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Decarbonization of Oil & Gas: International Experience and Russian Priorities

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FOREWORD

First and foremost I express heartfelt appreciation to our colleagues from Petroleum Advisory Forum and each of its member companies for making this study possible and sharing generously their knowledge and time. This research is the first collaboration of SKOLKOVO Energy Centre and Petroleum Advisory Forum and we were very excited to have an opportunity to incorporate intellectual contribution from leading international oil and gas teams into our study. The level of cooperation and enthusiasm of PAF members teams were unparalleled and this result would not be achievable without them. We look forward to continued collaboration between PAF, its member companies and SKOLKOVO.

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Irina Gayda,
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LIST OF ABBREVIATIONS

APG	Associated petroleum gas
BCM	Billion cubic meters
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CDP	Carbon Disclosure Project
CER	Certified Emission Reductions
COP21	UN Paris Climate Conference-21
CSP	Concentrated solar power
EOR	Enhanced oil recovery
ERU	Emission reduction units
ESG	Environmental, Social, and Corporate Governance
EU ETS	European Union emissions trading system
EV	Electric vehicle
GJ	Gigajoule
GHG	Greenhouse gases
GPP	Gas processing plant
$GtCO_2e$	One billion metric tons, or gigatons, of CO_2 equivalent
GTS	Gas transportation system
HSE	Health, Safety, and Environment
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPIECA	The International Petroleum Industry Environmental Conservation Association
IR	International Relations
ISWEC	Inertial sea wave converters
KPI	Key performance indicator
LSC	Luminescent solar concentrators
LNG	Liquefied natural gas
LULUCF	Land Use, Land-Use Change and Forestry
M&A	Merge and acquisition
MMbbl	Million barrels of oil equivalent
Mtpa	Million tons per annum
$MTCO_2e$	Metric tons of CO_2 equivalent
$MtCO_2e$	One million metric tons, or megatons, of CO_2 equivalent
NDC	Nationally determined contribution

NSR	Northern Sea Route
OGCI	Oil and Gas Climate Initiative
OPV	organic photovoltaic
PERC	Passivated emitter rear contact (solar cell)
PV	Photovoltaics
R&D	Research and development
REDD+	Reducing emissions from deforestation and forest degradation, plus forest enhancement
RES	Renewable Energy Source
RUR	Rouble
SBTI	Science Based Targets Initiative
TCFD	Task Force on Climate-Related Financial Disclosures
UNFCCC	United Nations Framework Convention on Climate Change
VC	Venture capital
VCS	Verified Carbon Standard

EXECUTIVE SUMMARY

Oil and gas companies are coming under increasing pressure from regulators, investors, and clients to reduce the carbon footprints of their products.

Although the oil and gas industry's emissions classified in scopes 1 and 2 (direct GHG emissions from company operations and indirect emissions from energy consumed by the company) are less than what most assume (12% of global anthropogenic GHG emissions), they are comparable to the agricultural industry's (13%) and higher even than those produced by other manufacturing industries. At the same time scope 3 (indirect emissions generated by the products) contains the largest volume of GHG emissions of the entire oil and gas sector. For vertically integrated oil companies, scope 3 emissions are on average 7 times the emissions in scopes 1 and 2 combined. And it is these emissions that cause the greatest concern and pressure on oil and gas companies in the context of the global paradigm of achieving carbon neutrality. Another specific feature of the oil and gas sector is high proportion of methane emissions (45% of aggregate GHG emissions).

At the same time oil and gas companies are well positioned to help address the climate problem. The industry has the science, engineering, financial and managerial expertise and know-how to roll back GHG emissions for generations to come. The COVID-19 pandemic and resulting economic downturn has heightened understanding that the industry must change and make decarbonization a reality.

In 2019-2020, leading international oil and gas companies (BP, Total, Shell, Equinor, ENI, Repsol, etc.) began setting emission reduction goals, including net-zero targets across scopes 1, 2, and even 3. But sometimes companies tend to be fairly selective, and not particularly detailed, about how these longer term goals are to be achieved. There is skepticism therefore that the companies making lofty future promises can actually live up to those. And, generally, so far, voluntary commitments made by oil and gas companies remain fairly conservative compared to those set by the Paris Agreement.

However, corporate best practices in decarbonizing the oil and gas business are gradually emerging. Oil and gas companies around the world are further advancing in their decarbonization efforts, including explicit decarbonization governance systems, top-down decarbonization targets, and voluntary climate and decarbonization monitoring and reporting with independent audit and credible verification. The best practice is to have decarbonization integrated into strategy and investment decisions, through internal CO2 pricing and the introduction of decarbonization KPIs into the performance management system.

Developing a decarbonization strategy is an integral, multistage process, unique to each individual company and dependent on its asset structure, production technologies, investment portfolios, and regional regulations. In terms of specific initiatives addressing decarbonization, there is already a wide palette of different decarbonization methods, from which companies can compose the optimal set for themselves:

- ***Operational methods***
  - **Operational efficiency improvemnet**. Although the primary objective of operational excellence is lowering production costs, in many cases those initiatives also result in carbon footprint reductions. This is a primary short-term focus with the lowest, or even zero, additional financing.
  - **Recycling, reuse, and the utilization of secondary energy sources**. Oil and gas companies are becoming more active in using the circular carbon economy principles. They use and process CO_2, convert the emissions into products with a smaller carbon footprint, and minimize their carbon footprint by reusing materials and resources.
  - **Energy efficiency.** The efficient use of energy resources by oil and gas companies is one of the cheapest methods for reducing GHG emissions. IN the short-term majority of the oil ad gas companies focus their decarbonization efforts on efficient energy and resource use. According to some of the companies that participated in this research via interviews, up to 40% of decarbonization opportunities are commercially viable even without additional financing.
  - **Relationships with suppliers and subcontractors** and the requirements for them to reduce their carbon footprint also play a special role.
- ***Effective monetization of methane and APG.*** Methane leaks and APG flaring account for up to 45% of total industry emissions, which is why reducing them is a top priority, especially assuming that it is a relatively easy thing to do, for which companies have technologies available. This is also a primary focus of several syndicated initiatives, such as the Oil and Gas Climate Initiative (OGCI)[1], Global Methane Alliance[2] and Methane Guiding Principles[3], who work in conjunction with oil and gas companies. Initiatives like these often represent low, or even no, cost options for reducing GHG emissions.
- ***Shifting to low carbon energy sources.*** More and more, oil and gas companies are focusing on renewable energy and electricity storage for their own operations, biofuels as a

[1] https://oilandgasclimateinitiative.com/
[2] https://www.ccacoalition.org/en/activity/global-methane-alliance
[3] https://methaneguidingprinciples.org/

substitute for traditional feedstock, and also low-carbon fuels for the marine transportation of their products.

- ***Corporate strategy methods of decarbonization***
  - **Optimized portfolios** include divestments (removing unattractive, carbon-intensive assets), M&As allowing for resource quality improvement and diversification within the new less carbon-intensive business (first of all increasing their activities in natural gas and NGLs), restructuring, development of the petrochemical business, and creation of corporate venture capital funds focused on innovation in the fields of methane leakage reduction, operational efficiency, CCUS, hydrogen technologies, and more. A few important emerging aspects of corporate decarbonization strategies include industrial cooperation on R&D, venture investments, and the piloting of deep decarbonization projects in order to increase the quality and speed of these new technologies' developments and to understand whether these tools may fit well into the longer term plans of a company.
  - Oil and gas companies are becoming increasingly **interested in the petrochemical and chemical industry**, as well. They see the potential for synergy through integration with oil refining systems, as well as potential for the monetization of available raw hydrocarbons, improvement of output marginality, and realization of decarbonization goals.
  - **Trading and offsetting carbon credits** is taken with a caution, with a selective approach taken to the origin and verification of credits or offsets. "Reduce what you can, offset the rest" emerges as a prevailing approach.
  - Increasingly, oil and gas companies are looking into **projects focused on nature-based carbon sinks**, albeit with apprehension in the selection of the project and of the project partners due to the inherent difficulty of measuring the impact of nature-based carbon sinks, as well as the negative publicity associated with not yet matured projects.
- Finally, most of these companies have deep ***decarbonization visions and strategies involving carbon capture, utilization, and storage (CCUS) projects and the use of hydrogen as fuel.*** There are European, Middle Eastern, and U.S. companies with projects in various stages of construction and operation. These projects currently rely on extensive government subsidies and would not be feasible without such support. However, the total capacity of operating assets is far below the forecast demand for decarbonization methods. Today's operating CCUS projects have an annual CO_2 capacity of just 10 Mt. By 2050, the annual volume of CO_2 capture and storage in volumetric

equivalent may reach 4,6GtCO_2 per year, which is comparable with the scale of today's global oil industry annual production. It is representing a new, major diversification opportunity for the oil and gas industry.

International oil and gas companies are actively testing all these methods of decarbonization and are constantly looking for new options, receiving increasingly stringent signals in favor of decarbonization from consumers, investors and regulators.

In Russia, things are different.

- Unlike many other countries of the world, in Russia the problem of climate change is still of low priority for the population, business and government, which hinders the process of decarbonization of the oil and gas sector in comparison with the best international practices.
- The national target for emissions of 70% from the level of 1990 by 2030 has been set. Provided that in 2017, GHG emissions amounted to 50.7% of the level of 1990, it actually allows Russian Federation not to introduce any restrictive measures on GHG emissions until 2030, The actual absence of a national climate strategy leads to the lack of real government incentives for decarbonization in general and in the oil and gas sector in particular.
- In Russia, GHG emission regulation is still in the initial stage, it is only in 2021, the draft law on GHG emissions limitation has been submitted to the State Duma. Meanwhile GHG requirements remain very fragmented (and limited to APG flaring and methane regulation) and there is currently no federal mandate for reducing GHG emissions, no carbon pricing, and no effective standards on energy efficiency or GHG emission intensity.
- At the same time, within Russia, the proportion of GHG emissions from the oil and gas industry is twice the world average.
- Despite these circumstances, some oil and gas companies managed to stay ahead of politics. They prepared voluntary reporting and disclosures, proactively adopted decarbonization methods, and even began internal carbon pricing for investment projects. In the most recently reported CDP-rankings of 2020, one of Russia's oil and gas companies scored a "B", while two others were given a "C", making them competitive with their international peers. However, the development stages of these decarbonization strategies varies greatly, and some are still in the early stages of structuring their goals and methods for decarbonization.

Given the regulatory changes in foreign markets, the requirements of foreign investors, the increasing role of the carbon footprint in international competition and the significant role of oil and gas exports for the entire Russian economy, a serious transformation of the regulatory and corporate approach to decarbonization of the Russian oil and gas industry is is required already in the medium term:

- Regulators should develop climate strategy with more ambitious targets and adopt a comprehensive framework to bring down GHG emissions (including comprehensive strategy on methane) and. It could include many different policy options such as permits, targets, emission standards, measuring, reporting, and pricing GHG emissions, as well as rules of certification and verification of emission reduction projects. It is also important to establish comprehensive, national R&D and pilot project financing for GHG emission reduction, particularly for deep decarbonization. Russia's competitive advantages in decarbonization should be further analyzed in an internationally recognized technical and commercial framework, and promoted within the country and on the global market.
- Corporate entities should incorporate decarbonization into overall strategy and investment discussions, involving all operations, not just the Health, Safety, and Environment (HSE) or International Relations (IR) departments. Effective decarbonization is a major strategic shift and requires a comprehensive review by corporate governance.
- A comprehensive review of GHG emissions sources will enable each oil and gas company to pinpoint their unique, competitive advantage, which it can then share with clients and investors.
- Companies should also create a network of partners that can support its decarbonization plan. This network could include educational and research institutes, international peers for sharing R&D, venture investors, those working on deep decarbonization projects, technology companies that can help better measure and disclose emissions data, local suppliers, and customers facing similar challenges.

This research has been prepared by the Energy Center, Moscow School of Management SKOLKOVO, in cooperation with the Petroleum Advisory Forum. We would like to thank all the companies, associations, and experts who contributed to the preparation of this report. It is our hope that this report will aid those looking to create strategies for reducing anthropogenic GHG emissions within the oil and gas sector in Russia and around the world.

INTRODUCTION

Now, in the 21st century, humankind faces the threat of global climate change induced by anthropogenic GHG emissions.[4] As concerns about this challenge are growing, there is increasing pressure from key stakeholders (population, representatives of civil society and NGOs, investors, etc.) on companies and governments to ensure immediate action adequate to the scale of this threat.

To address this threat, the global community is undertaking efforts to reduce these emissions, focusing mostly on those of carbon dioxide (decarbonization), methane emissions are also a separate issue for the oil and gas industry.

Adopted internationally in 2015, the Paris Agreement aims to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels in order to improve adaptability to the consequences of climate change. The Agreement also aims to transition to low-carbon development. At the same time, the UN adopted Sustainable Development Goals, e.g., to take urgent action to combat climate change and its impacts (Goal 13) and to ensure access to affordable, reliable, sustainable, and modern energy for all (Goal 7).

As of today, 189 states have joined the Paris Agreement (including Russia, the USA rejoined the Agreement in February 2021).[5] All member countries are voluntarily committed to reducing net atmospheric emissions of CO_2 and other GHG. So far, more than 70 countries have stated their goals to achieve carbon neutrality (i.e., net-zero CO_2 emissions) by 2050.[6]

Late in 2019, the European Union (EU) announced a comprehensive legislative initiative, the European Green Deal, which focuses on having all EU member states achieve 100% climate neutrality (i.e., zero emissions of all greenhouse gases) by 2050, both across the EU as a whole and nationally within each country. On September 17, the European Commission presented its 2030 Climate Target Plan, in which the main objective is the reduction of greenhouse gas (GHG) emissions to at least 55% below 1990 levels by 2030[7] instead of the 40%

[4] The reasons for and consequences of climate change are not covered in this study. For more details on the threat posed by climate change, please see: Global Climatic Threat and the Russian Economy: Searching for the Way / Mitrova, T., Khokhlov, A., Melnikov, Yu., et al. // Moscow School of Management SKOLKOVO, May 2020. https://energy.skolkovo.ru/downloads/documents/SEneC/Research/SKOLKOVO_EneC_Climate_Primer_RU.pdf
In terms of climate change, each of the greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and ozone in the lower atmosphere) has a unique impact. Carbon dioxide and methane are the highest contributors to global warming.
[5] https://unfccc.int/process/the-paris-agreement/status-of-ratification
[6] State and Trends of Carbon Pricing Initiatives 2020. World bank, 2020. https://openknowledge.worldbank.org/handle/10986/33809
[7] https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=EU%20Commission%20Unveils%20EU%20Climate%20Target%20Plan%202030_Brussels%20USEU_European%20Union_09-26-2020#:~:text=On%20September%2017%2C%20as%20part,existing%20target%20of%2040%20percent.

proposed in 1990. In October 2020, the European Commission presented a new strategy for methane emission reduction. The legislative policy called the Carbon Border Adjustment mechanism (CBAM), which will establish the carbon price for importing certain goods into Europe, is expected to be adopted by mid-2021. It is estimated that the additional burden on Russian exporters (including oil, gas, and chemical companies) will amount to between €6 billion and €50.6 billion through 2030 in different scenarios of the policy adoption.[8]

In September 2020, China announced its commitment to achieving carbon neutrality by 2060 and to pursuing green development.[9] In October 2020, Japan and South Korea made similar commitments to carbon neutrality by 2050. Canada in January 2021 also announced carbon neutrality by 2050.[10]

Many Paris Agreement signatories have either already launched CO_2 emissions trading systems (or some other forms of carbon pricing and taxing) or are set to do so in the near future. Many are introducing bans on the use of combustion engines, setting targets for the proportion of renewable energy sources in their national energy balance, or setting targets for the proportion of low-carbon fuels in their fuel suppliers' basket. As is clear, various decarbonization initiatives are gradually taking shape throughout the world.

Reducing GHG emissions is becoming an important objective not only for governments but also for businesses in all sectors. Nowadays, decarbonization is not only a tool for achieving environmental and climate goals but also for differentiation and becoming more competitive on the international market.

The carbon footprint is gradually becoming an important quality characteristic of any product - companies with environmental commitments and sustainability programs see much faster sales growth than their competitors. The non-energy corporate sector is changing its requirements for energy supply: for example, as part of the global RE100 initiative, the world's largest companies have committed to a complete transition to renewable energy sources (including IKEA, 3M, Apple, Danone, Decathlon, eBay, Coca-Cola European Partners, The Goldman Sachs Group, Google, etc.).[11]

Niot only consumers, but also investors around the world are starting to consider the climate risks of potential investments and are starting to withdraw from those that produce high emissions, in particular, the ultra heavy oil, Arctic oil and tar sands. For instance, major global investors, such as BlackRock, the World Bank, JP Morgan, the Swedish pension fund Sjunde,

[8] https://tass.ru/ekonomika/8906921
[9] China pledges to become carbon neutral by 2060. September 22, 2020. https://www.theguardian.com/environment/2020/sep/22/china-pledges-to-reach-carbon-neutrality-before-2060
[10] https://ihsmarkit.com/research-analysis/canada-upgrades-decarbonization-plan-.html
[11] https://www.there100.org/

the Norwegian Government Pension Fund Global, Goldman Sachs, Deutsche Bank, BNP Paribas, Societe Generale, the European Investment Bank, Allianz, and more, have all made statements saying as much and launched corresponding initiatives.[12] Worldwide, thousands of corporate and private investors, whose joint asset control amounts to more than $14 trillion, have committed to divesting from the fossil fuel industry.

The financial sector (lenders and investors) is also playing an increasingly active role, requesting faster decarbonisation from their clients. Different types of climate finance policies are used fot this purpose, namely target lending, green bond policy, loan guarantee programmes, weather indexed insurance, feed-in-tariffs, tax credits, national development banks, disclosure policies and national climate funds.[13] Financial institutions today pay special attention to various reporting mechanisms (important frameworks include GRI, TCFD, and SASB), increasingly using them to assess and report on their exposure in terms of climate risk (especially the emissions associated with their loan book / investment portfolio). Once a financial institute knows this footprint, then it can begin to have a meaningful conversation about alignment with GHG emissions reductions goals as for instance formulated under the Paris Agreement (either to engage with the clients on emissions reduce or divest). Large institutional investors like pension funds, and investment funds like BlackRock and others that have a huge influence over oil and gas companies – most of them are now making public statements about climate and sustainability.

Regulatory authorities are also piushing this trend forward, becoming increasingly more demanding in what they want banks and investors to disclose to the outside world. One of the most well-known examples is the EU taxonomy initiative that is pretty far advanced, and defines what 'sustainability' means. It is widely expected that EU rules will also inform discussions in other jurisdictions on ESG investment, such as those in Northeast Asia, but also the US (where the SEC or FED under President Biden will surely develop a framework in the coming years for the financial sector). Central banks are increasingly signaling that they want to play a more active role in the climate policy, therefore, this pressure on oil and gas companies from the financial sector will only increase.

Given all this, the development prospects of the oil and gas sector, one of the noticeable GHG emitters that accounts for 12% of global emissions, are directly dependent on its decarbonization ability.

