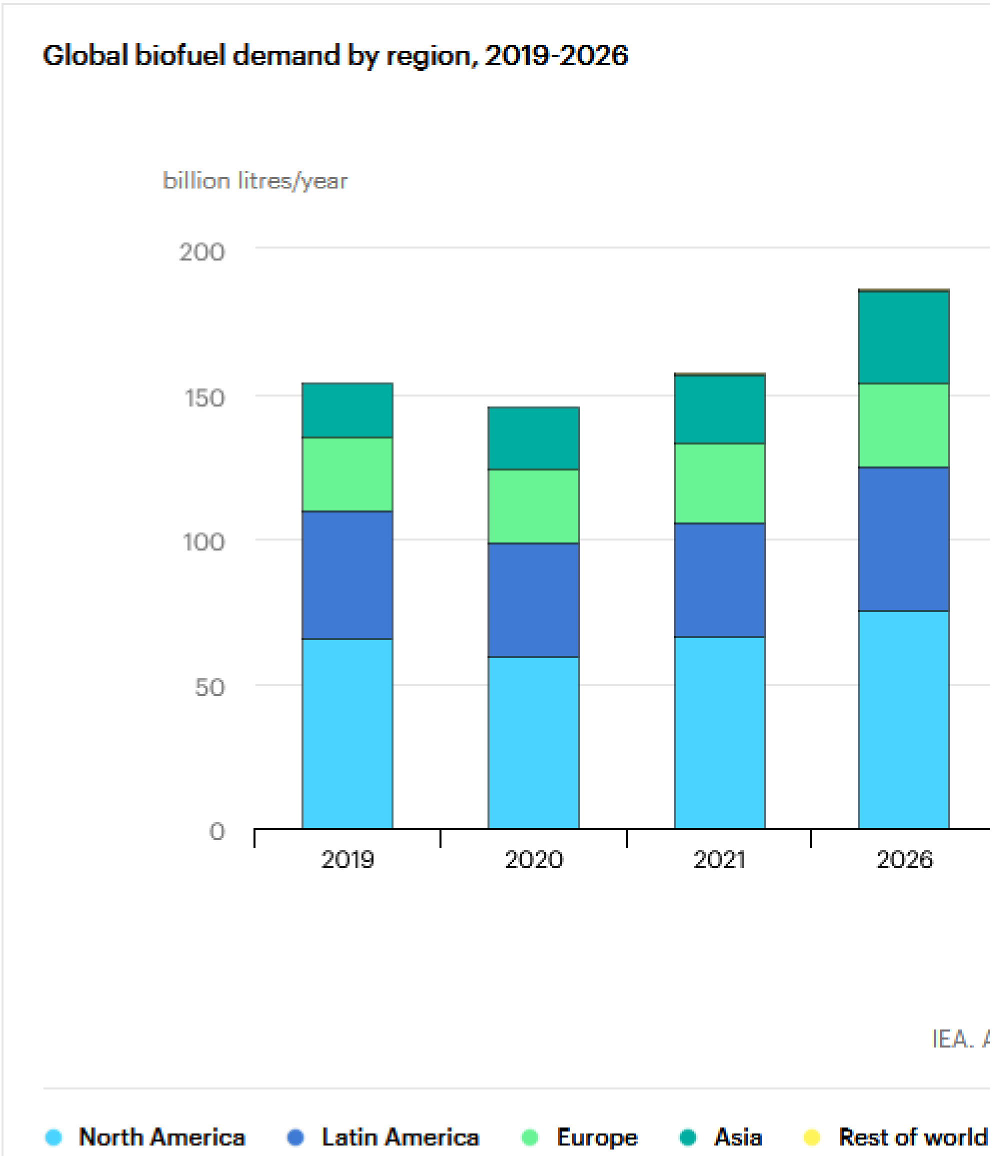

Fig. 2.4 Global Biofuel Demand

Retrieved from: https://www.iea.org/fuels-and-technologies/bioenergy

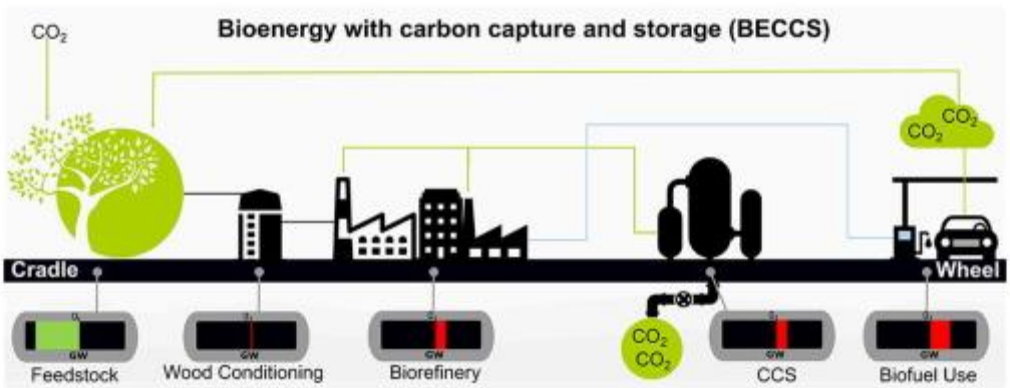

Fig. 2.5 Bioenergy with carbon capture and storage (BECCS)

Retrieved from: https://www.sciencedirect.com/science/article/pii/S0306261920313556