[12] For more details on the change in investors' preferences, please see: Global Climatic Threat and the Russian Economy: Searching for the Way / Mitrova, T., Khokholov, A., Melnikov, Yu., et al. // Moscow School of Management SKOLKOVO, May 2020. pp. 32-36.
[13] https://www.tandfonline.com/doi/full/10.1080/14693062.2020.1871313

This study focuses on how the oil and gas sector can remain a significant part of the global energy system while achieving net zero emissions. This study aims to review the structure of greenhouse gases emitted by the oil and gas industry and to systematize potential methods for reducing these emissions, using cases of leading oil and gas companies.

The methodology of this study was based on the analysis of a broad range of sources, case studies, and in-depth interviews with representatives of international oil and gas companies focused on their strategies and methods for reducing GHG emissions. The study comprises four main sections, namely:

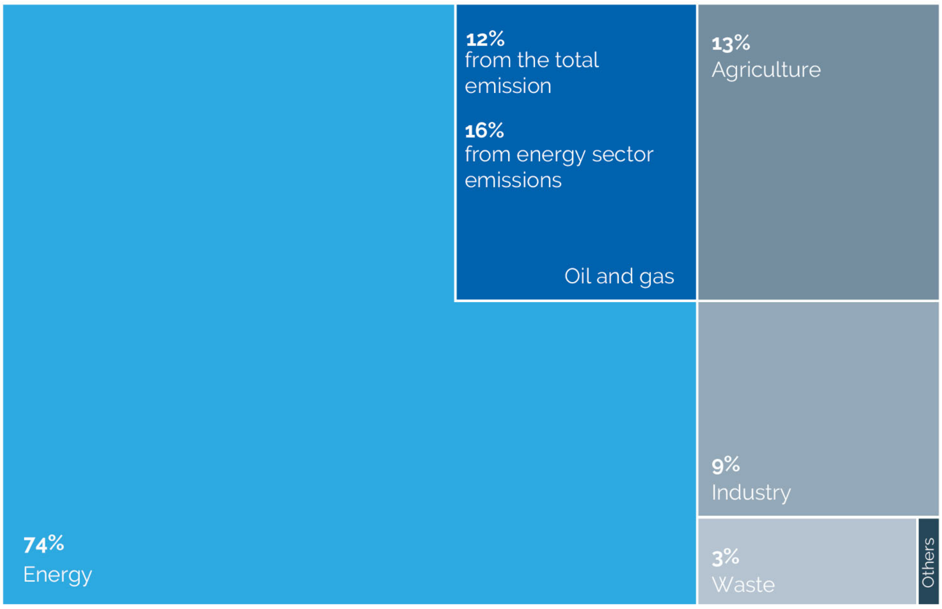
- the structure of GHG emissions, for which the oil and gas sector is responsible,
- climate goals and decarbonization strategies of leading international oil and gas companies, decarbonization methods and technologies used in the global oil and gas sector,
- decarbonization methods used by Russian oil and gas companies, and
- conclusions and recommendations for the Russian companies and regulators.

GHG EMISSIONS IN THE OIL AND GAS INDUSTRY

The oil and gas industry accounts for approx. 12% of global GHG emissions.

In 2017, global antropogenic GHG emissions reached 47 gigatons of CO_2 equivalent ($GtCO_2e$),[14] almost three fourths (74%) of which are emitted by the energy sector (mainly due to the combustion of various fossil fuels and methane leaks during their extraction, transportation, and distribution). In that same year, the oil and gas industry's emissions (scope 1 and 2) reached 5,668 megatons of CO_2 equivalent ($MtCO_2e$), which accounted for 16% of all energy sector emissions and approximately 12% of aggregate global emissions (comparable to those of the agriculture industry; see Fig. 1).

Fig. 1 – GHG emissions in 2017, by industry



Sources: Gütschow, J., Jeffery, L., Gieseke, R., and Günther, A. (2019): The PRIMAP-hist national historical emissions time series (1850-2017). v. 2.1. GFZ Data Services. https://doi.org/10.5880/pik.2019.018, IEA WEO 2018, Paris 2018.

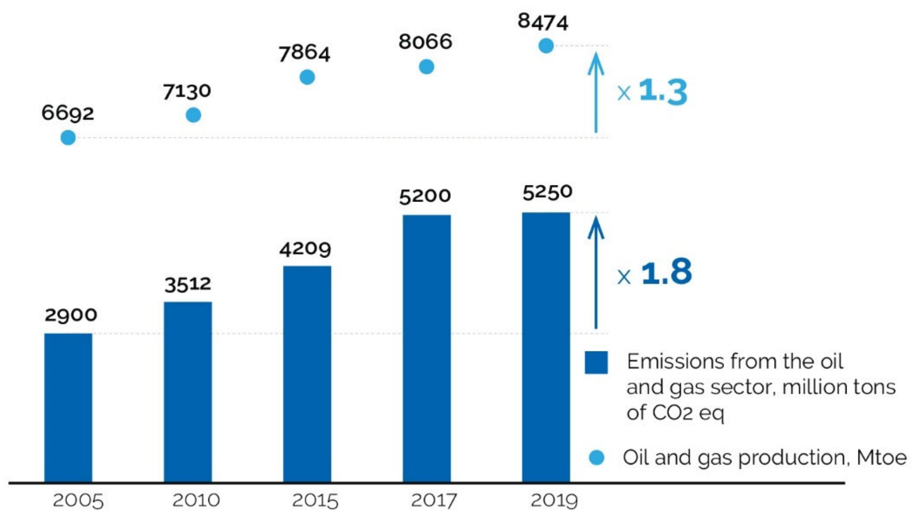
Growing share of the oil and gas sector in the global GHG emissions

The oil and gas sector's share of global GHG emissions is 1.8x what it was 15 years ago, even though production is just 1.3x greater.

Even though 12% of aggregate emissions may seem insignificant, it is noteworthy that the oil and gas sector's proportion of global GHG emissions has risen from 7% to 12% in the last 15 years.[15][16] The increase in GHG emissions has been partially attributed to the growth in the consumption, and consequently, the production, of oil and gas. However, our analysis suggests that despite the growth in production seen in 2019 being just 1.3x greater what it was in 2005, GHG emissions were 1.8x greater (see Fig. 2).

[14] https://www.pik-potsdam.de/paris-reality-check/primap-hist/
[15] CO2 abatement: Exploring options for oil and natural gas companies, McKinsey on Oil & Gas, 2009.
[16] WEO 2020.

Fig. 2 – GHG emissions from the oil and gas sector and oil and gas production growth

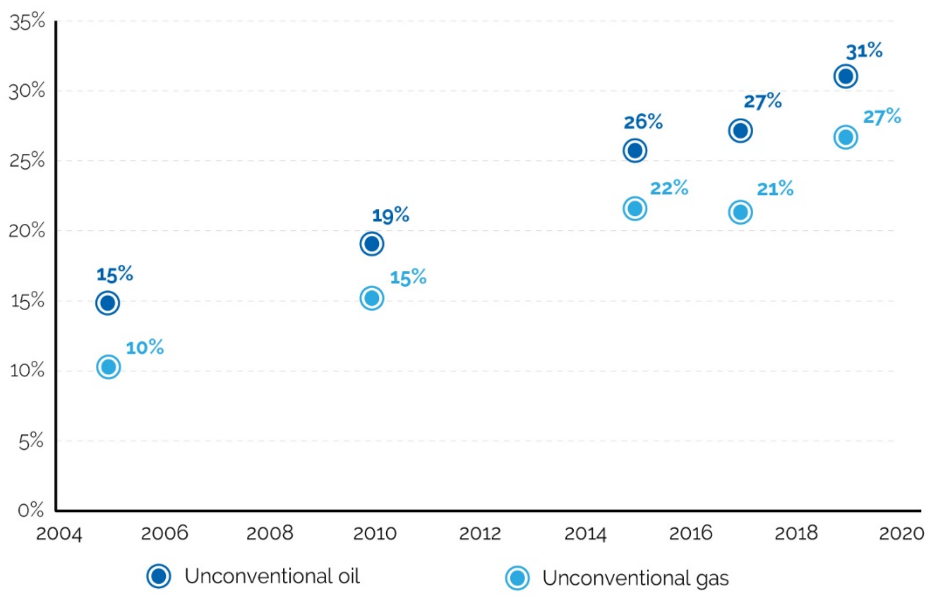


Sources: CO_2 abatement: Exploring options for oil and natural gas companies, McKinsey on Oil & Gas, 2009, https://www.accenture.com/t00010101t000000__w__/br-pt/_acnmedia/pdf-11/accenture-strategy-energy-perspectives-consequences-cop21.pdf, https://www.mckinsey.com/industries/oil-and-gas/our-insights/the-future-is-now-how-oil-and-gas-companies-can-decarbonize, WEO 2018, WEO2020, BP statistical review 2020.

The main reason for the growth in the oil and gas industry's GHG emissions is the increased production of unconventional oil and gas.

An increase in the production of unconventional oil[17] (from 15% in 2005 to 31% in 2019) and unconventional gas (from 10% in 2005 to 27% in 2019, see Fig. 3) became a key factor in the growth in the oil and gas industry's GHG emissions. Growing methane emisison as well as measurement improvements are explaining part of the increase.[18]

Fig. 3 – Growth in unconventional oil and gas production

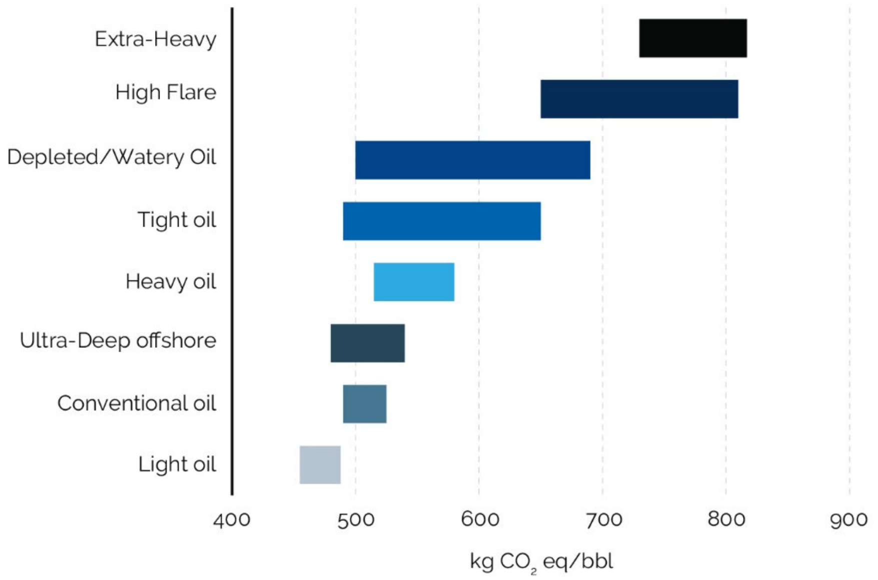


Sources: WEO 2005, 2010, 2015, 2016, 2017, 2018, 2019, 2020.

[17] Unconventional oil is petroleum produced or extracted using techniques other than the conventional method (oil well). Industry and governments across the globe are investing in unconventional oil sources due to the increasing scarcity of conventional oil reserves.
[18] https://www.iea.org/reports/methane-tracker-2020/improving-methane-data

GHG emissions depend on the type of oil produced. For instance, GHG emissions from light and conventional oil production do not exceed 525 kg CO_2e per barrel (bbl), with the average indicator for unconventional oils ranging from 570 kg CO_2e/bbl for shale oil to 775 kg CO_2e/bbl for extra heavy oil (Fig. 4).[19] For the production of hard-to-recover oils (e.g., high viscosity oil and sand oil), deep marine shelf oils, high temperature and pressure oils, depleted reservoirs pressure maintenance methods are increasingly energy intensive and, consequently, these production methods have a higher GHG emission indicator than that of conventional oil production methods. As noted above, the amount of oil being produced related to high GHG emissions is constantly growing, in line with the depletion of conventional fields.

Fig. 4 – GHG emission levels for different types of oil produced



Source: Gordon, D., et al. (2015). Know your oil; creating a global climate-oil index. Carnegie Endowment for International Peace. http://carnegieendowment.org/2015/03/11/knowyour-oil-creating-global-oil-climate-index/i3oy

As for unconventional gas, the range in GHG emission indicators for it is not as wide as it is for oil. Additional emissions of shale gas production are mostly formed at the well completion.[20][21] For dry gas production fugitive emissions do not have to be very problematic. And most leaks in gas production tend to come from old vertical wells, just because of aging materials, etc.

[19] It should be emphasized that these estimates are based on specific benchmarks, and not on full-scale measurements, and therefore may be adjusted in the future.
[20] Climate impact of potential shale gas production in the EU Final Report, Report for European Commission DG CLIMA AEA/R/ED57412 Date 30/07/2012 Issue 2
[21] https://www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/clean-fossil-fuels/natural-gas/shale-tight-resources-canada/environmental-considerations-shale-and-tight-resource-development/17682

Breakdown of GHG emissions in the oil and gas industry

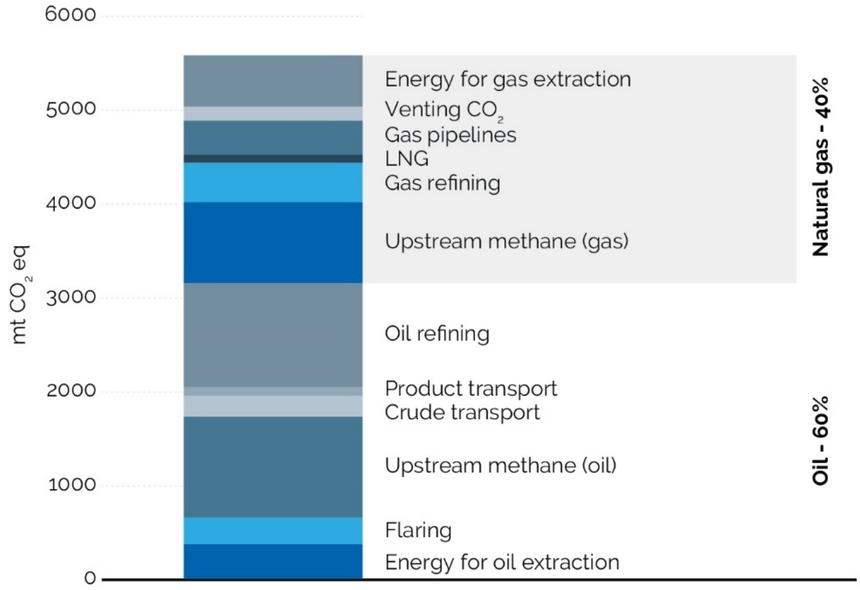
Of the total emissions produced by the oil and gas industry, oil accounts for 60% and gas accounts for 40% (Fig. 5). Most GHG emissions from the oil and gas sector are associated with land operations (namely, with methane and CO_2, the water-oil or gas mixture component at production, emissions, and GHG flaring).

Methane emissions account for the significant proportion of GHG emissions within the oil and gas industry (45% of aggregate emissions).

Methane emissions are a significant problem; they account for 45% of the total emissions of aggregate emissions.

However, despite different approaches to reducing methane emissions in gas production and transportation, concentration of efforts, for example, in the upstream sector can bring greater benefits. Emissions from refining operations rank second at 21%.

Fig. 5 – Oil and gas industry's GHG emissions structure in 2017



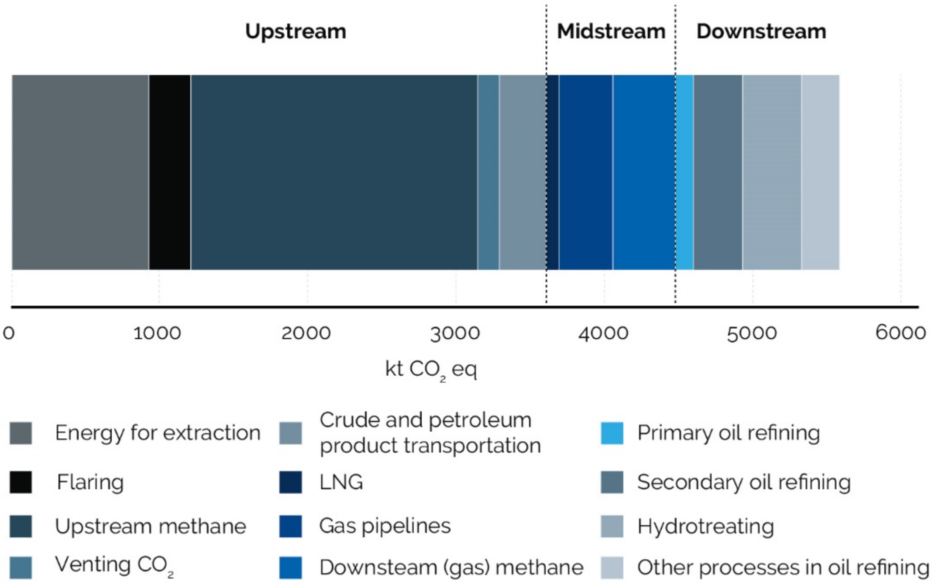
Sources: IEA, World Energy Outlook 2018, Paris 2018.

Emissions in the oil and gas sector can be structured by the supply chain (upstream/midstream/downstream) or by so-called scopes. These two methods for structuring largely overlap, but there are certain, unique features described in detail below.

GHG emissions across the supply chain

In terms of the supply chain (upstream/midstream/downstream), the bulk of GHG emissions in the oil and gas sector is classified as upstream (Fig. 6).

Fig. 6 – GHG emissions by supply chain



Source: IEA, World Energy Outlook 2018, Paris 2018.

Upstream

Upstream GHG emissions account for 59% of the aggregate GHG emissions of the oil and gas sector, which is equal to 3,292 $MtCO_2e$, in absolute terms. Methane emissions and leakages at production account for the greatest proportion of upstream GHG emissions (59%), closely followed by emissions from the energy spent on oil and gas production (28%).

Oil production. Oil production is energy intensive. Energy is required for operating drilling rigs (pumps that extract oil or pump water and other liquids to maintain pressure in the collector) and for running auxiliary equipment used on-site. The IEA estimates emissions from these operations stood at 380 $MtCO_2e$ in 2017.

During oil production, GHG are emitted not only when burning the energy to secure the production process itself, but also when flaring APG, a byproduct of oil production. APG is flared mainly for economic reasons, as building an additional infrastructure for its collection and transportation is simply unprofitable as long as emission is not priced. In 2017, 140 BCM of APG were flared, equivalent to 284 $MtCO_2e$.

When APG is flared, methane is not 100% disposed. In 2017, slightly more than 3 Mt of methane (84 $MtCO_2e$)[22] were emitted into the atmosphere. There are also other methane emission sources in oil production. These vary by region, supply chain route, processing, and equipment, but, according to the IEA, in 2017 an additional 33 Mt of methane (924 $MtCO_2e$) were emitted as a result of global oil operations in 2017. In 2020, according to the IEA Methane Tracker Database,[23] against the reduced oil

[22] The conversion factor of 28 is applied in this research to convert methane emissions to CO_2e.
[23] https://www.iea.org/articles/methane-tracker-database

production, methane emissions from oil production were almost 20% lower amounted to 27.3 Mt (764 $MtCO_2e$).

Gas production. Many sources of GHG emission in the production of natural gas are the same as those in the production of oil, such as the energy required to operate drilling equipment, maintain pressure, and run auxiliary services. Natural gas flaring is minor, though.

A particular feature of natural gas production is that it may contain numerous impurities, such as CO_2, hydrogen sulfide, or sulfur dioxide. CO_2 volume can account for as much as 50% of total gas produced. These impurities must be extracted before long-distance gas transportation as not doing so could lead to pipeline corrosion. The gas must also meet certain quality requirements. Removal of these impurities requires additional energy, and the removed CO_2 is often released into the atmosphere. CO_2 discharge amasses more than 150 $MtCO_2e$ of emissions annually worldwide.

As with oil, natural gas production also adds to atmospheric emissions of methane. However, unlike with oil, emissions from natural gas production are not limited to upstream only. They may come from midstream because transported natural gas is mostly represented by methane. According to the IEA, methane emissions resulting from natural gas production amounted to 29 Mt (812 $MtCO_2e$) in 2017. In 2020, according to the IEA Methane Tracker Database, the total methane emissions from gas production remained at the same level.

Midstream

GHG emissions from midstream account for 14% of GHG emissions within the entire sector (they amount to 766 $MtCO_2e$ in 2017). The bulk of emissions is generated by gas transportation via pipelines (48%), followed by oil transportation (29%). When transporting natural gas through gas pipelines, the main problem is associated with GHG emissions at compressor stations, where gas is burned to ensure the operation of gas pumping units.

Oil transportation. In 2017, GHG emissions from crude oil transportation stood at 221 $MtCO_2e$ while those from refined product transportation stood at 95 $MtCO_2e$. The bulk of crude oil and refined products are transported via pipelines and by tankers. Oil can also be transported by rail or by motor transport, but the low profitability of these routes, as compared with pipelines, limits their application.

To maintain the pressure system of an operating pipeline, pumps and sometimes heaters are necessary along the route. To provide the energy required for this equipment, various fuel types can be used, the most common of which are oil and gas.

Most long-distance marine crude oil transportation is carried out by very large crude carriers fueled most often by oil. Long-distance trade of refined products is less common than of crude oil, for refineries are most often built close to consumers.

Gas transportation. LNG tankers and pipelines are used for transporting natural gas to end consumers. According to the IEA, 15 Mt of methane (420 $MtCO_2e$) were emitted in gas transportation in 2017.

Usually, approximately 9% of feed gas supplied to a natural gas liquefaction plant is required for LNG production processes. Additional energy losses occur during transit: up to 0.15% of LNG cargo is evaporated daily, which means the total quantity of gas consumed depends on its transportation distance. Moreover, gas is often used as fuel for LNG tankers, which contributes to CO_2 emissions. For example, the 7,500 km route from the U.S. to Europe takes approximately 9 days, over which time around 1.3% of LNG cargo is expended, resulting in CO_2 emissions during transport. Thus, not less than 10% of gas initially set to arrive at a liquefaction plant will be consumed through liquefaction, transportation, and re-gasification.[24] The bulk of this gas is flared and emitted as CO_2, not as methane.

Compared with LNG, gas is typically transported by pipelines across shorter distances. However, compressor stations that maintain system pressure are necessary for gas pipeline operation, and these require energy, too. These compressors may be fed from a power grid, but it is more often that some transported pipeline gas is used. Moreover pipelines can age and become more prone to leakage.

Downstream

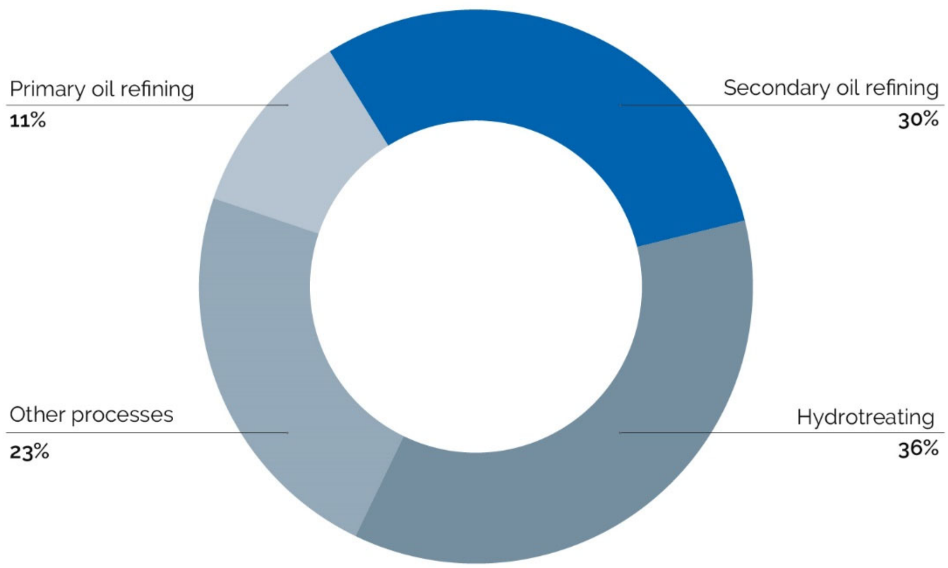
GHG emissions from downstream account for 1,526 $MtCO_2e$, with methane leakages being the key source of emissions in gas processing (28% of overall GHG emissions from oil and gas refining). The rest is accounted for by oil refining (72%). Oil refining is the main process in the oil industry value chain; nobody needs crude oil as the ultimate commodity, everybody is interested in refined products. The process is energy-intensive and leads to major greenhouse gas emissions. In general, in 2017 downstream emissions amass 1,174 $MtCO_2e$ annually. About 50% of GHG emissions from refineries comes from furnaces and boilers, 20% from associated utilities, and nearly 15% from hydrogen production.

Approximately two thirds of GHG emissions from refineries are accounted for by secondary processes and hydrotreatment. Thus, comprehensiveness, i.e., the number of secondary processes, is the most significant factor that determines the emission volumes of a refinery. Simple refineries that deal with

[24] The assessment is based on the example of feed gas consumption as fuel for Australian LNG plants. (9%, https://www.energy.gov.au/sites/default/files/australian_energy_statistics_2019_energy_update_report_september.pdf) and evaporation of LNG gas during transportation (for a 10-day trip with an average consumption of 0.1% per day, about 1% of the cargo will evaporate).

primary crude oil refining only and have a small scope of hydrotreatments are characterized by rather low emission intensity. More complex refineries generate greater emission volumes (Fig. 7).

Fig. 7 – GHG emissions in refining



Source: IEA, World Energy Outlook 2018, Paris 2018.

Moreover, the quality of crude oil used as raw material influences the level of emissions, because it is closely related to the refinery's configuration. For instance, compared to light oil refining, heavy oil refining results in a greater volume of GHG emissions.[25]

GHG emissions by scopes 1, 2, and 3

Determining the scopes of sources of GHG emissions aims to comprehensively assess GHG emissions and identify opportunities for reducing emissions inside and outside production facilities. The method for assessing the scopes of GHG sources has been used for more than 20 years within the GHG Protocol framework.[26] The GHG Protocol represents a comprehensive and global set of standards for measuring and managing GHGs emitted by enterprises from varying industries and with varying forms of ownership. The GHG Protocol supports the world's most common GHG reporting standards.

The International Petroleum Industry Environmental Conservation Association (IPIECA)[27] that represents the oil and gas sector as part of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) has expanded and updated the oil

[25] Estimating the petroleum industry value chain (scope 3) greenhouse gas emissions • Overview of methodologies, IPIECA/API 2016.
[26] https://ghgprotocol.org/about-us
[27] https://www.ipieca.org/

industry's guidelines for reporting GHG emissions based on the GHG Protocol.[28]

These documents highlight three scopes (Fig. 8).

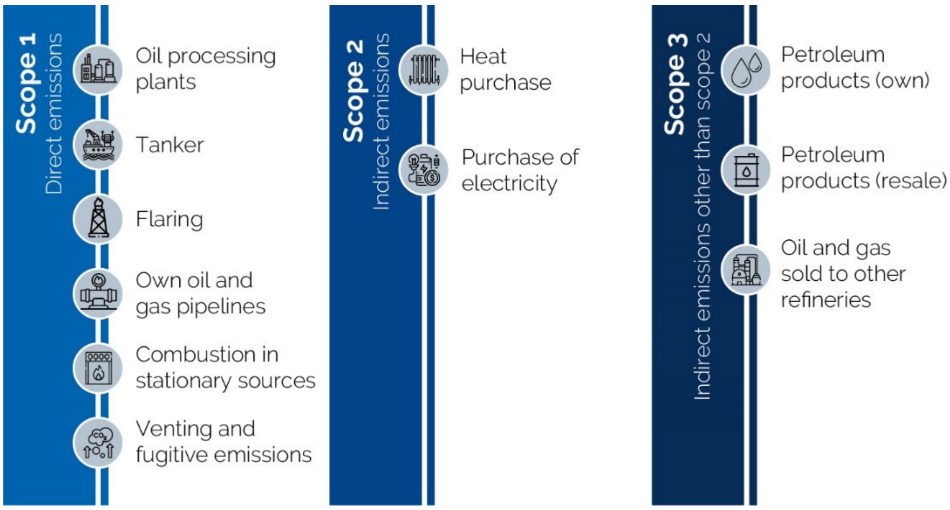
Scope 1 – direct emissions: GHG emissions from sources owned or controlled by a company. These include emissions from fuel burning and process emissions unrelated to burning.

Scope 2 – indirect energy emissions: emissions from electricity production or thermal energy used in the company's production processes, which is supplied from other companies.

Scope 3 emissions are all indirect emissions related to a company's operations (mostly the consumption of the hydrocarbons a company produces) and are generally 7-x greater than scopes 1 and 2 combined.

Scope 3 – all other indirect emissions: indirect emissions related to a company's operations, but come from sources owned or controlled by other entities. These include emissions from the manufacturing of consumed raw materials and fuel, in cargo transportation and in the use of manufactured products by consumers.[29] This also includes other sources of indirect emissions such as transport of employees, etc. In other words, scope 3 covers those indirect emissions that occur in the value chain of the reporting company and are not included in scopes 1 and 2.

Fig. 8 – GHG emission scopes



Source: Petroleum industry guidelines for reporting greenhouse gas emissions - 2nd edition.

Scopes vary from one oil and gas company to another. For instance, the emissions from refining are classified under scope 1 for a refinery, but under scope 3 for an exploration and prospecting company (for which refining is outsourced to other companies down the value chain) and for a petrochemical company (for which refining operations occur at the top of the value chain).[30] For a vertically integrated oil company, scope 1

[28] Petroleum industry guidelines for reporting greenhouse gas emissions - 2nd edition / https://www.ipieca.org/resources/good-practice/petroleum-industry-guidelines-for-reporting-greenhouse-gas-emissions-2nd-edition/
[29] http://greening-sochi2014.isedc-u.com/docs/otchety/2013/Issledovanie-institutcional-nykh-aspektov-po%20uglerodnoi-otchetnosti_ru.pdf
[30] Estimating the petroleum industry's value chain (Scope 3) GHG emissions.

includes prospecting and exploration, oil and gas refining, logistics of goods and personnel (business trips), transporting, own fuel burning for electricity, cooling, and heating. Scope 1 may also extend to the production of biofuels, synthetic fuels, and hydrogen (besides generation at own refineries). Scope 2 includes procurement of electricity, heat, cooling, and steam. Scope 3 includes GHG emissions from the end consumption of the company's products, e.g., the burning of the fuel sold by the company in cars' gas tanks, the refining of the oil sold by the company at another company's refinery, or the use of refined products for manufacturing petrochemicals at another company's refinery.

For the VIOCs scope 3 GHG emissions are on average 7x greater than scopes 1 and 2 combined (Table 1). In general, scopes 1 and 2 of the oil and gas sector account for 12% of all global emissions, while scope 3 is responsible for about 33% of global emissions.[31]

Table 1 - GHG emissions of the leading international oil and gas companies by scope

	GHG emissions scope 1,2	GHG emissions scope 3	Ratio
BP	55	360	7
Conocophillips	20,5	173,4	8
ENI	43	252	6
Total	41,5	410	10
Shell	116	576	5
Chevron	57	639	11
Exxon Mobil	120	570	5
Repsol	25,2	180	7
Average			**7**

Source: Energy Centre, Moscow School of Management SKOLKOVO based on companies' data.

It is worth noting that the methodology of scope 3 emissions calculation is still under discussion, (since they include those elements that companies do not control themselves, and often do not have access to relevant information on them), and different companies calculate scope 3 emissions differently.[32] Nonetheless, the above figures show that, for the oil and gas sector, the majority of CO_2 emissions are classified under scope 3.

[31] https://www.mckinsey.com/industries/oil-and-gas/our-insights/the-future-is-now-how-oil-and-gas-companies-can-decarbonize

[32] https://www.api.org/~/media/Files/EHS/climate-change/Scope-3-emissions-reporting-guidance-2016.pdf
https://ghgprotocol.org/standards/scope-3-standard

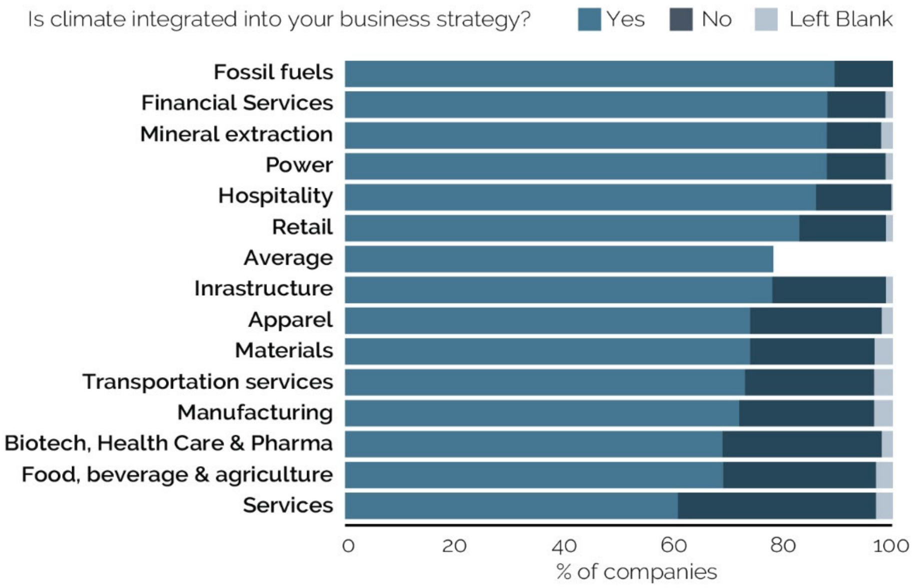
THE DECARBONIZATION GOALS, STRATEGIES, AND METHODS OF LEADING INTERNATIONAL OIL AND GAS COMPANIES

Decarbonization goals of leading international oil and gas companies

More so than those in other industries , oil and gas companies tend to account for the climate when formulating their business strategies, given their extreme vulnerability to potential hydrocarbons demand loss.

Decarbonization trends have more and more impact on oil and gas companies (Fig. 9). In 2016, the Paris Agreement, UN Sustainable Development Goals[33] and the Task Force on Climate-Related Financial Disclosures (TCFD)[34] significantly incentivized companies within the industry to begin articulating and disclosing decarbonization efforts. And the trend is accelerating as it begins to include companies from more and more places across the globe. By 2016, only 5 oil and gas companies had articulated emission reduction targets, but by 2019, that number had increased to 15. Despite having never before reported its emissions data, in August 2020, the Chinese megacorporation, PetroChina, pledged to near net-zero by 2050 and invest in geothermal, wind, and solar power, as well as pilot hydrogen projects.[35]

Fig. 9 – Accounting for the climate within the business strategies of companies within different sectors



Source: CDP 2019.

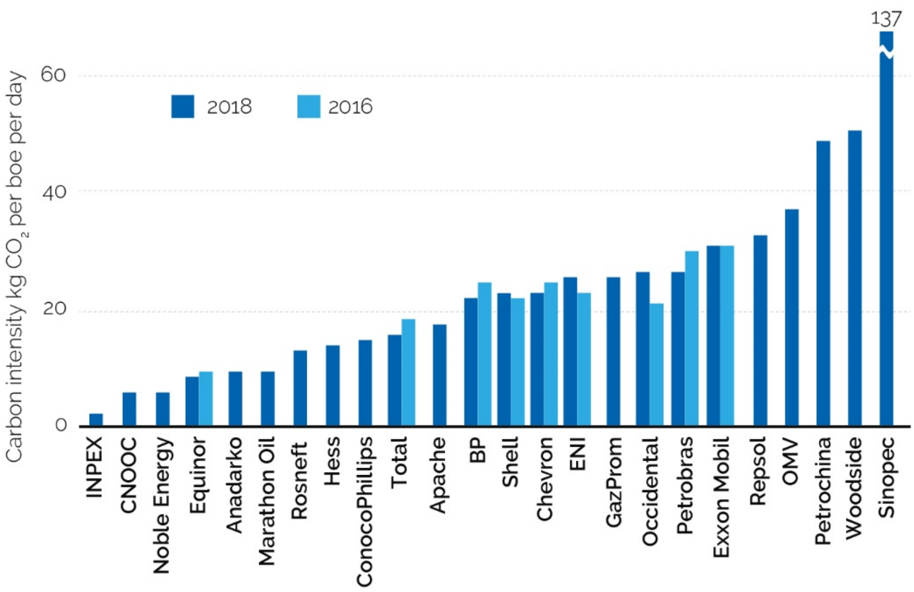
More so than those in other industries included in Carbon Disclosure Project (CDP)[36] reporting, oil and gas companies tend to account for the climate when formulating their business strategies. This is driven by the fact that demand projections

[33] For details on how the SDGs relate to oil and gas industry activities, see: https://www.undp.org/content/undp/en/home/librarypage/poverty-reduction/mapping-the-oil-and-gas-industry-to-the-sdgs--an-atlas.html
[34] https://www.fsb-tcfd.org/
[35] https://www.reuters.com/article/us-china-petrochina-results-idUSKBN25N1CC
[36] https://www.cdp.net/en/

differ greatly depending on demand scenario assumptions, and a significant part of investments in oil and gas projects may become economically non-viable with a lower demand forecast.[37]

Within the oil and gas sector, companies' positions in terms of their GHG emissions differ greatly. The European oil and gas companies have been operating in a carbon-regulated environment longer than anyone else in the industry (in Norway, for example, carbon tax has existed since 1992). As a result, their operations are less carbon-intensive (Fig. 10) and they are more focused on gas and investing more in renewable energies and low-carbon technologies, including CCUS and setting absolute, rather than intensity, targets for future GHG emissions.[38]

Fig. 10 - GHG intensity during production for leading international oil and gas companies

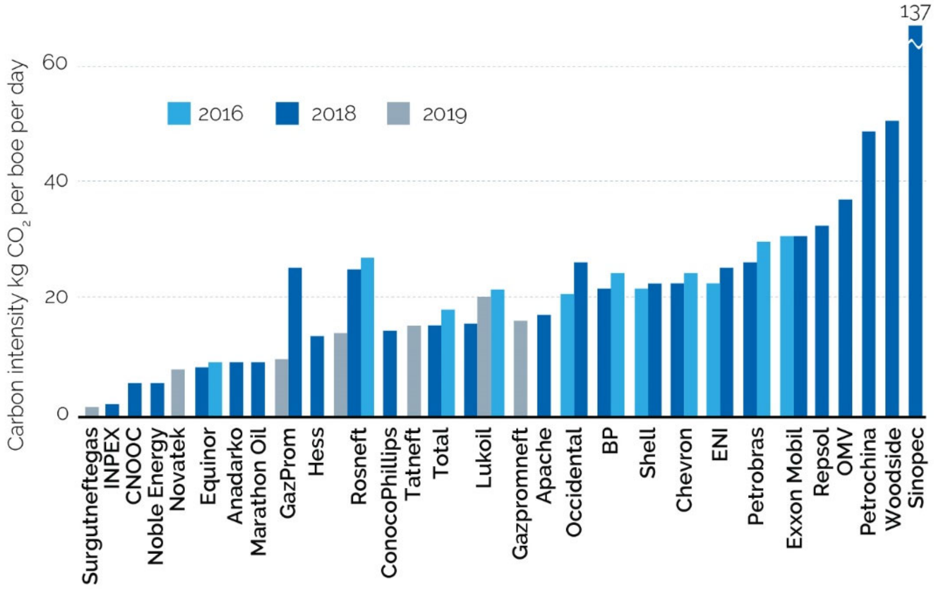


Sources: Energy Centre, Moscow School of Management SKOLKOVO based on CDP data (CDP industrial report for oil and gas 2016 and 2018).