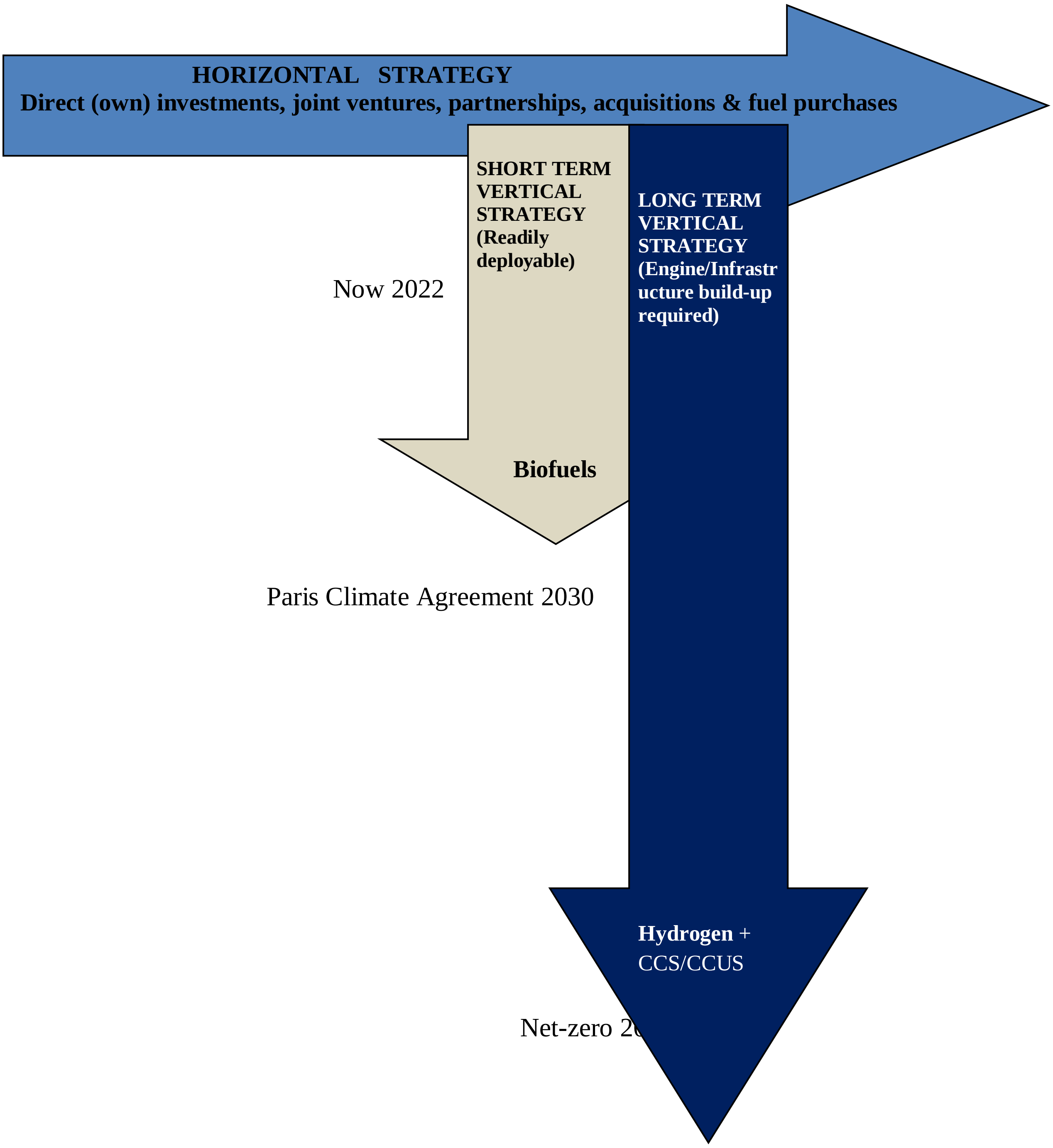

Fig. 4.0: IOCs overall transition strategy

STRENGTHS	WEAKNESSES
Readily deployable low sulphur. 2nd Generation feedstock (wood/plant residues/waste), non-food competitive; widely available 3rd generation algae, not food competitive. Has required fuel density energy content. Renewable energy source – will not be depleted like fossil energy. Profitable business; has IOC investments. Viable options for shipping, aviation & trucking. ICAO & IOCs working on biojet fuels.	**Requires massive scale-up Requires supply sustainability. High cost reduction required. 1st generation biofuel feedstock competes with food sources. Still emits CO_2, though significantly lower than hydrocarbon emissions. Concerns about long term storage & oxidation stability. Requires high volumes of water; exerts pressure on water resources; serious negative impact in arid regions**
OPPORTUNITIES	**THREATS**
Climate regulations & energy transition presents new business opportunities. Farmers & rural dwellers will benefit from feedstock supply & job creation. Environmental and health improvements due to hydrocarbon air pollution avoidance. Energy security for non-hydrocarbon producing nations.	**Low oil price restricts deployment. Inadequate policies for demand increase, scale-up & cost reduction. Biofuel neglect, in comparison with solar, wind & H_2 . Concerns about feasibility of high volume commercial production for shipping**

Fig. 4.1: SWOT Analyses for Biofuel

Adapted from Ofili, (2021).

STRENGTHS	WEAKNESSES
High density, efficient energy carrier. Highest energy content by weight of any common fuel. Renewable energy source. Most abundant element in universe. Profitable business, with IOC investments. Energy security for producers. Greater efficiencies than EV, same as fossil fuel. Little/no visual pollution, unlike solar & wind power. No noise pollution. Charging faster than EV; similar to ICE. No CO_2 emissions; just H_2O.	**Requires massive scale-up High cost reduction required. High tankage weights. Global green H_2 production requires electricity input greater than EU electricity output. Blue H_2 uses fossil CH_4 & CCS. Emits (captured/stored) CO_2 CCS increases blue H_2 cost. Massive infrastructure & engine adaptation required. Storage & transport more complex than fossil fuel. Platinum & iridium catalysts required for fuel cell & water electrolyser – higher costs.**
OPPORTUNITIES	**THREATS**
Climate regulations & energy transition presents new business opportunities. Will benefit IOCs & electric companies. Environmental and health improvements due to hydrocarbon air pollution avoidance. Energy security for non-hydrocarbon producing nations.	**High H_2 cost. Low oil price restricts deployment. Inadequate policies for demand & supply increase, scale-up & cost reduction. Explosive & flammable. Inadequate regulations for commercial deployment.**

Fig. 4.2: SWOT Analyses for Hydrogen

Adapted from Ofili (2021)