In terms of actual change in total GHG emissions and GHG intensity, the speed of change varies among operators, with Petrobras leading in improvement and Occidental showing a significant deterioration of their per unit emission of GHG (Fig. 11).

[37] Carbon Tracker "Fault Lines: How diverging oil and gas company strategies link to stranded asset risk", October 2020.
[38] Equinor 2020 Q3.

Fig. 11 – Change in per unit of GHG emissions during production



Source: CDP industrial report for oil and gas 2016 and 2018, 2019 data taken from company reports.

In recent years, many leading international oil and gas companies have begun setting voluntary emission reduction goals.

In recent years, many leading oil and gas companies began setting voluntary emission reduction goals (Table 2). Most of these targets are related to emissions classified under scopes 1 and 2 Some companies, though, are currently setting targets for scope 3 emissions.

Oil and gas companies are mainly focusing on scopes 1 and 2 and aim for a 0.3% to 1.7% annual absolute reduction with similar goals for reducing emission intensity.[39] In comparison, to truly play their part in reducing global emissions, a very aggressive 90% reduction in current emissions by 2050 would be needed.[40] So new and more ambitious cuts will inevitably be required from a much wider range of companies.

[39] Selected CDP reports 2019 and SKOLKOVO Energy Center analysis.
[40] https://www.mckinsey.com/industries/oil-and-gas/our-insights/the-future-is-now-how-oil-and-gas-companies-can-decarbonize

Table 2 - Climate targets of leading international oil and gas companies

Company	Climate Goals
BP	1. optimize the company's operations in order to zero emissions by or before 2050 and zero carbon emissions in the course of the oil and gas industry's operations by or before 2050 (scope 1 and 2) 2. reduce carbon intensity of sold products by 50% and methane emissions by 50% (scope 3) 3. achieve 50 gigawatts (GW) of renewable energy capacity by 2030
Total	1. net-zero on operations by or before 2050 (scopes 1 and 2) 2. worldwide emissions in 2030 less than in 2015 (scope 3) 3. reduce carbon Intensity by 60% or more by 2050 (scopes 1, 2, and 3) 4. in Europe, net-zero by or before 2050 (scopes 1, 2, and 3) and a 30% reduction by 2030 (scope 3)
ENI	obtaining an 80% reduction in net emissions from the entire life cycle of sold energy products by 2050, which include Scope 1, 2 and 3 emissions and 55% of the emission intensity
Shell	net-zero emissions in the energy business by or before 2050 (scope 1 and 2); reduce carbon intensity of energy products by 30% by 2035 and by 65% by 2050, compared with 2016 (scope 3), keeping in pace with society[41]
Equinor	to reach net-zero emissions by 2050, reduce absolute GHG emissions (scopes 1 and 2) from operations in Norway by 40% by 2030, 70% by 2040, and towards net-zero by 2050, compared to 2005 the 2030 target means reducing more than 5 $MtCO_2e$[42]
Repsol	net zero emissions by 2050 (includes emissions both from production and products) (scopes 1, 2, 3)
ExxonMobil	achieve a 10% decrease in GHG emissions intensity by 2023, using 2016 as a baseline[43]
Chevron	Chevron is targeting a 40% reduction in the carbon dioxide intensity of oil production and 26% from gas production by 2028 (based on a 2016 baseline). It is also targeting a 53% reduction in the intensity of methane emissions by 2028.
ConocoPhillips	Reduce GHG emissions intensity by up to 15% (CO2e per boe) by 2030 per boe vs 2017 levels
PetroChina	PetroChina aims for near-zero emissions by 2050[44] the company formulated relevant work plans for low-carbon and green development and established a special low-carbon management division the company is deeply involved in OGCI activities[45]
CNOOC	On June 10, 2019, China National Offshore Oil Corporation (CNOOC) issued the Green Development Action Plan for the first time, which clearly outlined its green development targets for the short-term (2020), mid-term (2035), and long-term (2050). It contains three specific action plans addressing green oil fields, clean energy, and green and low carbon emissions. CNOOC responds to national policy requirements for climate change and incorporates low-carbon management into the company's overall oil and gas development process.[46]

Sources: Energy Centre, Moscow School of Management SKOLKOVO based on companies' data, Infosys[47].

Despite formulating ambitious targets for the long term, these are seldom accompanied by tangible targets in the short term,

[41] https://www.shell.com/energy-and-innovation/the-energy-future/shells-ambition-to-be-a-net-zero-emissions-energy-business.html#iframe=L3dlYmFwcHMvY2xpbWF0ZV9hbWJpdGlvbi8
[42] https://www.equinor.com/content/dam/statoil/documents/climate-and-sustainability/climate-roadmap-2020.pdf
[43] https://corporate.exxonmobil.com/-/media/Global/Files/energy-and-carbon-summary/Energy-and-carbon-summary.pdf
[44] https://www.globalbusinessoutlook.com/petrochina-commits-become-carbon-neutral/#:~:text=Company%20President%20Duan%20Liangwe%20told,well%20as%20pilot%20hydrogen%20projects.%E2%80%9D
[45] http://www.petrochina.com.cn/ptr/xhtml/images/2019kcxfzbgen.pdf
[46] https://www.cnooc.com/col/col46301/index.html
[47] https://www.infosys.com/insights/industry-stories/oil-gas-industry.html

which would make it easier to measure progress, and hold senior executives accountable. Companies tend to be fairly selective, and not particularly detailed, about how these longer term goals are to be achieved. These companies' short-term GHG reduction goals are often even less ambitious. There is skepticism therefore that the companies making lofty future promises can actually live up to those – so the companies will have to prove that they are indeed moving ahead in line with their committments.

Developing a decarbonization strategy

Developing a decarbonization strategy is an integral, multistage process, unique to each individual company and dependent on its asset structure, production technologies and regional regulations.

The decarbonization of the oil and gas industry and individual enterprises is an integral, multistage process. No company within this industry has reached integral competency in this area. Therefore, to reach the proposed emission reduction, each company searches, through trial and error, for its own set of measures and initiatives. That being said, it is important to note that an all-in-one approach to decarbonization that would be suitable for both emission reduction and economic efficiency for all companies within this sector, is nearly impossible.

Apart from the common ultimate goal of carbon footprint reduction, companies vary in both their starting points (regional regulations, assets structuring, and quality, including specific carbon footprint per metric ton (MT) of output measures) and how is carbon market regulated in jurisdictions where they operated (availability of carbon markets, subsidization of renewable energy, etc.). In summary, companies choose the most appropriate decarbonization methods for their individual branches, production technologies, and regional regulations and shape their own structures of investment portfolios. For example, there is visible distinction between decarbonisation options and opportunities for oil and oil companies, and those for gas and gas companies. The latter have more mid- and downstream emissions problems for infrastructure companies.

Anyway, at the first stage, all companies have to take some initial administrative and managerial actions, without which decarbonization does not typically advance efficiently:

- **Carbon footprint assessment and disclosure** - revision of methods for calculating the company's direct (scope 1) and indirect (scopes 2 and 3) GHG emissions, development of methods for GHG emissions forecasting, preparation of reports on GHG emissions resulting from the oil and gas sector's operations (scope 1, as well as those classified under scopes 2 and 3) in the preceding 5-year period, with application of generally accepted methods for calculating emissions and further independent auditing. And the real challenge is do companies let third parties do this independently or do they do it on own data gathering.

- **Scenario analyses of the company's climate risks** as per the TCFD's recommendations, rating, and risk prioritization.
- **Development of the company's climate strategy**, setting out mid- and long-term climate targets for the company's GHG emissions in compliance with the Science Based Targets Initiative (SBTI).[48]
- **Changes to corporate governance system** - identification of executives responsible for implementing the climate strategy and introduction of relevant top-down decarbonization targets and decarbonization key performance indicators (KPIs). Upgrading the importance of climate governance - in many cases companies corporate climate functions are transferred in the Strategy or Finance departments and controlled personally by CEOs. The best practice is also to have decarbonization integrated into strategy and investment decisions, through internal CO_2 pricing.

Among major foreign oil and gas companies, there is currently quite a variety of measures being planned or already in application. However, it is important to note that the list of these initiatives will always be in flux as long as companies gain knowledge, become more experienced in emission reduction, and come to more accurately understand the efficiency of a given measure.

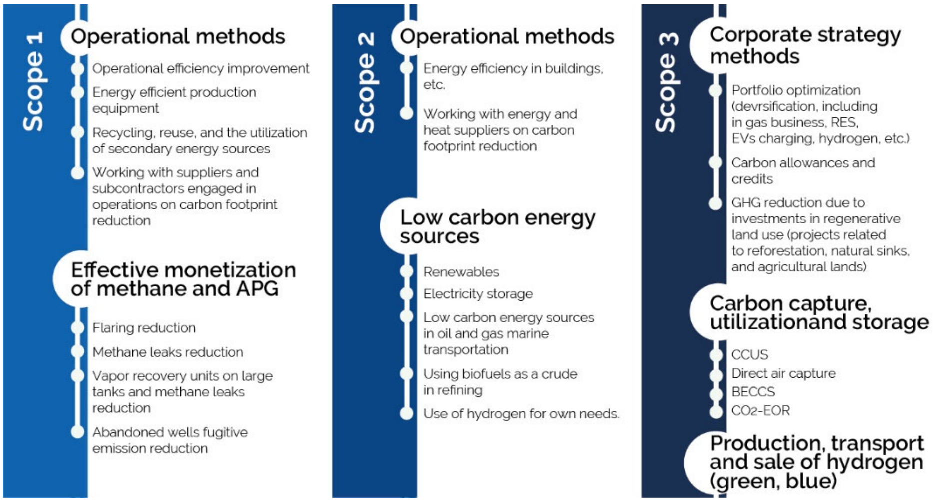
In many cases, emission reduction also provides for better return on operations due to the monetization of previously lost resources.

In terms of methods for decarbonization within the oil and gas industry, six main areas can be identified: operational methods, effective monetization of methane and APG, using low-carbon energy sources, corporate strategy methods, and deep decarbonization using CCUS technologies and hydrogen within the value chain. Common priorities of all companies include but not are limited to, complying with the Oil and Gas Climate Initiative (OGCI)[49], decreasing the energy intensity of production technologies and reducing methane emissions, also providing for better return on operations due to the monetization of previously lost resources, which is a very significant argument in favor of voluntary decarbonization targets. The commercialization of CCUS technologies is also gaining popularity among oil and gas companies..

All these methods of GHG emissions reductions can be classified under scopes 1, 2 and 3 (Fig. 12).

[48] https://sciencebasedtargets.org/
[49] https://oilandgasclimateinitiative.com/

Fig. 12 - Methods of decarbonization of the oil and gas industry



Source: Energy Centre, Moscow School of Management SKOLKOVO.

Operational methods

Operational efficiency improvement

Although the primary objective of operational excellence is lowering production costs, in many cases those initiatives also result in carbon footprint reductions.

A weakening oil and gas price environment has placed an additional emphasis on operational excellence management systems (Table 3), incorporating elements of Total Quality Management (TQM), Lean, or Six Sigma. Most oil and gas companies continuously focus on improving operational performance and reducing costs through identifying and rigorously implementing best practices, rolling out continuous improvement programs, and rigorous compliance monitoring.

Table 3 - Typical operating excellence management systems elements

Typical Operating Excellence Management System (OEMS) elements	bp	Chevron	ConocoPhillips	ExxonMobil	Shell
Strategy & Leadership	●	●	●	●	●
Organization & Capacities	●		●	●	●
Performance Management	●			●	●
Management of Change	●	●		●	●
Planning & Optimization	●		●		●
Operations & Production	●	●	●	●	●
Asset Integrity Management & Refabity	●	●	●	●	●
Health. Safety. Security & Environment	●	●	●	●	●
Management of Contractors	●	●	●	●	●
Capital Projects mgmt & execution	●	●	●	●	●
Operational Risk Management	●			●	●
Incidents & Emergency Management	●	●	●	●	●
External Stakeholders Responsibility	●	●	●	●	●
Knowledge Management	●			●	●

Source: Bain&Co, companies' websites.

For example, Shell and Suncor have implemented Lean principles into their operations. These include Value-Stream Mapping, a Six Sigma tool used to map production processes to find value leakages from errors and waste, as well as from equipment idle time, logistical errors, and planning mistakes.[50]

It is worth noting that onshore production is increasingly using solutions that were previously used on offshore platforms (e.g., compacting: requiring a minimum number of people and resources).

Although the primary objective of operational excellence is lowering production costs, in many cases those initiatives are directly linked to carbon footprint reduction. For example, better material and crew allocation planning, remote diagnostics, and preventive well maintenance will result in reduced maintenance crew relocations, a decreased need for related logistics, and lower well idle time (often accompanied by wasted energy, not resulting in the production hydrocarbons).

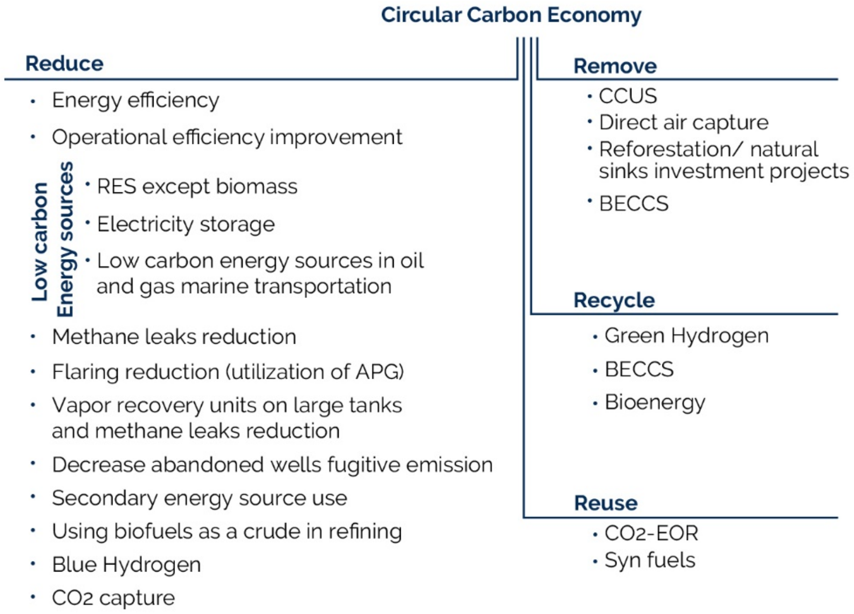
Recycling, reuse, and the utilization of secondary energy sources

The circular carbon economy concept was first developed by Saudi Aramco as an extension of the closed-loop economy (circular economy) concept.[51] It is a new approach to reducing GHG emissions and achieving corporate climate goals. This concept is intended to reduce resource consumption while maintaining the output of goods and services, organizing reuse, secondary utilization, and recycling of items, that cannot be reused. This allows the transition to use more sustainable resources, mitigating the quantity of resources in use and the amount of waste and, consequently, curtailing greenhouse gas emissions. This approach relies on the 4Rs (reduce, reuse, recycle, and remove).

Within this framework (Fig.13), most of the methods for the decarbonization of the oil and gas sector fall into the reduce segment, i.e., they only involve the reduction of CO_2 emissions. The pool of technologies that allow CO_2 to be reused, recycled, and removed from the atmosphere applicable for the oil and gas sector is currently limited. Prospective technologies in these 3R-solutions are being developed in related industries such as the chemical industry, synthetic fuel production, construction and materials industry, and nature management.

[50] https://www.sixsigmadaily.com/lean-processes-help-improve-global-oil-gas-industry/
[51] https://www.aramco.com/en/making-a-difference/planet/the-circular-carbon-economy

Fig. 13 - Methods for the decarbonization of the oil and gas industry within the 4R framework



Source: Energy Centre, Moscow School of Management SKOLKOVO.

Reduce

The reduce category includes these methods for the reduction of fugitive carbon emissions: energy efficiency and fuel switching to less carbon-intensive energy sources (e.g., renewables, nuclear, or blue hydrogen).

Energy efficiency is one of the most efficient methods within this sector. According to IRENA, more than 90% of the power industry's reductions in CO_2 emissions for the nationally announced climate goals may be achieved through energy efficiency strategies combined with a quick transition to renewable energy sources.[52] Moreover, the efficient use of resources and the reduction in leakages and emissions of hydrocarbons and their usage for the oil and gas companies' own needs will also help to reduce their GHG emissions. For instance, hydrocarbon leakages directly at oil and gas pipeline transport facilities are a major problem. They are usually caused by design errors, material defects, external factors, and metal corrosion. State-of-the-art technologies allow for a substantial reduction in both the resulting losses and GHG emissions, but these are used not as frequently as they should.

Since oil production is based on a large amount of drilling and associated with huge volumes of drill cuttings, there is a great potential for reducing the carbon footprint by changing production standards in the field of drill cuttings disposal, in particular, technologies for the injection of cuttings into the reservoir for enhanced oil recovery.

[52] Reduce: Non-bio renewable August 2020International Renewable Energy Agency. https://www.cceguide.org/wp-content/uploads/2020/08/02-IRENA-Reduce.pdf

The utilization of new technologies allows for the use of secondary energy products produced in the technological process.[53] Many technological processes are accompanied by the release of large amounts of unused heat, which is dissipated into the atmosphere. Its utilization with the use of new technologies is becoming a promising topic for development. Work on the utilization of low-potential heat is being carried out in many countries. More traditional approaches use a technology based on the Organic Rankine Cycle (ORC) for this purpose. Co-generation is another heat application field – this technology allows the heat obtained in electricity generation to be used in production, refining, and chemical and technological operations. ExxonMobil uses co-generation at the company's refineries, which helps avoid the emission of 6 MT of GHG annually.[54].

Reuse

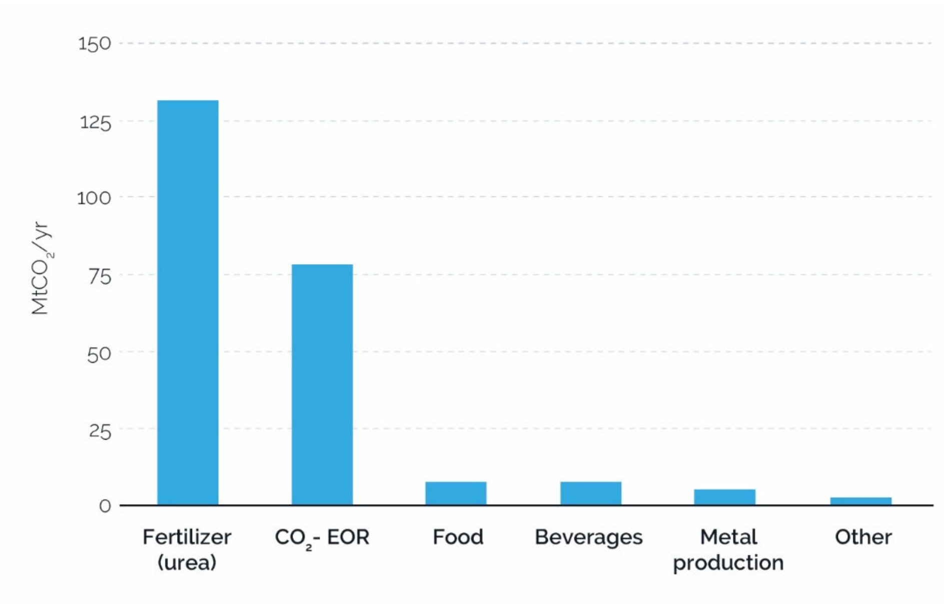
This category comprises trapped CO_2 reuse methods. In addition to the well-elaborated methods of CO_2 use in food and beverage production, cooling, fire extinguishing, water treatment, healthcare, fertilizer production, and enhanced oil recovery (EOR), more scalable technologies for the production of synthetic fuels, chemicals, and CO_2 use in the construction industry are evolving. CO_2 reuse may play a major part in the circular carbon economy by transforming waste into valuable products and reducing the carbon footprint.

The current commercialized technologies of modified and unmodified carbon dioxide reuse allow the use of a rather low CO2 volume of up to 270 MtCO2 annually by 2025.

According to the IEA, fertilizer production, followed by EOR and food, beverage, and metal production enabled the use of approximately 230 $MtCO_2$ annually in 2015 (see Fig. 14).[55] If the current trend persists, we can expect a slight increase in CO_2 use of up to 270 Mt a year by 2025. New technologies for turning CO_2 into fuels (synthetic methane, synthetic liquid fuels, synthetic methanol), chemical agents (chemical intermediates, polymers, soda ash, and baking soda), and construction materials (CO_2-cured concrete, construction aggregates) are the most promising and might have the greatest impact.

[53] Energy Statistics Manual. IEA, Paris, 2005. https://webstore.iea.org/download/direct/746
[54] https://corporate.exxonmobil.com/Energy-and-environment/Tools-and-processes/Energy-efficiency/Avoiding-6-million-metric-tons-per-year-of-greenhouse-gas-emissions-through-cogeneration
[55] IEA (2020) Reuse: Carbon Reuse. G20 Circular Carbon Economy Guide Report https://www.cceguide.org/wp-content/uploads/2020/08/04-IEA-Reuse.pdf

Fig. 14 - Breakdown of global demand for CO2, 2015



Source: IEA (2020) Reuse: Carbon Reuse. G20 Circular Carbon Economy Guide Report https://www.cceguide.org/wp-content/uploads/2020/08/04-IEA-Reuse.pdf

CO2 reuse technologies are not only capable of reducing emissions but of making the products net carbon negative, e.g., Net Carbon Negative Oil.

Of note, EOR is capable of not only reducing the carbon footprint of produced oil but also of making it net carbon negative oil (NCNO)[56], by using the non-fossil CO_2 source, when the quantity of CO_2 that is stored exceeds the emissions from production and subsequent burning of the oil itself throughout its life cycle.

The new promising technologies making use of high energy-intensive chemical and biological processes for CO_2 transformation are the production of synthetic fuels (synthetic methane, synthetic liquid fuels, synthetic methanol), chemical agents (using carbon from carbon dioxide, such as chemical intermediates, polymers, soda ash, and baking soda), and new construction materials (CO_2-cured concrete, construction aggregates), as well as super-critical CO_2 applications (e.g. upgraded Brayton and Rankine cycles, Allam power cycles) and, of course, CO_2-enhanced water recovery.

Recycle

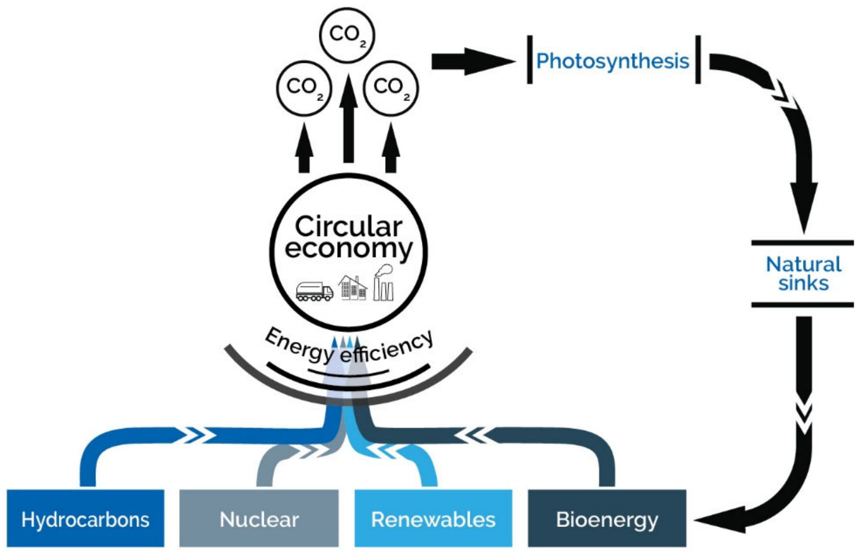
A number of technologies, including bioenergy use together with carbon capture and storage (BECCS), may be included in the recycle section.[57] Use of bioenergy is also viewed as a part of circular carbon economy, in terms of the natural carbon cycle

[56] Núñez-López V., Gil R., González-Nicolás A., Hovorka S. Carbon Balance of CO_2-EOR for NCNO Classification // Energy Procedia. 2017. 114:6597-6603. DOI: 10.1016/j.egypro.2017.03.1803 https://www.researchgate.net/publication /319194859_Carbon_Balance_of_CO_2_-EOR_for_NCNO_Classification; Núñez-López V., Gil R., Hosseininoosheri P., Hovorka S. Final report: Carbon Life Cycle Analysis of CO_2-EOR for Net Carbon Negative Oil (NCNO) Classification work performed under agreement DE-FE0024433. https://www.researchgate.net/publication/336375814_FINAL_REPORT_Carbon_Life_Cycle_Analysis_of_CO2-EOR_for_Net_Carbon_Negative_Oil_NCNO_Classification_WORK_PERFORMED_UNDER_AGREEMENT_DE-FE0024433

[57] Some sources refer BECCS to the Remove section of CCE, e.g., Saudi Aramco https://www.ief.org/_resources/files/events/1st-ief-irena-seminar-on-renewable-and-clean-energy-technology-outlooks/ahmad-al-khowaiter.pdf

(so-called living carbon).[58] The application of photosynthetically grown biomass with the involvement of CO_2 already available in the atmosphere does not result in a net addition of carbon to the atmosphere until the new biomass growth has surpassed the already captured volume (see Fig. 15). Thus, the substitution of biofuel for hydrocarbons allows for maintaining the constant atmospheric CO_2 concentration while reducing the hydrocarbon-based carbon quantity.

Fig. 15 - Adding "recycle" to the circular carbon economy



Source: CCE Guide Overview.

The use of biofuels in refining is also of great interest; oil to be processed at conventional refineries may not only be produced from subsoil but also synthesized as bio-based oil. For instance, algae-based oil can potentially be processed at ordinary refineries into a fuel that does not differ from the convenient, energy-intensive diesel fuel. Algae-based oil also has the potential to become a raw material for the chemical industry.

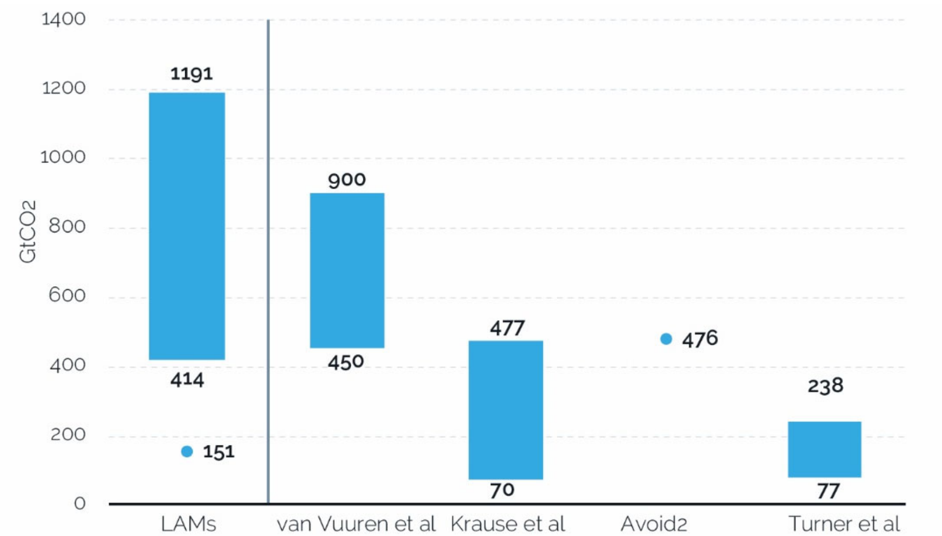
This technology has not yet been commercially approved.[59] However, Total, for example, is going to transform the Grandpuits refineries into bio-refineries in 2024. The investment is estimated at more than €240-300 million. La Mede refinery has already been transformed into a bio-refinery. The following processes will be implemented at bio-refineries: production of renewable diesel fuel intended foremost for the aviation industry, bioplastic production, plastic processing. Meanwhile, oil refining on the platform is to be terminated in Q1 of 2021, and the refined product storage is to be finished in late 2023.[60]

[58] A guide to the circular carbon economy (CCE), CCE Guide Overview, King Abdullah Petroleum Studies and Research Center, August 2020, https://www.cceguide.org/wp-content/uploads/2020/08/00-CCE-Guide-Overview.pdf
[59] https://corporate.exxonmobil.com/Research-and-innovation/Advanced-biofuels/Advanced-biofuels-and-algae-research
[60] https://www.total.com/media/news/actualites/energy-transition-total-is-investing-more-than-eu500-million-to-convert-its

Phillips 66 is re-equipping its 120,000 bbd refinery in Rodeo, CA for the manufacturing of renewable fuel types. The bio-refinery will produce 2.5 Mt of renewable diesel fuel, renewable gasoline, and "pollution-free" kerosene-type jet fuel. The refinery will use vegetable oil, fats, and soybean oil.[61]

Bioenergy combined with carbon capture and storage (BECCS) is, in turn, the negative emissions technology. If bioenergy uses carbon capture and storage, it leads to negative emissions with the potential ranging from 3 $GtCO_2$ to 7 $GtCO_2$ per year by 2050, according to different estimates.[62] The estimate of BECCS use potential through the year 2100 varies significantly (see Fig. 16).

Fig. 16 – Estimate of BECCS use potential through 2100



Sources: Analysis: How 'natural climate solutions' can reduce the need for BECCS, Zeke Hausfather, https://www.carbonbrief.org/analysis-how-natural-climate-solutions-can-reduce-the-need-for-beccs (Left) Cumulative BECCS deployment in IAMs limiting warming to below 1.5 ˚C in 2100 by SSP, based on data provided by Rogelj et al. (2018). The AIM SSP1 scenario is shown as a dot outside the IAMs range to emphasize that it is the only model showing values below 400 GtCO2. (Right) Range of estimated BECCS potential in the literature from van Vuuren et al. (2013), Krause et al. (2018), Avoid2 (2015), and Turner et al. (2018).

Studies also note that a large-scale BECCS application may have significant impacts on freshwater use, land-system change, biosphere integrity, and biogeochemical flows.[63] In turn, if more biomass is grown than is used (e.g., forests and other natural sinks), such carbon storage technologies belong to the remove category.

[61] https://www.spglobal.com/platts/en/market-insights/videos/market-movers-americas/101920-us-midstream-2020-elections
[62] A guide to the circular carbon economy (CCE), CCE Guide Overview, King Abdullah Petroleum Studies and Research Center, August 2020, https://www.cceguide.org/wp-content/uploads/2020/08/00-CCE-Guide-Overview.pdf
[63] Biomass-based negative emissions difficult to reconcile with planetary boundaries Vera Heck 1,2 *, Dieter Gerten, Wolfgang Lucht and Alexander Popp, https://www.nature.com/articles/s41558-017-0064-y.epdf?sharing_token=LQpMwJif5MfWzXReOI9O8NRgN0jAjWel9jnR3ZoTv0OkhNv1HkUO82XZFYuXtY4gRoeX9acWvFM5DD025Q-fmDCjOnJ_tHvkGivOnGvYGLohl-SfXVi18RfeBBmCtXKunTPoi8AJAiaw6e5EuXyd7Jl9R47Uy6UwcdVj4bykFC3gIGtKiAc-Cf0goSVMbvMT56nVrdp7jev4dRKHuQhBqe7jKQBvWNi6Kf1HQKi5DQ1nWcSbNHjRzPb8GxlntzcOG2ZbdIbYAlKkuBjVeZ85QnfJTAWnL_QlLr9p5An6vOZKOw3dGOLj9iTuEwCAzpjn&tracking_referrer=www.carbonbrief.org

According to the IRENA report, the use of rapidly evolving modern bioenergy technologies may increase by almost five-fold by 2050.[64] To achieve climate goals, the use of the currently most common conventional bioenergy types must be gradually discontinued.

Remove

Natural carbon sinks, carbon capture technologies, direct air capture (DAC), EOR,[65] and CCS belong to the remove category. According to GCCSI estimates, 260 $MtCO_2$ are being constantly stored in geological formations, and the underlying underground storage technologies are constantly developing.[66] Natural carbon sinks are becoming important, but in no way fundamental, retention methods for accumulated carbon and, compared with geological storages, retain carbon for a shorter period because the accumulated carbon can be quickly released into the atmosphere, e.g., as a result of fires.

Energy efficiency

The efficient use of energy resources by oil and gas companies is one of the cheapest methods for reducing GHG emissions..

The efficient use of energy resources by oil and gas sector enterprises is one of the cheapest method for reducing GHG emissions. The monitoring of energy indicators to identify potential energy efficiency improvement areas is the first step in this direction. It is necessary to take into account the irregularity of specific energy consumption indicators at different oil and gas fields and oil and gas sector enterprises in general. These indicators depend on a number of factors, including the specific features of production, collection, and processing of hydrocarbon raw materials.[67]

The most common methods for enhancing the energy efficiency of oil and gas production facilities are:

- an increased amount of energy efficient equipment,
- investments in energy efficient technologies,
- the replacement of APG flaring with its use as an energy resource,
- converting existing power plants to cogeneration, and
- the improvement of energy efficiency in the operational business through energy management systems, modernization and digitalization.[68][69]

For individual equipment types, the appropriate energy efficiency improvement methods are applicable. For instance, to increase energy efficiency of boiler rooms that supply heat to oil

[64] International Renewable Energy Agency, 05. Recycle: Bioenergy https://www.cceguide.org/wp-content/uploads/2020/08/05-IRENA-Recycle.pdf
[65] EOR can also be regarded as the reuse method.
[66] Remove: CCS and DAC, the GCCSI reports https://www.cceguide.org/wp-content/uploads/2020/08/06-GCCSI-Remove.pdf
[67] https://www.itm-power.com/item/37-shell-rheinland-refinery-update
[68] https://europetro.com/media/2018/4-ways-oil-gas-companies-can-improve-energy-efficiency
[69] https://www.iea.org/reports/energy-efficiency-2019

and gas enterprises, water can be pre-treated, smoke gas analyzers can be used, smoke gases resulting from leaks can be reduced, excess air can be decreased, insulation can be improved, and regular maintenance and thermal energy recovery can be carried out. Increased energy efficiency of heat exchangers can be achieved through regular maintenance, cleaning, inhibitor application, and surface coating.[70]

Major oil and gas companies' resolutions to improve energy efficiency also include the use of thermal energy for the heating, the construction of co-generation plants for the supply of electricity to urban areas and the use of combined-cycle power plants instead of the conventional generating plants. Such methods allow for the recovery and use of the energy that would be otherwise emitted to the atmosphere as greenhouse gases.

Electricity consumption can be reduced by the preliminary identification of instances of inefficient electricity use, which is enabled by online tools that monitor energy efficiency improvements and were implemented, for example, at production facilities in Nangang and Zhapu (China) and at Shell's lubricant plant in Tianjin.

Total has implemented the innovative energy efficiency enhancement project Dual Internally and Externally Structured Tube for Air Coolers (DIESTA), which is used for gas liquefaction coolers.[71]

Aramco is channeling long-term investments into reducing APG flaring, enhancing recovery projects, reducing the use of liquid hydrocarbons for electricity generation in summer, and shifting to gas fuel as part of its energy efficiency enhancement strategy. Co-generation, i.e., the generation of thermal energy and electricity, and the use of the heat resulting from the plant operation for subsequent use of the thermal energy, is one of the energy efficiency enhancement methods. Reductions in fuel burning volumes, which would be necessary for heating the facilities, help curtail the GHG emissions.[72]

Greater energy efficiency in marine projects includes projects to downsize gas turbines to operate at higher levels than the average equipment workload, to reduce the number of gas turbines and reallocate the workload to the available turbines, and to use higher-efficiency small turbines and the thermal energy resulting from gas compression.[73] An important aspect of

[70] http://www.oil-gasportal.com/practice-and-technology-and-measures-for-improving-energy-efficiency-in-the-chemical-and-petrochemical-sector/
[71] https://www.total.com/energy-expertise/exploration-production/oil-gas/innovating-produce-tomorrows-oil-and-gas
[72] https://www.aramco.com/en/creating-value/sustainable-business-operations/energy-efficiency
[73] https://pubs.spe.org/media/filer_public/21/e3/21e3c337-7bf1-4d6d-9958-90a1730c437a/20_pr169811.pdf
https://www.bakerhughes.com/company/news/baker-hughes-lm9000-confirmed-worlds-most-efficient-simple-cycle-gas-turbine-after

improving energy efficiency is the reduction of fuel gas consumed by compressor stations on the gas pipelines.