Number of plants/units

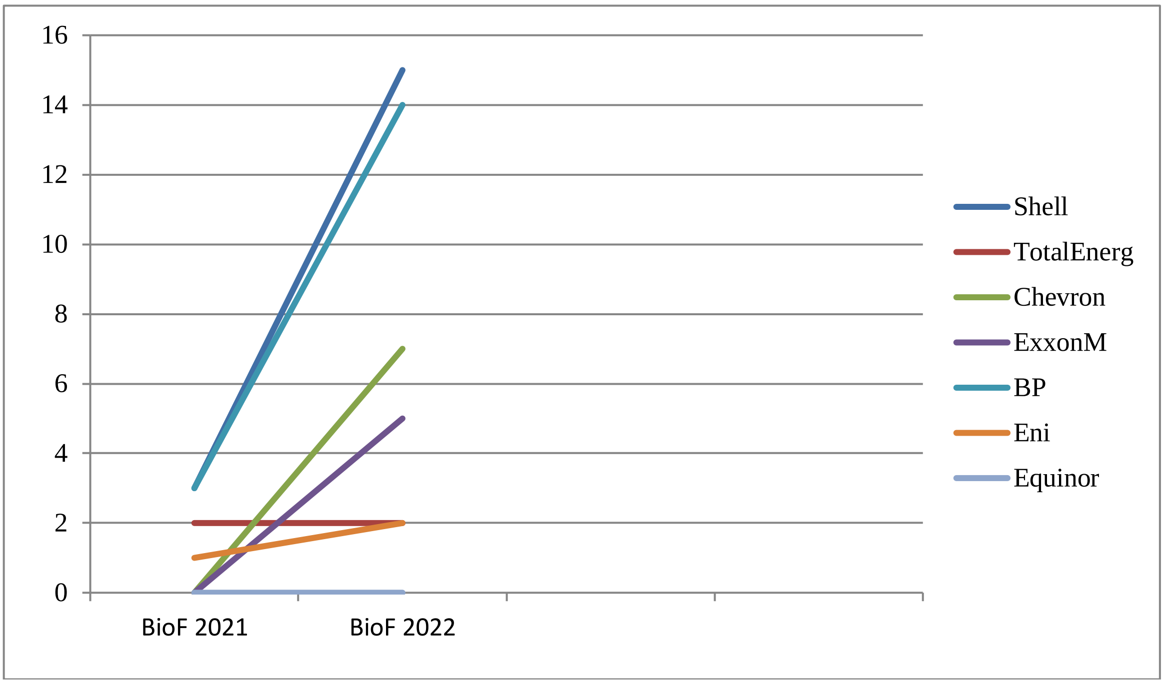

Fig. 4.3 Biofuel plants/units growth (2021 – 2022)

Number of plants/units

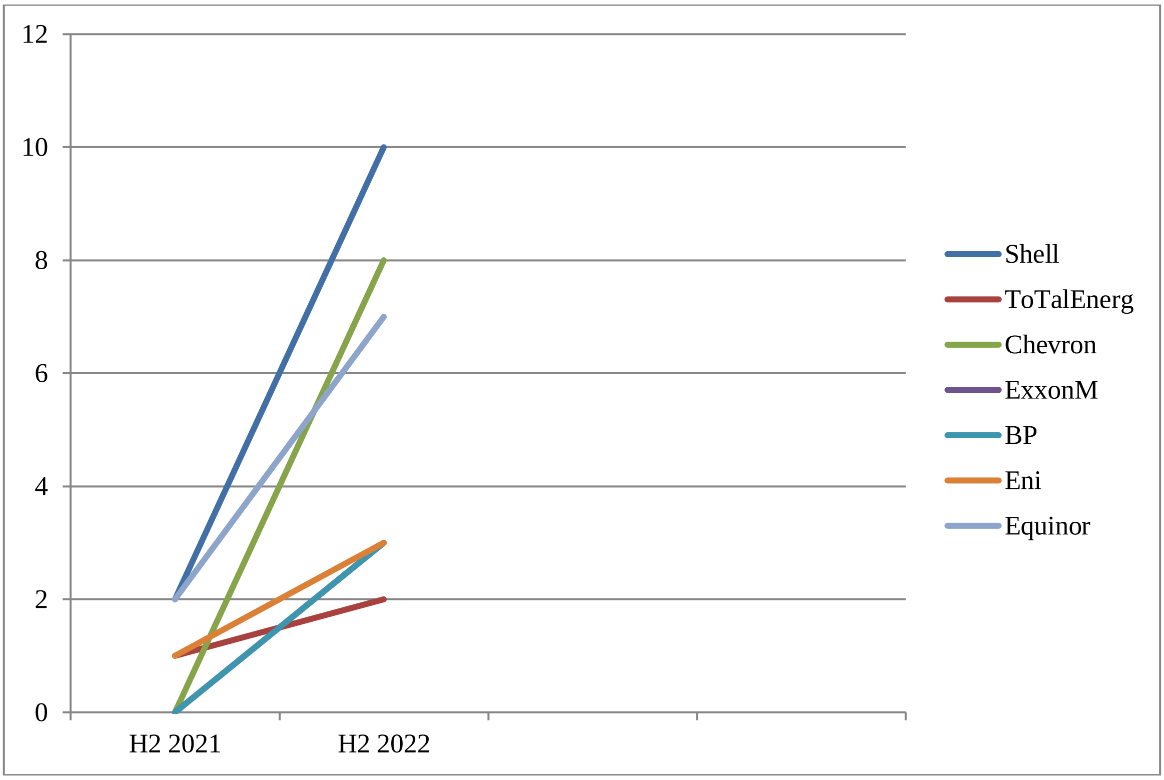

Fig. 4.4 Hydrogen plants/units growth (2021 – 2022)