Working with counterparties to reduce their GHG emissions

Oil and gas companies usually have a large number of subcontractors and suppliers of equipment, materials and services. Collaboration and systematic work with them aimed at GHG emissions reduction throughout the whole supply chain can provide a noticeable reduction in the oil and gas companies carbon footprint. For this purpose, tendering procedures are often used that introduce additional parameters and requirements for suppliers in terms of the carbon footprint of their products and services.

Effective methane and APG monetization

The monetization of gas (methane and APG) instead of its emissions and unproductive flaring is a very efficient and economically attractive way to reduce GHG emissions, specifically, through gas re-injection, gas utilization as a raw material for internal electricity generation needs, gas processing in mini-plants into compressed natural gas, LHG, gas into liquid, LNG, development of petrochemicals, etc.

Flaring reduction and utilization of APG

Associated petroleum gas (APG) is a mixture of gaseous hydrocarbons, which is dissolved in oil but may sometimes accumulate as a gas "cap" on top of an oil formation.[74] APG is a multi-component gas that comprises methane, ethane, propane, butane, and other hydrocarbons. Due to significant methane content, APG flaring is more advantageous than atmospheric emissions (as CO_2 is 28x less noxious than methane as a GHG).

APG atmospheric emissions and flaring lead to noticeable increases in GHG emissions. To address this problem, a wide range of technologies is available, from the use of APG trapped in a well to its use as a feedstock for the petrochemical industry.

Therefore, APG flaring is still wide-spread and driven by operation-related, safety-related, and economic reasons.[75]

The global APG flaring peaked at 171 BCM in 2005 and the lowest APG flaring level came to 134 BCM in 2010 (Fig. 17). Due to global efforts and initiatives (like the World Bank Group's Zero Routine Flaring by 2030 initiative,[76] the Global Gas Flaring Reduction Partnership - GGFR,[77] etc.), APG flaring has dropped by 9% worldwide since 1996, even though oil production has grown by 33% over the same period. In 2019, approx. 150 BCM natural gas was flared worldwide, which is a bit more than in previous years and equal to the gas demand of the entire African continent. This resulted in the emissions of approx. 275 $MtCO_2$ and the emissions of methane and other GHGs, such as black carbon and nitric

[74] http://www.avfinfo.ru/engineering/e-06/
[75] https://www.iea.org/reports/flaring-emissions
[76] https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030
[77] https://www.worldbank.org/en/programs/gasflaringreduction

oxide. This amounts to slightly more than 5% of the total CO_2 emissions from oil and gas sector operations.[78]

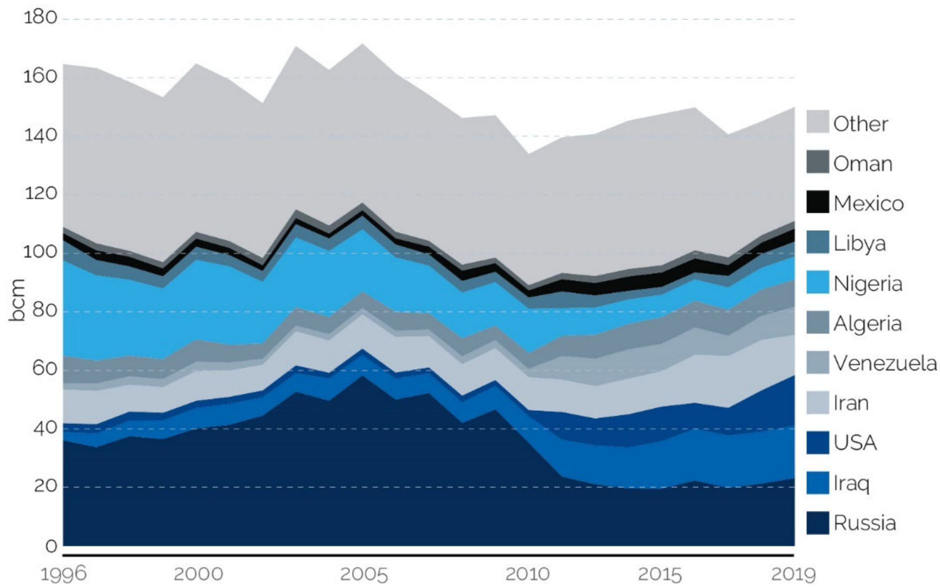
Fig. 17 - APG flaring volumes worldwide

Source: Global Gas Flaring Tracker Report JULY 2020, Global Gas Flaring Reduction Partnership,
https://www.worldbank.org/content/dam/photos/419x440/2016/oct/flaring_data.JPG, https://ngdc.noaa.gov/eog/interest/gas_flares.html

During the last two decades, the most significant reduction in APG flaring occurred in Russia and Nigeria. After 2010, the growth in APG flaring renewed, largely due to the increase in shale oil production in the U.S. In 2019, Russia, Iraq, Iran, Venezuela, and the U.S. accounted for more than half of worldwide APG flaring (Fig. 18).

[78] https://www.iea.org/reports/flaring-emissions

Fig. 18 - APG flaring volumes, by countries



Source: Global Gas Flaring Tracker Report JULY 2020, Global Gas Flaring Reduction Partnership, https://www.worldbank.org/content/dam/photos/419x440/2016/oct/flaring_data.JPG, https://ngdc.noaa.gov/eog/interest/gas_flares.html

In order to reduce flaring, projects to utilize APG are being implemented worldwide. They are driven both by the commitments imposed on the subsoil users by the regulators and by the voluntary commitments of the oil and gas companies to reduce their GHG emissions. The problem with APG utilization is related to the lack of infrastructure access and the need for substantial upfront investment. If the field development project does not include access to the natural gas transportation network, the field operator has just two options left: the use of APG for internal needs or gas re-injection. Field tests of a number of APG utilization technologies have proven viable, but in essence the flaring problem is also an issue related to business models. If no conditions for productive gas use are envisioned at the project planning stage, including the necessary gas infrastructure, finding a technological solution later on will be a more challenging problem.[79]

There is a number of APG utilization technologies that have already passed, or are undergoing, commercial testing.

1. Natural gas compression and transportation at short distances for use as fuel during operations in the oil fields. Gas can be compressed in a cluster and transported to a gas processing facility or to a location where it can be used as fuel. This technology can be applied in the wells located near a processing facility or elsewhere where the gas can be fed into the pipeline system (30-40 km, or less). The U.S. Environmental Protection Agency studied the possibility of compressed natural gas transportation in Western North Dakota and determined that

[79] https://www.iea.org/reports/flaring-emissions

at least 89% of gas flared in one district can be trapped using this technology.[80] GE and Ferus NGF tested the system for Statoil in the Bakken Shale, which they call the "Last Mile Filling Solution" because gas can be transported from the wellhead to the gasoline tank, without the need to lay down pipelines. It combines the GE CNG in a Box technology with the Ferus oilfield logistics for compressed natural gas delivery for power devices, car fleets, electric generators, and other equipment.[81] Certarus offers a similar portable solution for CNG compression and transportation, the Virtual Pipeline. The technology includes gas compression in the field and its subsequent transportation in tanks and containers for the oil company's internal needs.[82]

2. NGL extraction from APG before the remaining methane burning (partial solution). NGL can be removed from associated petroleum gas with mobile equipment and transported for sale. Such systems are most appropriate when the APG volume is high. Dry gas remaining after NGL extraction can be compressed into CNG and used for car fueling or electricity generation. The commercial systems that can trap the C_5 fraction and heavier hydrocarbons are simple and inexpensive, but they do not allow for reducing the associated gas flaring significantly. The technologies that trap the C_3 and C_4 fractions can trap most of the gas and result in smaller-scale flaring but require significant initial investments. A combination of this method with the first one (methane compression in CNG) seems to be the most efficient method. For instance, there are mobile APG processors, such as Flarecatcher™ from Pioneer Energy, with a capacity of between 40 and 5,000+ cubic feet daily, which extract NGL from associated petroleum gas and deliver dry gas to be used in electricity generation or for transformation into CNG or LNG.[83]

3. Electricity generation by small generators from APG. Different technologies, including piston engines and gas turbines, are available for electricity generation on site. Local systems operate at their best when dried APG is used (e.g., residual gas after NGL extraction). Capstone Turbines offers portable gas micro-turbine generators for gas-to-energy transformation.[84] CompAp elaborated a dual-fuel system that combines natural gas and diesel fuel for electricity generation using flare gas.[85] Gulf Coast Green Energy and ElectraTherm, in partnership with Hess, tested the ElectraTherm Power + Generator™, a technology of distributed exhaust heat-to-energy transformation, in an oil well in North Dakota, on reducing oil and gas flaring[86].

[80] Clean Air Task Force, "Putting Out the Fire: Proven Technologies to Improve Utilization of Associated Gas from Tight Oil Formations," November 17, 2015.
[81] https://www.ge.com/news/reports/taming-north-dakotas-gas-flares
[82] https://certarus.com/virtual_pipeline.php
[83] https://www.pioneerenergy.com/products
[84] https://www.capstoneturbine.com/
[85] https://www.comap-control.com/solutions/application/power-generation-from-flared-gas
[86] https://gulfcoastgreenenergy.com/waste-heat-to-power-projects/flare-gas-to-power/

4. Mini plants for gas-to-methanol or gas-to-liquids conversion. There are GasTechno® systems for the production of methanol or gas liquefaction products (e.g., high-quality diesel fuels), or the Primus Green Energy modular systems for the flare gas-to-methanol or fuel conversion, or compact module technologies for gas-to-liquid conversion from Compact GTL.[87]

5. APG transformation to LNG and its transportation over short distances for use as a fuel for oilfields. Gas can also be liquefied and transported in trucks to the site where it can be used as a fuel for cars or for electricity generation. This method is appropriate when gas does not require high purification. Galileo Technologies, in partnership with SPATCO Energy Solutions, supplied such a solution for Terra Energy in the Bakken Shale field, in order to integrate the flare gas capture and LNG production directly in the wellhead.[88] Primus Green Energy's developed modular systems for processing APG into methanol.[89]

6. Enhancing the efficiency of existing flaring reduction technologies. EcoVapor Recovery Systems, LLC offers a technology to trap vapors from condensate tanks, which cannot be trapped by the existing plants and which contain oxygen, and also the use of a patented catalyst system extract marketable gas.[90]

Digital innovations offer a cost-effective means to enhance flaring efficiency. The flare.IQ Advanced Flare Control and Digital Verification solution from Baker Hughes business, Panametrics, reduces methane emissions, ensures high-efficiency flare combustion, and reduces steam usage in flare systems, while flare meter digital verification functionality enables operators to collect data on gas composition and process pressure and temperatures safely, efficiently, and cost-effectively, to support ongoing efforts to further optimize and reduce flaring.[91]

Even though many of these process solutions have been technologically tested, many of them have never become widespread because of their non-profitability. Capital expenditures (CapEx) for equipment installation (or equipment rent) plus operating costs are commonly too high. In this case, the main incentive for APG utilization is regulation. For instance, Norway became one of the first countries to introduce APG regulation in 1993, specifically the requirements to account for flared APG and to impose taxes on CO_2 emissions from APG flaring. As a result, APG flaring volumes have dropped by more

[87] https://gastechno.com/gallery-mini-gtl.html
[88] https://www.galileoar.com/us/historias/distributed-lng-production-galileo-flare-reduction-solution-for-bakken-shale-2/
[89] https://www.primusge.com/application/flared-associated-gas/
[90] https://www.ecovaporrs.com/
[91] https://www.bakerhughesds.com/measurement-sensing/panametrics-flow-measurement/process-flow-measurement/ultrasonic-flare-gas-and-steam-flow-meters
https://neftegaz.ru/news/vtrende/482649-upravlenie-vybrosami-metana-kak-tekhnologii-mogut-pomoch-neftegazovoy-otrasli-poluchit-dopolnitelnyy/

than 60% since 1990. Many countries followed Norway's example. Governments and oil companies that support the Zero Routine Flaring by 2030 initiative are committed to annually reporting APG flaring volumes and the progress made towards achieving the initiative's goal to the general public. The data is aggregated by the World Bank.[92]

The utilization of APG is not only useful in environmental terms but also allows for the sale of the "collected" raw materials and deriving of profits from their processing and sale. For instance, in the U.S., the process of NGL extraction from APG is, at minimum, paid back, and, in favorable market conditions, can earn up to $89 per non-emitted $MTCO_2$. APG in electricity generation yields$30-200 in profit per non-emitted $MTCO_2$. APG as car fuel allows for compensation of the technology costs and, in favorable market conditions, can earn up to $160 per non-emitted $MTCO_2$ (Table 4).

Table 4 - Comparison of APG utilization technologies

	Emission reduction costs, $/MT of CO_2e.
NGL extraction, including	
C5 + extraction	0-21
C3 + extraction	0-89
Electricity generation, including	
Piston compressor	165-194
Gas turbine	33-54
CNG for transport, including	
High gas content	0-53
Low gas content	107-159

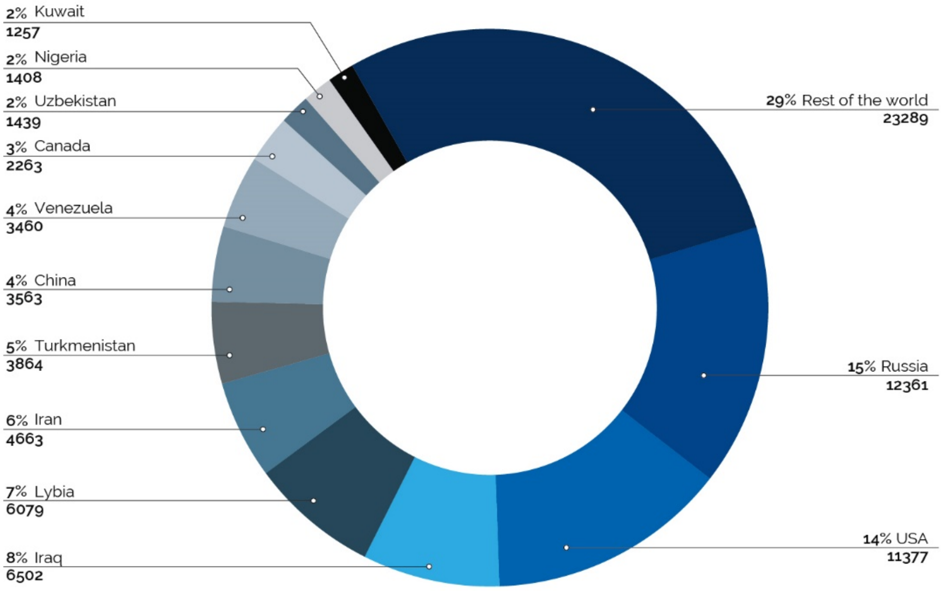
Source: Putting Out the Fire: Proven Technologies to Improve Utilization of Associated Gas from Tight Oil Formations, LESLEY FLEISCHMAN, RESEARCH ASSOCIATE, NOVEMBER17, 2015.

Methane leaks reduction

Methane emissions accompany the production, collection, preparation, transportation, and processing of hydrocarbons. Special attention is paid to this greenhouse gas because of how significantly it contributes to climate change. Its climate impact is 28x greater than that of carbon dioxide, and the aggregate contribution of methane to global warming accounts for 25%.[93][94] Approximately 13% aggregate methane emissions come from the oil and gas sector.[95] Figure 19 shows the methane emission structures by countries as of 2019.

[92] https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030#:~:text=This%20%E2%80%9CZero%20Routine%20Flaring%20by,perspective%2C%20and%20who%20agree%20to
[93] https://oilandgasclimateinitiative.com/investment-call/
[94] https://www.euractiv.com/section/climate-environment/opinion/eus-climate-credibility-rests-on-tackling-methane-emissions-from-gas/
[95] https://www.shell.com/energy-and-innovation/natural-gas/methane-emissions/_jcr_content/par/textimage_438437728.stream/1587995196996/53beef2f8ba2e90560c074f56552e2acfe30582b/shell-methane-case-study.pdf

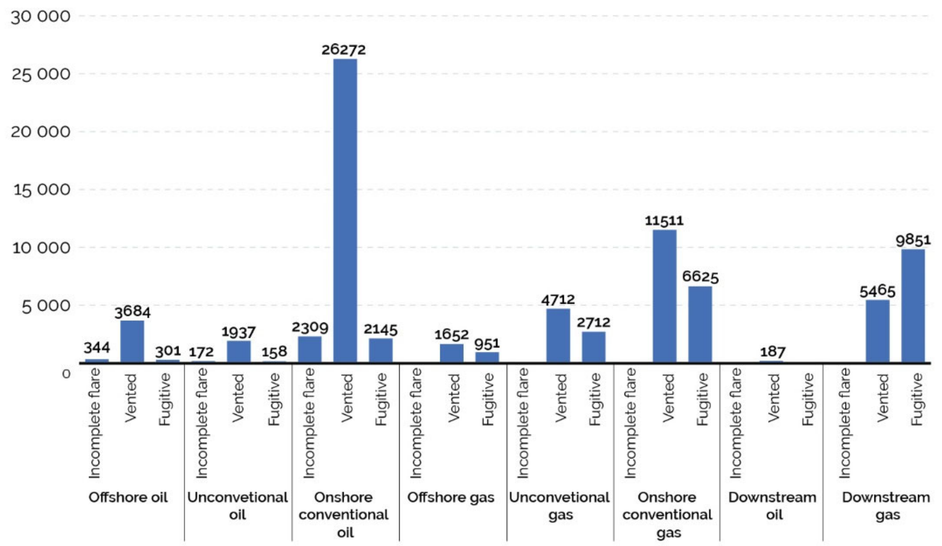
Fig. 19 - Global methane emissions by countries



Source: International Energy Agency, 2019.

Methane is emitted into the atmosphere as a result of an array of process flows that are typical of the oil and gas sector. These include the operation of various ventilation systems, dissipation of APG and its incomplete burning, pipeline blowdowns, compressors, wells, leaks caused by faulty sealing and poor securing of the equipment, and gas depressurization before repairs and emergencies (Fig. 20).[96]

Fig. 20 - Sources of methane (CH4) emissions



Source: International Energy Agency, 2019.

Methane emissions from the upstream sector of the oil and gas industry are caused by well development, when natural or associated petroleum gas that comprises mostly methane is depressurized. The maximum methane emissions are recorded

[96] http://onefuture.us/wp-content/uploads/2018/05/ONE-Future-Supplemental-Technical-Information.pdf

as a result of dissipation when conventional hydrocarbons are produced. Operation of an oil and gas field includes the collection, preparation, and transportation of hydrocarbon fuel. Such operations may be accompanied with methane emissions and leaks that are triggered by technological issues and accidents. For instance, natural or associated petroleum gas can be depressurized to ensure the industrial safety of hazardous production facilities in preparation for repairs. Occasional emissions via non-airtight gas producing equipment and wells are also likely. All these give rise to methane emissions.