Total no of project/units

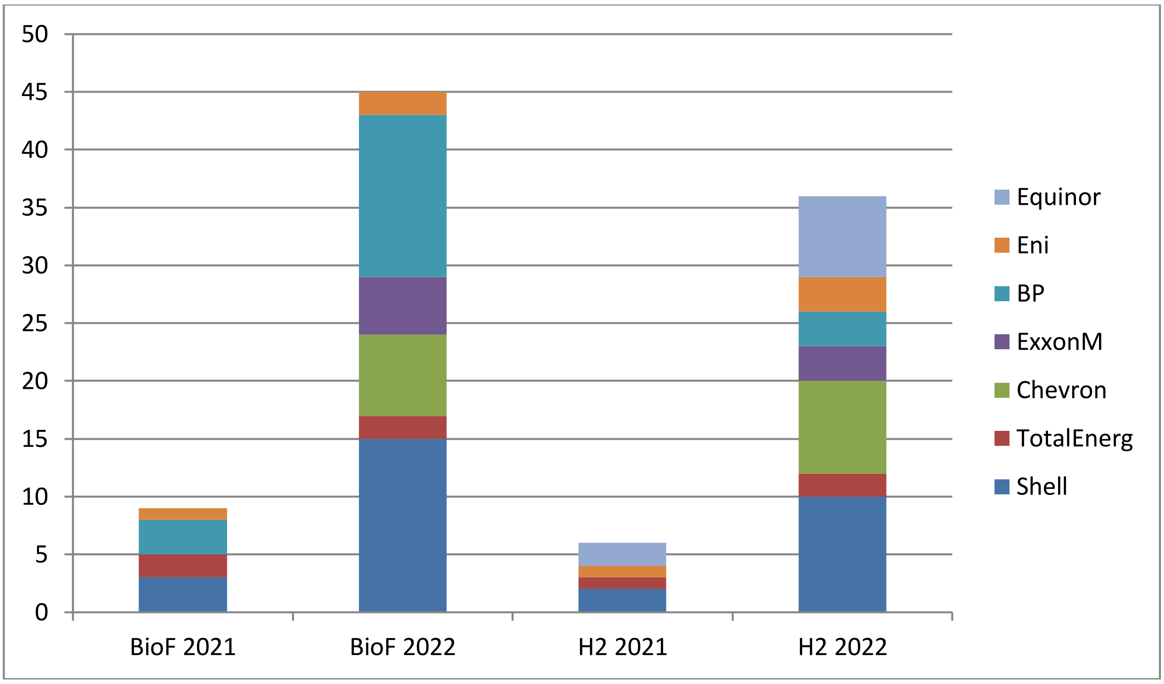

Figure 4.5 Harder-to-abate sector fuels units for 2021 and 2022

Total no of project/units

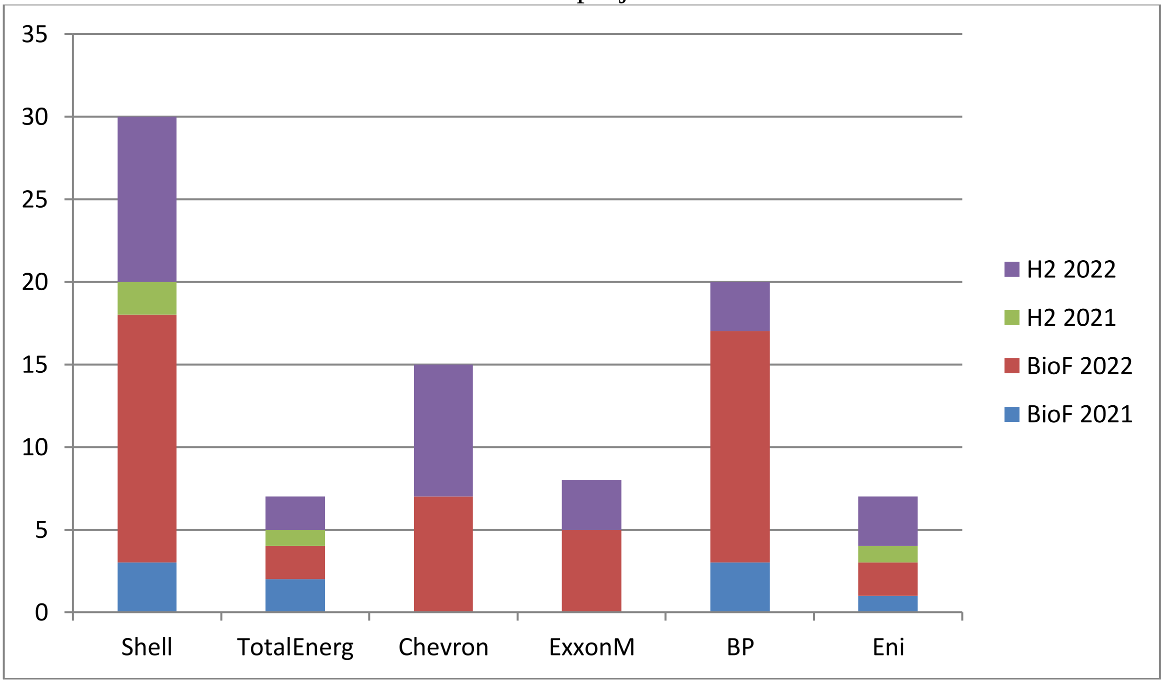

Fig. 4.6: IOCs harder-to-abate sector comparative performance

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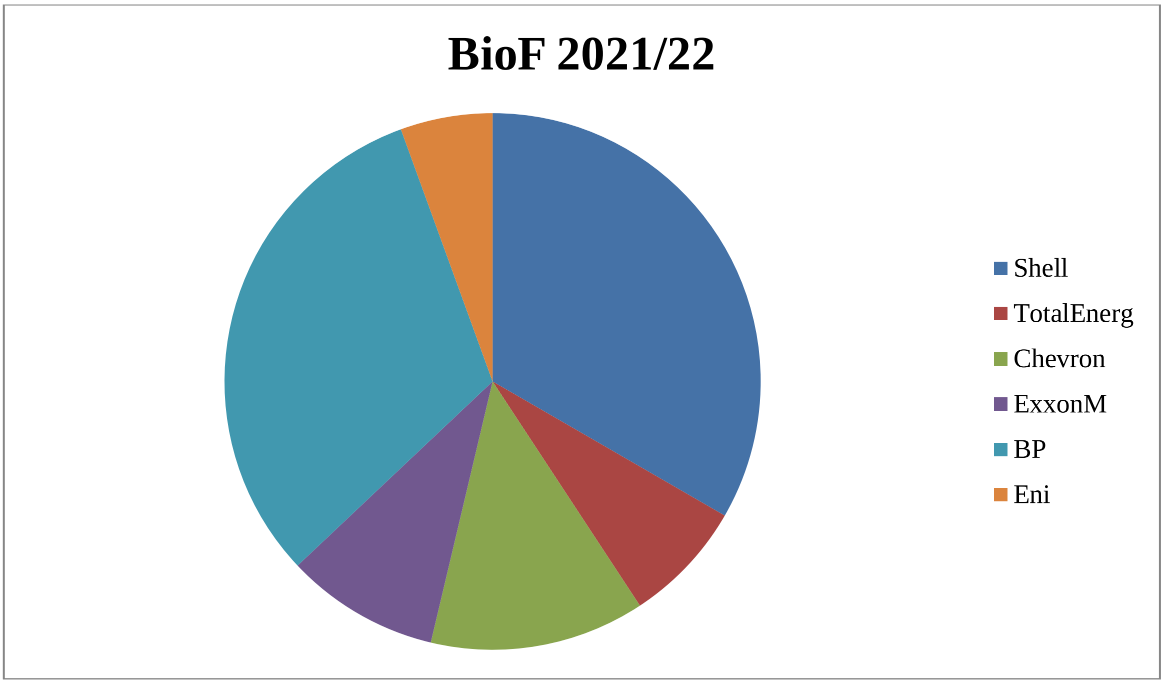