Abandoned, or suspended, wells are another source of methane emission. Though this problem is not yet widely covered, there are already a number of studies showing that wells, especially gas wells, continue to emit methane even after their period of operation has ended. In 2016, one such study on 88 suspended wells in Pennsylvania published that 90% of them had methane leaks.[97] German scientists have found bubbles of methane on the seabed around abandoned wells in the North Sea. Having directly measured 43 wells, they found significant methane leaks at 28, or 65%, of the studied wells.[98] In Alberta, researchers estimated that there were methane leaks at nearly 5% of the province's 315 000 oil and gas wells. In the U.K., researchers found fugitive methane emissions at 30% of the 102 wells studied.[99]

In the midstream sector, GHG emissions coming from oil pipelines are significantly less than those coming from the gas pipelines. For instance, in Canada, GHG emissions from oil pipelines account for just 1% of total GHG emissions.[100] Emissions mostly originate from oil storage tanks. The pipeline system operators use the below methods and technologies.[101]

To prevent methane leaks, they must first be identified. Then, the equipment should be modified and gas utilisation should be increased.

The transportation, storage, and distribution of gas are associated with methane emissions due to its incomplete burning for industrial safety, gas leaks caused by non-airtight equipment, and depressurization during repairs in gas pipelines, gas fuel accumulation, and distribution containers. Methane emissions are also possible when gas fuel is incompletely burned when it is directly used in gas-fueled engines and also when other household and industrial equipment is operated. A significant scope of methane emissions occurs in preparation for repairs as overhauling and current repairs necessitate depressurization of the entire gas volume from the compartment

[97] https://www.pnas.org/content/pnas/111/51/18173.full.pdf
[98] https://www.bloomberg.com/news/features/2020-09-17/abandoned-gas-wells-are-left-to-spew-methane-for-eternity
[99] https://theecologist.org/2017/jul/26/one-third-british-columbias-oil-and-gas-wells-are-leaking-significant-levels-methane
https://www.nytimes.com/2020/10/30/climate/oil-wells-leak-canada.html
https://thetyee.ca/News/2017/04/26/acp-2017-109.pdf
[100] https://www.aboutpipelines.com/en/environmental-protection/climate-change/
[101] https://cepa.com/wp-content/uploads/2020/05/2020_Climate-Change_ENG.pdf

being repaired. Storage of raw hydrocarbons in containers and tanks is also associated with methane atmospheric emissions.

For gas, not all assets are equal in the midstream sector: pipeline gas transportation produces less GHG than LNG. Due to the fact that gas liquefaction usually consumes about 7-9% of the volume of methane, which must be completely cleaned of CO_2 impurities, GHG emissions from LNG are usually greater than those from pipeline transportation. Indeed, according to various sources, GHG emissions from LNG exports from the U.S. to Central Europe are much higher than those from natural gas exports via pipelines.[102][103]

Oil and gas treatment and processing also give rise to methane emissions due to incomplete burning and other fuel use types, as well as due to leaks caused by seal failure and unplanned breaks of oil and gas processing equipment.[104]

According to the IEA, oil and gas companies could achieve a 75% reduction in methane emissions with currently available technologies.[105]

The detection and elimination of methane leaks, reconstruction and replacement of high methane emissions equipment, and reduction in raw hydrocarbon dissipation and burning volumes are the key methods for reducing methane emissions. The international practice of methane emission data collection and processing provides for taking stock of and accounting for CH_4 emissions that are typical of some processing equipment (vent and blowdown systems, flare device pipes, and storage facilities for liquefied natural gas from pneumatic pumps, exhaust valves, centrifugal compressors, gas vents, etc.).[106]

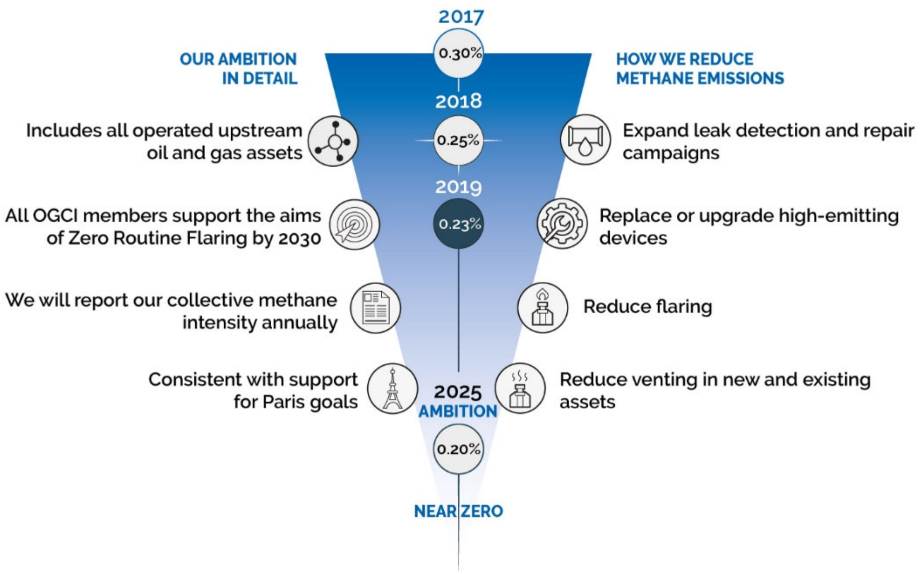
Detected faulty sealing and poor tightness, which lead to methane emissions, can often be eliminated by maintaining equipment, improving diagnoses, and defectoscopy. To eliminate the organized emission sources, depressurization, or dissipation as a result of process flows, separate process solutions must be elaborated: the use of systems for collection of this gas and its return to the production process. The comprehensive efforts aimed at preventing the emergencies, which include compliance with industrial safety, proper and timely maintenance of pressure equipment, will help avoid unforeseeable and emergency situations, with significant methane emissions.

[102] https://www.europeangashub.com/wp-content/uploads/attach_795.pdf
https://www.iaee.org/eeep/eeepexec/eeep82_shaton_ExecSum.pdf
[103] Wood Mackenzie, LNG versus pipeline gas: how do lifecycle emissions compare? 2017.
[104] Methane's role in climate change, edited by Prof. A.G. Ishkov, Ph.D. in Chemistry, NIIPE, 2018. http://www.vernadsky.ru/files/Publishing/rol_metana_v_izmenenii_klimata.pdf
[105] https://www.euractiv.com/section/climate-environment/opinion/eus-climate-credibility-rests-on-tackling-methane-emissions-from-gas/
[106] Regulation of accounting and reporting on methane emissions for oil and gas companies in Russia ad new rules of greenhouse gas emissions in the United States. I.G. Gritsevich, E.A. Kutepova, Moscow 2009. https://wwf.ru/upload/iblock/681/methane_reg_rus_us.pdf

Many international oil and gas companies declare their intention to follow the "zero methane emissions" strategy.

Most of the leading international oil and gas companies, including BP, Equinor, ENI, Shell, and Total, declared intentions to follow the "zero methane emissions" strategy, whereby only 0.2% of emissions per unit of produced gas coming from methane must be achieved by 2025, thus ensuring the annual reduction of emissions at 350,000 MT of methane per year.[107]

Fig. 21 - OGCI Initiative on methane emission reduction



Source: https://oilandgasclimateinitiative.com/action-and-engagement/provide-clean-affordable-energy/#methane-target

Leading foreign oil and gas companies have begun implementing various technologies intended to reduce methane leaks and emissions. For example, Shell introduced the EcoVaporZERO2 technology at Shell fields in the Permian basin of western Texas (U.S.), which resulted in a 32 MT methane burning reduction in 2018. In this ZERO2 technology, oxygen is depressurized, which makes the gas in compliance with the standards adopted for a commodity gas.[108] In addition, at the Shell facility, Appalachia, four pumps fed by gas fuel were replaced with electric pumps, which helped reduce GHG emissions by 625 MT. The Shell Groundbirch Project in Canada provides for a reduction in methane emissions from the operated gas wells by using electric power drives, instead of the previously used tools, to control valve operation.

The innovative approach to automatically collecting potential methane leakage data was tested at Shell's Oman-based liquefied natural gas plant in 2018. Digital stocktaking helps detect potential methane leaks and apply them to 3D maps. Thermal cameras and sensors installed in unmanned aircrafts, quadcopters, are used for the same leak detection purposes. For instance, in the Permian Basin, where Shell operates 500 sites

[107] https://oilandgasclimateinitiative.com/oil-and-gas-climate-initiative-sets-first-collective-methane-target-for-member-companies/
[108] https://www.shell.com/energy-and-innovation/natural-gas/methane-emissions/_jcr_content/par/textimage_438437728.stream/1587995196996/53beef2f8ba2e90560c074f56552e2acfe30582b/shell-methane-case-study.pdf

covering 500,000 acres and more than 1,300 wells, the operator recently signed a deal with Baker Hughes' drone venture company, Avitas, to help the company reach its goal of limiting emissions in its North African operations to less than 0.2% of its produced natural gas volumes by 2025. This move will improve methane leak detection through drone technology featuring optical gas-imaging cameras and a laser-based detection system.[109]

Chevron has replaced and upgraded its pneumatic meters operating continuously at onshore facilities by installing low-emitting meters or periodical operating devices.[110] When electric equipment can be used instead of gas-fueled equipment, the company opts for the former so as not to emit methane.

In 2018, Saudi Aramco introduced its comprehensive leak detection and elimination program, which enables a reduction in emissions by identifying existing leaks and preventing potential hidden leaks, the principal source of methane emissions.[111]

Project Astra in the Permian is collaboration of the University of Texas at Austin, Environmental Defense Fund, ExxonMobil, Gas Technology Institute (GTI) and Pioneer Natural Resources Company, aims to demonstrate a novel approach to measuring methane emissions from oil and gas production sites, using network of sensors that will monitor emissions across an oil and gas production region with multiple operators.[112]

Aerial surveys are another technology that is increasingly used, specifically to detect the larger methane plumes that engineers can then plug. Kairos Aerospace is one company that has experience in this field.[113] Satellite imaging, also as a technology that will increasingly get better. For instanse KAYRROS METHANE WATCH is an automated emissions surveillance system using data from the European Space Agency's Sentinel-5P satellite. Unique Kayrros algorithms detect, quantify and attribute emissions directly to their sources. Abnormal concentrations of methane are linked to assets such as oil wells or gas compression stations based on local information and satellite imagery resolution.[114]

Vapor recovery units on large tanks, methane leak reduction, and stripping gas utilization

One more source of GHG emissions within the gas sector, is stripping gas (methane). It is derived from using environmental heat to heat LNG in cryotanks (gas carriers, storage terminals, motorway or railway tank cars, car tanks, etc.). As a result, some

[109] https://pubs.spe.org/en/jpt/jpt-article-detail/?art=7576
[110] https://oilandgasclimateinitiative.com/knowledge-base/chevron-case-study/
[111] https://oilandgasclimateinitiative.com/knowledge-base/saudi-aramco-case-study/
[112] https://dept.ceer.utexas.edu/ceer/astra/
[113] http://kairosaerospace.com/society-of-petroleum-engineers-published-pioneer-natural-resources-case-study/
[114] https://www.kayrros.com/methane-watch/

of the gas evaporates. This process is natural and does not cause a problem, until the maximum permissible working pressure in the tank is exceeded. If this happens, to avoid adverse consequences, the stripping gas must be depressurized into the air or used for some other purpose.

In the LNG marine transportation sector, stripping gas losses are calculated in percentage of total cargo volume. This parameter is normally equal to 0.15% per day, which amounts to a 3% cargo loss in transportation over the standard three-week route of a tanker. Modern LNG tankers have an LNG boil-off rate (BOR) of 0.1%, or less, per day. The Indonesian tanker, LNG Ekaputra, built in as early as 1990, has a BOR of 0.1% per day.[115]

The application of a multi-layer insulation for LNG tanks reduces the volumes of stripping gas. So far, there are no 100% efficient, commercial solutions in the thermal insulation of LNG tanks. Thus, the main areas for reducing stripping gas emissions can be either reducing the percentage of cargo volume or improving the utilization rate.

Table 5 - BOR ratios for different tanker types

Tanker type	Loaded % per day	Ballast % per day
New generation tanker (135,000 m^3)	0.15	0.08
Old generation tanker (40-50,000 m^3)	0.23	0.18

Source: https://www.onthemosway.eu/wp-content/uploads/2015/06/BOIL-of-GAS.pdf

One of the most popular utilizations for stripping gas is as a fuel for a vessel's engine system. In this case, heavy fuel oil or vessel diesel fuel are used as backup fuel. Given the new requirements from the International Maritime Organization (IMO), since January 1, 2020, ship owners and operators have had to comply with the sulfur content requirement of no more than 0.5% in vessel fuel. But, such low-sulfur fuel oil is not currently manufactured. Therefore, a fresh impetus could be given to further the use of stripping gas as vessel fuel.

According to Transport & Environment, the complete emissions from using LNG as vessel fuel, subject to responsible management of potential methane emissions, may prove to be by 12-27% lower than when using fleet fuel oil or gas oil.[116] Thus, emissions resulting from gas transportation by gas carriers can be managed in two ways: improving thermal insulation of

[115] https://www.wartsila.com/encyclopedia/term/boil-off-rate-(bor)#:~:text=The%20amount%20of%20liquid%20that,a%20BOR%20close%20to%200.1%25

[116] https://www.transportenvironment.org/sites/te/files/publications/2015_02_TE_briefing_natural_gas_shipping_FINAL.pdf

cryotanks and improving gas use as vessel fuel (the latter refers to scope 3 emissions).[117]

Besides thermal insulation, tank size influences the volume of stripping gas. A large surface produces major heating and evaporation. The following LNG and stripping gas handling methods are potential options for reducing both atmospheric emissions and an operator's monetary losses. (The majority of these options is applicable for fixed LNG tanks or cryo-filling stations.)

- Cooling equipment based on the nitrogen cycle can be installed (the liquefaction temperature for nitrogen is -196 ˚C and -162 ˚C for LNG). Nitrogen evaporation will become an adverse effect of that cycle.
- Stripping gas can be supplied to the network. The pressure gradient at exit from the cryotank and entry to GTS must be compliant.
- It is critical to monitor the temperature of the gas supplied to GTS and its odorization in cases of direct supply to the utilities and household sectors.
- Stripping gas can be supplied to generating sites for heat and electricity generation.
- Compressed natural gas (CNG) can potentially be manufactured from stripping gas.

One of the still theoretical ways to handle the stripping gas onboard an LNG carrier is hydrogen production.[118]

Shifting to low carbon energy sources

Shifting to low carbon power supply sources is another important direction companies within the oil and gas sector are developing in order to reduce their GHG emissions in scopes 1 and 2. This includes both renewables combined with electricity storage and a shift to low-carbon fuel types for the transportation of produced hydrocarbons.

Using renewable energy sources

Depending on the volumes and methods of electricity consumption at individual facilities, renewables can be introduced into a company's power supply structure. This allows for fuel saving and, consequently, for reductions in GHG emissions. Moreover, it is the most appropriate method of cutting down operating costs (particularly the spending on conventional fuel types).

The use of renewables is preferable when a constant power supply is not a mandatory condition, otherwise, the use of

[117] https://www.mckinsey.com/industries/oil-and-gas/our-insights/forced-boil-off-gas-the-future-of-lng-as-a-fuel-for-lng-carriers
[118] https://www.researchgate.net/publication/340265411_Hydrogen_production_with_excess_BOG_generated_on_LNG_vessels

renewables can be implemented within hybrid power supply systems.

Leading oil and gas companies are implementing projects with renewables. They are using solar, wind, and geothermal energies and waste as energy sources to power the operation of wells, oil recovery enhancement, and marine platforms. There is a growing amount of cases where renewables are accompanied by electricity storage, which is one of the innovative solutions facilitating the introduction of renewables to the oil and gas industry's production.

Different types of renewables are suitable for individual field operation stages. As the deposit development progresses, energy consumption increases because the pressure drops and additional methods for recovering hydrocarbon to the surface must be used. The secondary and tertiary oil recovery methods require more electricity. Replacing traditional diesel-fired or gas-fired power plants by renewables will lead to significant reduction in fossil fuel consumption. The shift to electricity and the connection to the existing power grids may be the first step towards reducing fuel consumption (provided that the generation has a lower carbon footprint or that the companies purchase green electricity and use solutions based on renewables for micro-power grids).[119]

There are several areas where the application of renewables is already economically efficient for the oil and gas sector, especially when it comes to the problem of expensive delivery of diesel or other fossil fuels to remote production facilities.[120] Renewables are widely suitable for the power supply of flooding operations to enhance oil recovery. Wind energy is particularly suitable, because consistent rate of pumping water is not critical for the flooding processes. This solution is also recognized as acceptable and economically efficient for the power supply of marine platforms. The use of solar or geothermal energy may be applicable for certain regions to supply energy for production operations and for oil recovery enhancement efforts. The generated thermal energy may be channeled towards the implementation of the methods of oil viscosity reduction and the acceleration of its recovery to the surface.[121]

Taking into account the dynamic reduction in the introduction costs of local renewables, their use may decrease a company's operating costs. At facilities where continuous and smooth electricity supply is necessary, (e.g., drilling rigs, refineries, and compressor stations), the renewables can be integrated into the conventional power supply systems, resulting in hybrid power supply systems.[122]

[119] https://www.nrel.gov/docs/fy19osti/72842.pdf
[120] https://www.renewableenergyworld.com/2014/04/14/when-renewables-meet-the-oil-and-gas-industry-opposites-attract/#gref
[121] https://www.nrel.gov/docs/fy19osti/72842.pdf
[122] https://www.nrel.gov/docs/fy19osti/72842.pdf

There are obvious advantages of integrating renewables into the power supply structures of oil and gas facilities: they allow to reduce both GHG emissions and production costs and also to offset the difficulties in the regulation of the power supply during electricity consumption peaks, enhancing reliability, sustainability, and safety of electricity supply at the production site.[123]

Virtually all leading oil and gas companies are implementing renewables projects. Below there are just a few examples:

Eni is implementing projects involving next generation solar plant systems, concentrated solar power (CSP), organic photovoltaic (OPV) and luminescent solar concentrators (LSC), and inertial sea wave converters (ISWEC).

The Oman Petroleum development Miraah solar EOR project is a $600 million, 1,021 MW solar thermal plant located in South Oman. It is one of the biggest solar stations in the world. The thermal energy generated as steam here is used to increase oil recovery in the Amal field. This enables the country to redirect the natural gas saved by the project to meet growing industrial demand and allows the offsetting of 300,000 tons of CO_2 equivalent emissions annually.