Fig. 4.7: Average biofuel units

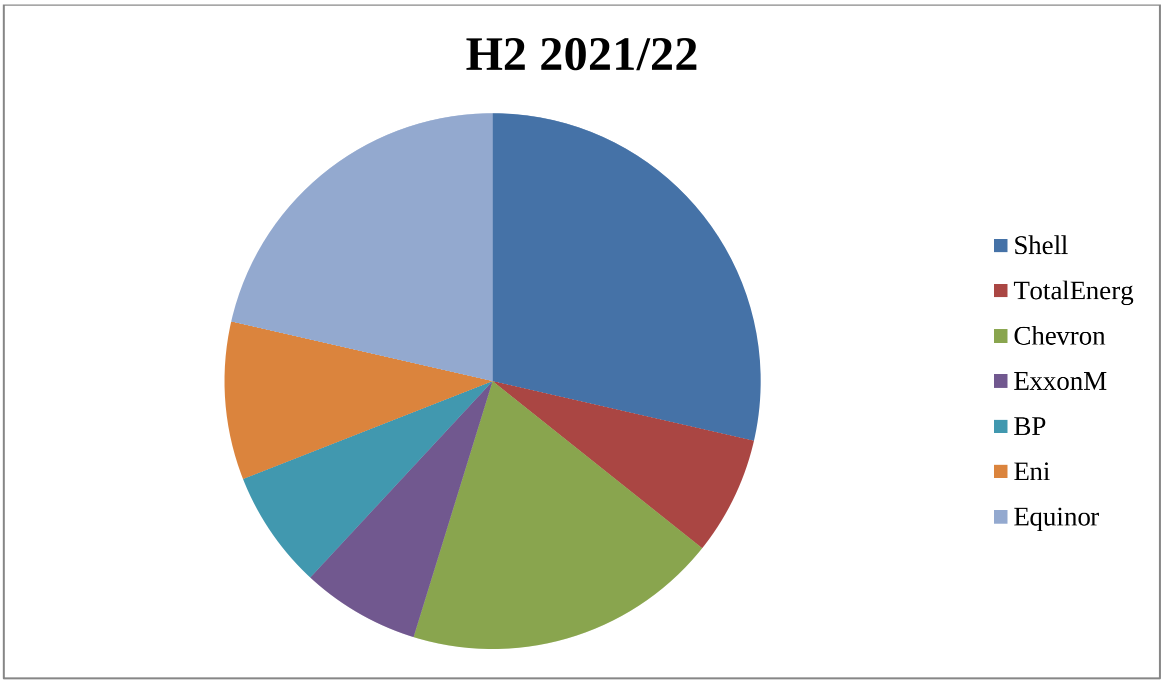

Fig. 4.8: Average hydrogen units

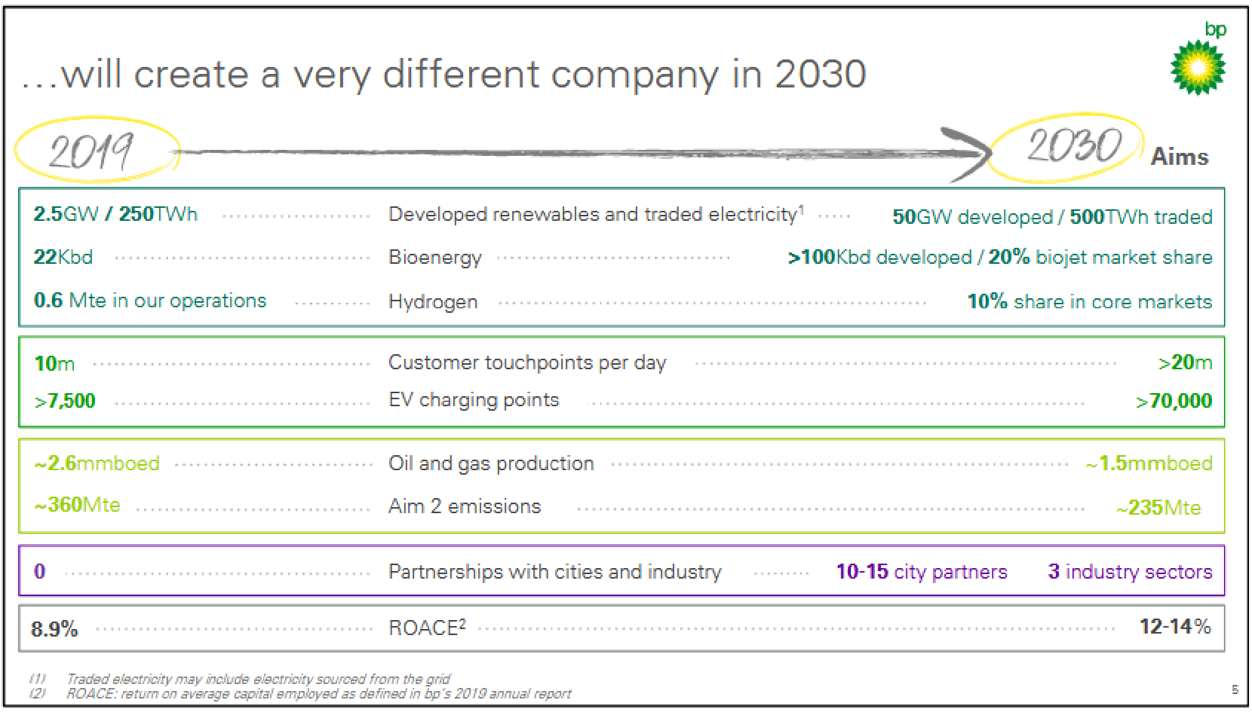

Fig. 4.91: BP strategy

Retrieved from: https://www.bp.com/en/global/corporate/what-we-do/our-strategy.html

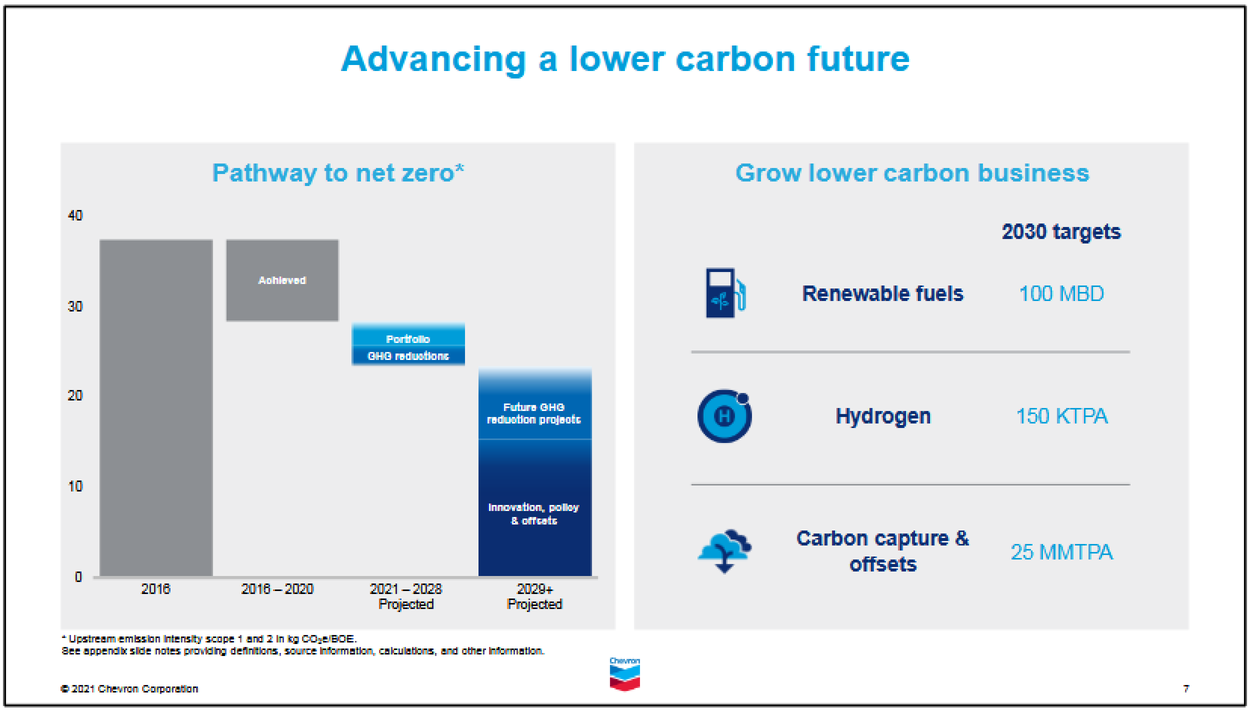

Fig. 4.92: Chevron strategy

Retrieved from: https://chevroncorp.gcs-web.com/static-files/1ba3162e-f798-444b-9368-fc7b4ab7842a

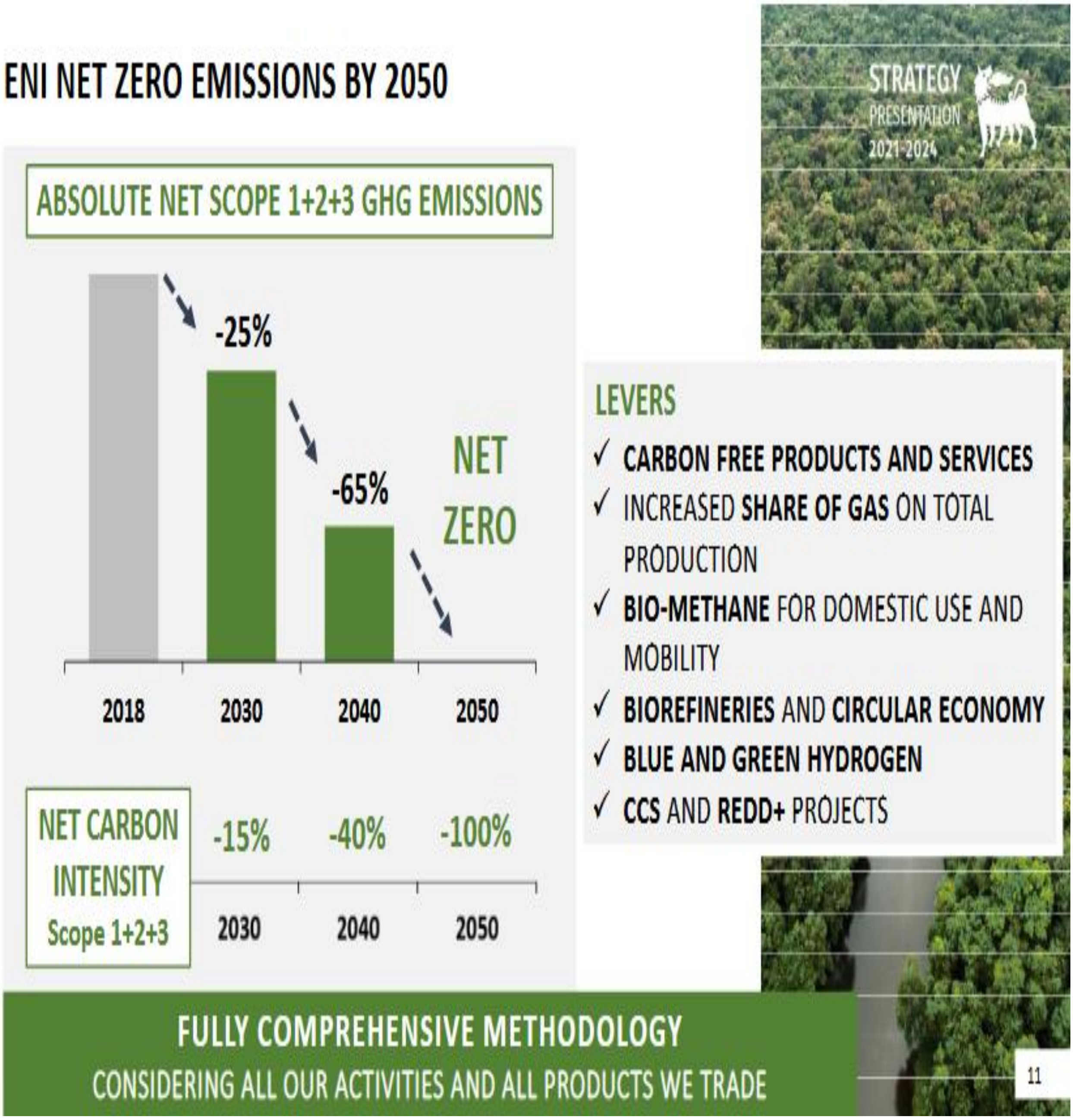

Fig. 4.93: Eni strategy

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Figure 4.94 ExxonMobil strategy

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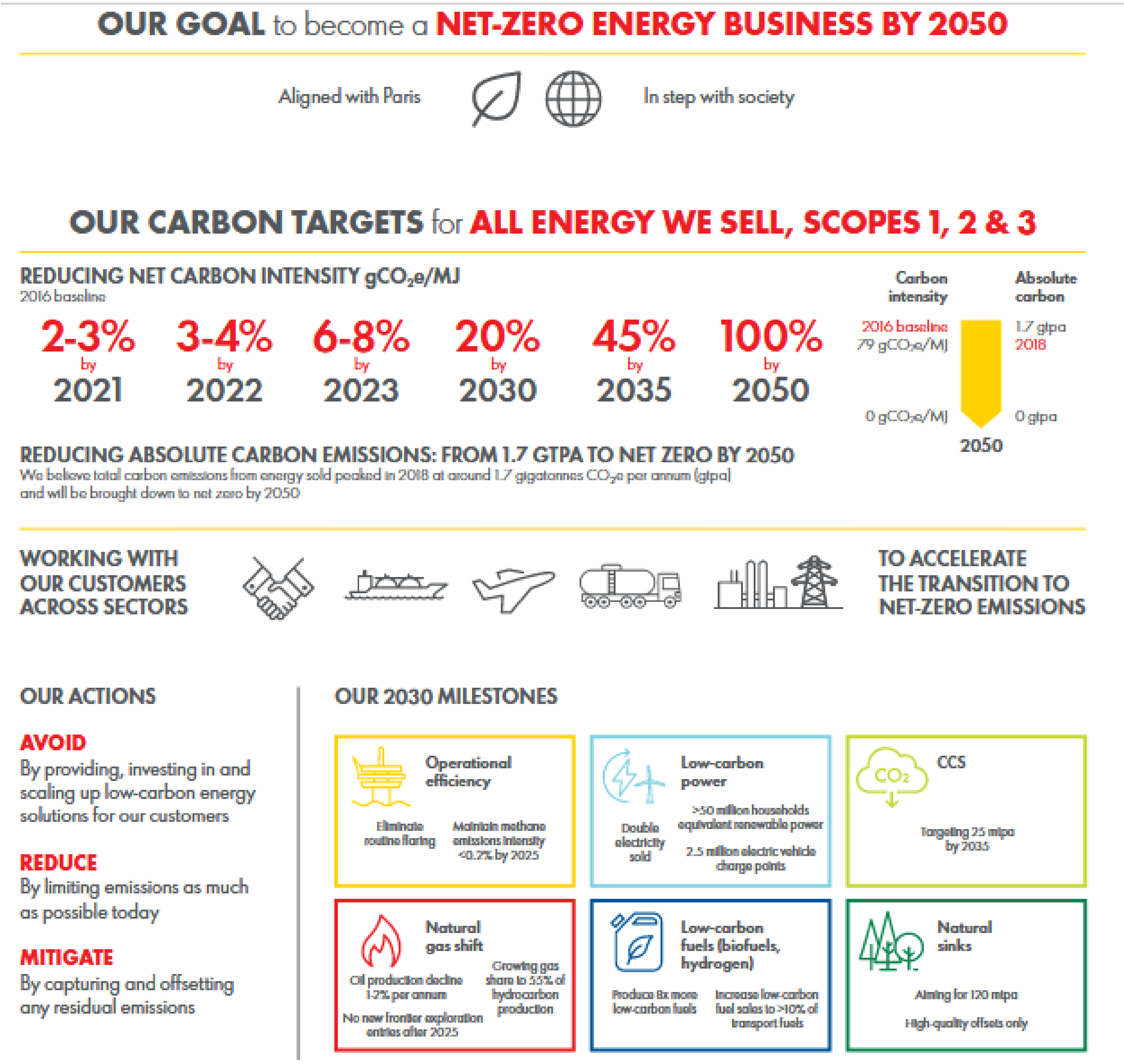

Fig. 4.95: Shell energy transition strategy (summary)

Retrieved from: https://www.shell.com/promos/energy-and-innovation/shell-energy-transition-strategy/_jcr_content.stream/1618407326759/7c3d5b317351891d2383b3e9f1e511997e516639/shell-energy-transition-strategy-2021.pdf

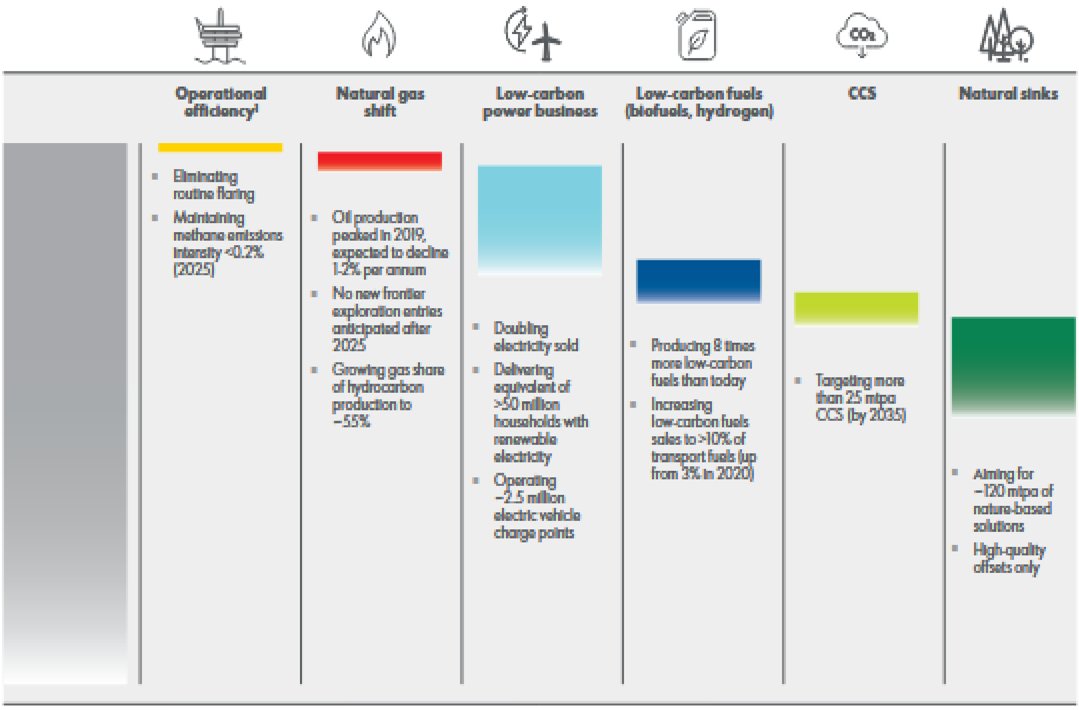

Fig. 4.96: Shell's energy transition milestones

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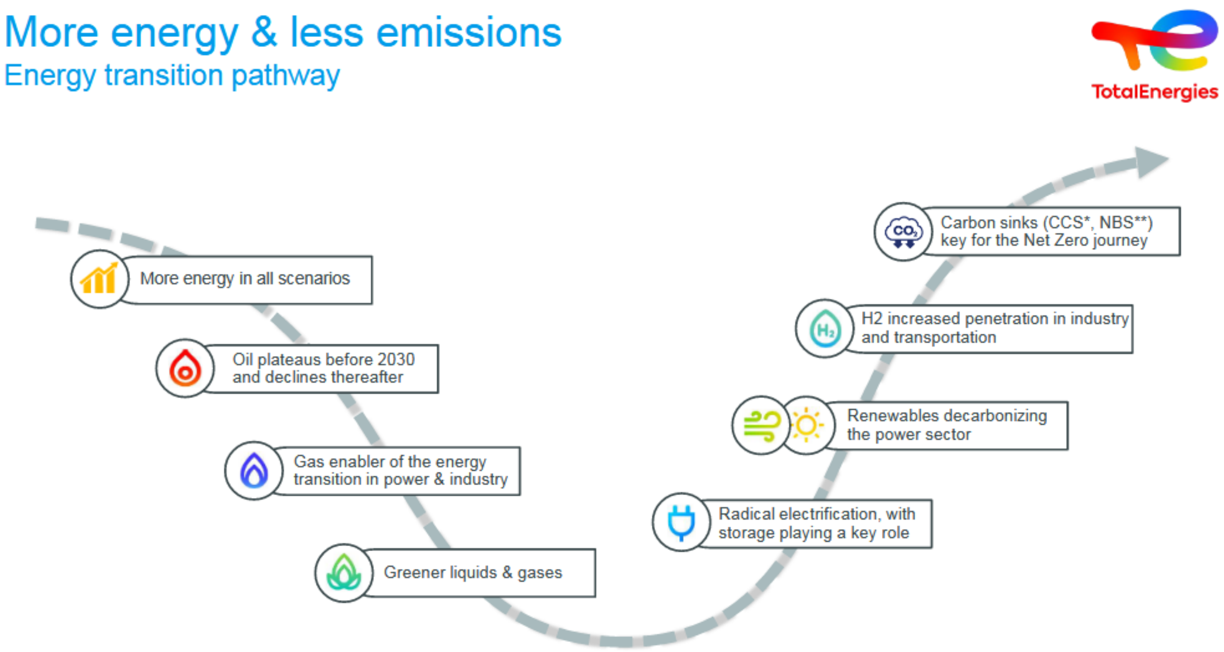

Fig. 4.97 Total Energies energy transition pathway

Retrieved from: https://totalenergies.com/system/files/documents/2021-09/2021_TotalEnergies_Energy_Outlook.pdf

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