For Shell, the use of solar panels in office buildings, product sale outlets, distribution terminals, processing plants, and sea platforms at company facilities in China, India, Italy, Singapore, and Switzerland is enabling the reduction of GHG emissions by 4,500 $MTCO_2$ per year.[124]

BP in Vietnam has 48.3 MW Solar Power Plant which is expected to generate 80 million kWh of electricity and reduce CO_2 emissions by 79,760 MT per annum.[125]

PetroChina promotes the commercialization of geothermal resources through the simultaneous development of oil fields and thermal fields. Jidong Oilfield completed a 2.3 million m^2 geothermal heating project in New Caofeidian City. The project is the largest single geothermal heating project in China. For the first time, it achieved zero CO_2 emissions and zero dust pollution with coal combustion, making Caofeidian the first dust-free city in the Tangshan region. The results are an annual savings of 53,600 MT of coal equivalents and a reduction of 140,400 MT in CO_2 emissions, which is equivalent to planting 500,000 trees.[126]

Equinor provides an example of the installation of wind turbines in the North Sea. The Hywind Tampen Project is an 88 MW floating wind power plant that supplies electricity to the Snorre and Gullfaks fields in the Norwegian part of the North Sea. It is

[123] https://www.sciencedirect.com/topics/engineering/renewable-energy-source
[124] https://reports.shell.com/sustainability-report/2019/sustainable-energy-future/managing-greenhouse-gas-emissions/energy-efficiency-in-our-operations.html
[125] https://www.nsenergybusiness.com/news/ja-solar-supplies-perc-modules/
[126] http://www.petrochina.com.cn/ptr/xhtml/images/2019kcxfzbgen.pdf

the world's first floating wind power plant for operation on marine oil and gas platforms.

The use of biofuels for electricity generation is also an attractive field for the oil and gas sector. This is illustrated by the projects being implemented by Eni, in particular the project of waste-to-fuel conversion at the Gela biorefinery. This is a pilot project on using solar energy and the CO_2 extracted at the Ragusa-based refinery to artificially increase growth of algae. Algae is used to purify polluted waters that are subsequently used for processing needs.

In the United States, PVs are used for the power supply of various sensors or cathode protection in pipelines. There are also projects where solar energy is used for the power supply of compressor stations in the gas pipelines. For example, Enbridge, a gas transmission operator, has started using solar power plant energy for its compressor station in New Jersey. The implementation of this project will facilitate a reduction in the compressor station's emissions by 58,500 MT during its life cycle, according to the company.[127]

Another way for oil and gas companies to reduce their carbon footprint is to use low-carbon fuels in refineries. Currently, refinery gas is the main energy source for refineries, but other higher-emission fuels, such as fuel oil or petroleum coke, are also widely used. Petroleum coke accounts for about 12% of the total energy consumption and over 15% of the total global emissions from refineries, although this data is difficult to verify, according to the IEA analysis. Petroleum coke is a residue that results from the refining of heavy crude oil and, when burned, it emits more CO_2 and other pollutants than coal. Petroleum coke is increasingly being used in refineries in China as a cheaper alternative to coal, which explains the higher emission rates at Chinese refineries compared to others.[128]

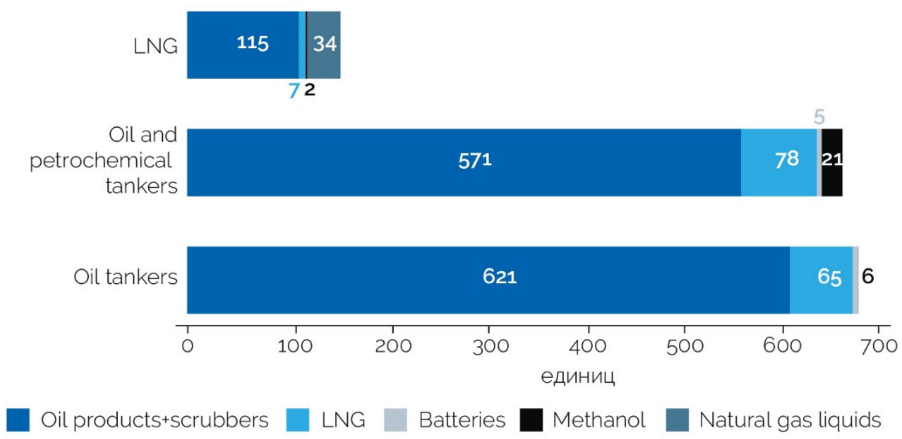
GHG emission reductions during oil and gas marine transportation by shifting to low-carbon fuel types

Currently, only 15% of tankers transporting hydrocarbons are fueled by alternative fuels, namely LNG, storage batteries, methanol, and LHG.

There were 1,500+ tankers involved in the worldwide transportation of oil, gas, refined products, and petrochemicals in 2019, according to DNV GL Alternative Fuels Insight. More than 85% of these were fueled by refined products and the rest by alternative fuels, namely LNG, storage batteries, methanol, and LHG. LNG is the most popular alternative fuel currently (Fig. 22).

[127] https://www.pipeline-journal.net/news/solar-power-station-helps-power-gas-pipeline-compressor-station
[128] WEO 2018.

Fig. 22 – Number of tankers in the oil and gas industry by type of fuel



Source: DNV GL Alternative Fuels Insight Database.

Below are the fuels regarded as alternative fuels for shipping in the long term.

Liquefied natural gas. Shell serves as an illustrious example of shifting to LNG for oil transportation. For instance, Shell Tankers (Singapore) Private Ltd. signed a long-term contract to rent a fleet of 10 dual-fuel Aframax class LNG-fueled oil tankers from Sinokor Petrochemical Co Ltd., which, in turn, is planning to construct them with Samsung Heavy Industries in South Korea in 2021. Shell separately agreed on the long-term transport of four new dual-fuel tankers for the transportation of refined products. The vessels are expected to be supplied in 2021.[129]

According to DNV GL Alternative Fuels Insight, in 2019, the oil and gas industry used a total of 12 LNG-fueled tankers for crude oil transportation (43 are in the pre-order stage), 20 tankers for crude oil or petrochemicals transportation (29 are in the pre-order stage), and 7 LNG tankers – and their number is growing fast.

Ammonia. Ammonia was noted as one of the most likely fuel types of the future, with zero emissions, in line with the IMO's goals for the decarbonization of shipping by 2050. Ammonia is a nitrogen and hydrogen compound. Though common in nature, it is caustic and dangerous when concentrated. Ammonia used as a fuel has the advantage of containing no carbon, but fuel is necessary for its combustion.[130]

Ammonia-fueled tankers are not currently in use, but an Aframax-class oil tanker with an ammonia engine is currently being designed as part of a multinational project headed by Samsung Heavy Industries. It has already obtained basic certification from Lloyd's Register, a London-based marine classification society. The Aframax-class tanker has a

[129] https://www.shell.com/business-customers/trading-and-supply/trading/news-and-media-releases/shell-charters-fleet-of-lower-carbon-oil-tankers.html
[130] https://www.ajudaily.com/view/20200924125922807

deadweight of 80,000-120,000 Mt,[131] and Samsung Heavy Industries is going to commercialize the technology by 2025.

Hyundai Mipo Dockyard (HMD) is involved in similar developments. The shipbuilder has been working on a joint project to create an ammonia-based power plant with Lloyd's Register and the German engine manufacturer, MAN Energy Solutions, since last October. In the project, HMD is responsible for the basic design and MAN Energy Solutions for the development and technical features of the dual-fuel ammonia-based engine. The vessel is also set to be commercialized in 2025.[132]

Hydrogen. Just as with ammonia, hydrogen fuel components in tankers are in the technology development stage. The South Korean shipbuilder, Samsung Heavy Industries (SHI), and the U.S. manufacturer of solid oxide fuel components, Bloom Energy, signed an agreement to jointly design fuel component based vessels.[133] [134] Tankers based on fuel components that are environment-friendly due to the substitution of solid oxide fuel components (SOFC) using LNG as fuel for the oil-based generators would enhance energy efficiency and reduce GHG emissions significantly. If fuel components are used conventionally in Aframax-class tankers using 3 MW engines/generators, the GHG emissions decrease by more than 45%.[135] Both companies announced their cooperation in 2019.[136]

Methanol. Methanol use in tankers is regarded as an already commercialized technology. At present, the fleet of methanol-fueled tankers has 21 units.[137] The first designed vessels to make use of dual-fuel methanol-based engines, were the MAN and the ME-LGI.[138]

Electricity. The use of fully electric vessels is currently limited. Only ferries and short-distance vessels are fitted with fully electric engines. The use of electric engine, e.g., in tankers, is currently limited by the battery unit size or their price. However, according to DNV GL Alternative Fuels Insight, in 2019, the fleet of tankers using hybrid installations comprised two tankers, and three more vessels are under construction.

The costs of transitioning to low-carbon bunkering fuel types vary significantly depending on the fuel type. Fuel oil and LNG

[131] https://www.maritimebusinessworld.com/korean-shipbuilders-to-develop-zero-carbon-ammonia-powered-vessels-1922h.htm
[132] https://www.offshore-energy.biz/hyundai-mipo-dockyard-wins-lr-approval-for-ammonia-powered-ship/
[133] https://www.offshore-energy.biz/samsung-heavy-bloom-energy-push-forward-with-developing-fuel-cells-for-ships/
[134] http://www.samsungshi.com/Eng/pr/news_view.aspx?Seq=1127&mac=3b071cb26f3a5cbd0b63a5ac0857622e
[135] http://www.samsungshi.com/Eng/pr/news_view.aspx?Seq=1127&mac=3b071cb26f3a5cbd0b63a5ac0857622e
[136] https://www.offshore-energy.biz/samsung-heavy-bloom-energy-to-develop-fuel-cell-powered-ships/
[137] DNV GL Alternative Fuels Insight Database.
[138] https://gmn.imo.org/wp-content/uploads/2018/11/4.-Jason-Methanex-Marine-Presentation.pdf

were the cheapest fuels in 2020, and LNG proved to be cheaper than fuel oil per MT of 3.5% fuel oil equivalent, due to its higher energy intensity. Hydrogen was estimated to be the most expensive. However, hydrogen tankers are currently in the early design stage, and these figures are just rough estimations (see Table 6).

Table 6 - Price for different bunkering fuels in 2020

Fuel	Price, $/MT of 3.5% fuel oil equivalent
Biodiesel	800-950
Ammonia	450-500
Methanol	350-500
LHG	250-370
Hydrogen	1,170-2,770
LNG (TTF)	100-180
Fuel oil	180-210

Source: https://afi.dnvgl.com/Statistics?repId=4

In terms of capital investments per kW of capacity, oil-based fuel tankers fitted with scrubbers and liquefied hydrocarbon gas (LHG) tankers are currently the cheapest type (Table 7).

Table 7 - Price per kW of tanker capacity in 2019

	CapEx $/kW
Scrubbers	100-150
LNG	200-300
LHG	100-200
Methanol	130-250
Batteries	600-900
Fuel components	2,200-5,600

Source: DNV GL – Maritime assessment of selected alternative fuels and technologies, 2019, LNG AS A MARINE FUEL – THE INVESTMENT OPPORTUNITY SEA\LNG STUDY - NEWBUILD 14,000 TEU LINER VESSEL ON ASIA-USWC TRADE, DNV GL – Maritime assessment of selected alternative fuels and technologies, 2020.

Corporate strategy methods

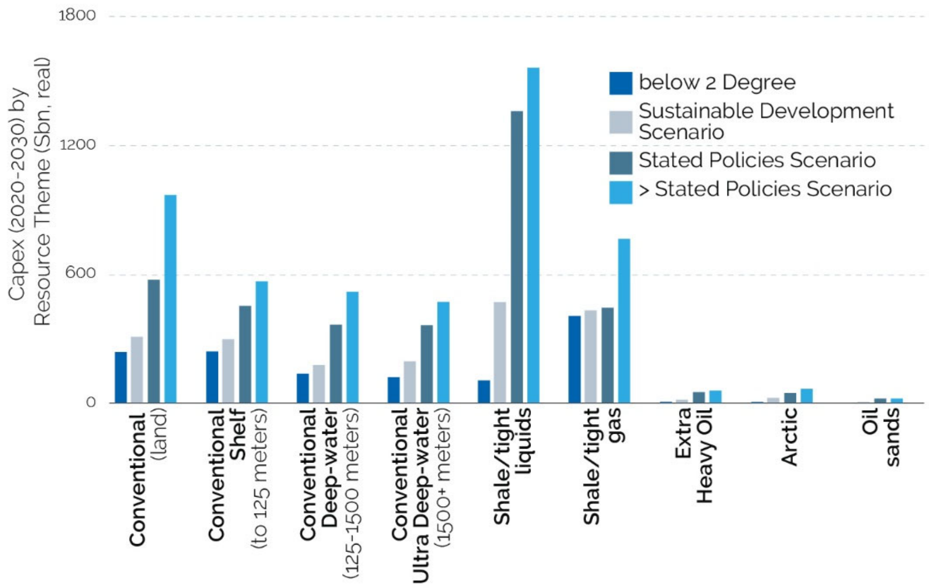
Portfolio optimization

The lower pricing of hydrocarbons in 2014-2020, enhancement of the climate agenda, and divestment trends stimulated oil and gas companies to optimize their portfolios in favor of less expensive and less carbon-intensive businesses and projects. Most of these companies had to decrease their costs and turn away from less cost-efficient, dirtier assets. Optimized portfolios include divestments (removing unattractive, carbon-intensive assets), merges and acquisitions (M&As) allowing for resource quality improvement and diversification within the new less carbon-intensive business, restructuring, development of the petrochemical business, and creation of corporate venture capital funds focused on innovation in the areas of methane leakage reduction, operational efficiency, carbon capture and storage, hydrogen technologies, and more. Oil and gas companies base their optimized portfolios on, among others, long-term risk mitigation strategies and inquiries of stakeholders, shareholders, and regulators.

Divestments

Companies have to get rid of some most unattractive resources. Research from Carbon Tracker Initiative, based on various IEA climate-driven demand scenarios, shows varying feasibility for the main types of oil and gas resources (Fig. 23). Deep water projects are riskier than onshore/ shelf projects in lower demand scenarios (although, of course, project costs need to be analyzed). In shale/ tight developments, gas is more resilient than liquids. And there is very limited space for extra-heavy oil and Arctic projects. And it will be increasingly difficult to get such projects financed, even if companies want to develop them.

Fig. 23 - Potential 2020-2030 CapEx for oil and gas projects that fit within different IEA scenarios by resource type



Source: Energy Center, Moscow School of Management SKOLKOVO based on Rystad Energy, IEA, CTI analyses.

Recent transactions show that carbon footprint modeling has become one of the major drivers of portfolio-related decisions. For example, in 2019, BP announced the sale of its assets in Alaska, which the company attributed to wanting to considerably reduce its carbon footprint.[139] The company had worked in the state since 1959. Earlier, in 2015, similar actions to exit business in Alaska were taken by the Norwegian company, Statoil.[140] In 2017, Royal Dutch Shell and Total pulled out of carbon-intensive oil-sand extraction projects. However, these sold assets are just

[139] BP to Exit Alaska With $5.6 Billion Sale /Aug. 27, 2019 / https://www.wsj.com/articles/bp-to-exit-alaska-with-5-6-billion-sale-11566932341
[140] https://www.worldenergynews.com/news/norway-statoil-exit-alaska-636412

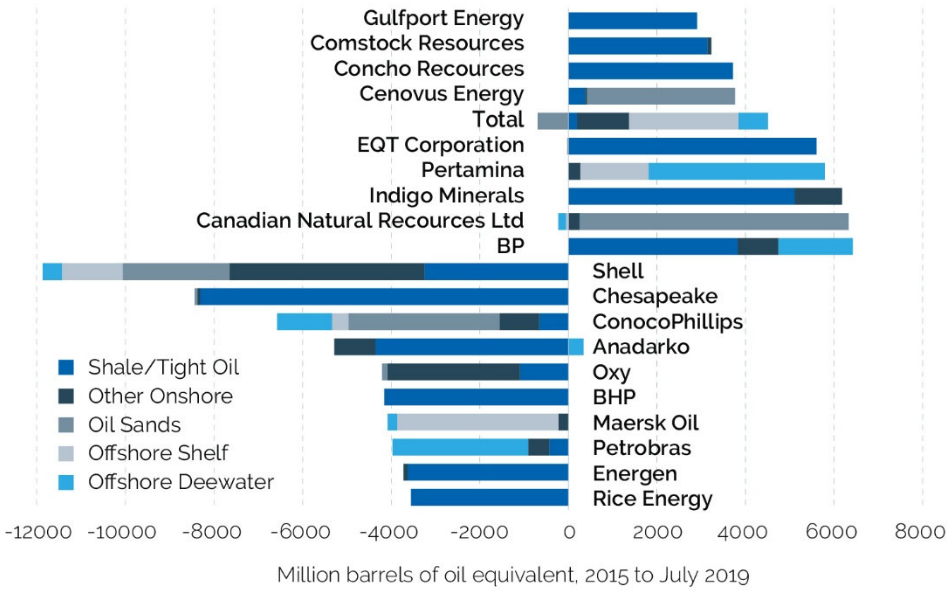
purchased and commissioned by other oil and gas companies, thereby resulting in no immediate decrease in the industry's carbon footprint. Nevertheless, smaller carbon intensive players are more likely to experience difficulties in accessing capital and shutdown of carbon intensive production will accelerate.

Merges and acquisitions

The decarbonization agenda has accelerated some of the emerging M&A trends: companies are selling small, exhausted assets and shale assets and focusing on new, major projects, such as gas.

Oil and gas price dynamics together with the decarbonization agenda accelerated some of the emerging M&A trends in the industry: companies are selling small, exhausted assets and shale assets and focusing on new, major projects, such as gas.[141][142] With all this, companies are choosing different strategies for optimizing their portfolios. BP, for example, showed the greatest growth in its resource base due to M&A in all supply segments and has added almost 6.5 MMbbl since 2015. Meanwhile Shell on opposite is substantially ahead in sales - almost 11 MMbbl since 2015 (excluding the results of Shell's 2015 purchase of BG) (Fig. 24).[143]

Fig. 24 -Top 10 companies with inorganic growth in resources and Top 10 companies with inorganic reduction in resources



Source: Rystad Energy UCube, Rystad Energy Research and Analyses.

Diversification in green assets and technologies

In the decarbonizing world the main focus of the companies on the O&G value chain should be complemented with initiatives that may help to decarbonize scope 3 emissions. So another direction of portfolio optimization is the purchasing of green assets or shares thereof. Since 2011, major companies have

[141] https://www.rystadenergy.com/newsevents/news/press-releases/BP-and-Shell-on-opposite-ends-of-MA-ranking/
[142] https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-oilandgas-mna-2020-outlook.pdf
[143] https://www.rystadenergy.com/newsevents/news/press-releases/BP-and-Shell-on-opposite-ends-of-MA-ranking/

spent more than $5 billion on green projects.[144] Companies are looking at different assets: Equinor strengthened its leadership offshore wind power; Shell and BP emphasized biofuels; Repsol and Eni focused on solar power.[145]

Shell, which has already strong retail business with its fuelling stations, has acquired car charging companies Ubitricity[146] and NewMotion.[147] In 2019 it has bought German battery startup Sonnen[148] while Shell Technology Ventures invested in Aquion, a manufacturer of saltwater batteries.

BP in 2017, announced the purchase of a large stake in Lightsource, a prominent solar power developer based in Britain.[149][150] In 2018 BP has also acquired the UK's biggest electric car charging network Chargemaster[151] and invested in StoreDot which develops lithium ion-based battery technology enabling ultra-fast charging for the mobile and industrial markets.[152]

Total implemented most significant reduction of carbon footprint through increase of lower-carbon gas and electricity generation in its product portfolio. In May 2016, Total purchased the battery manufacturer Saft for $1.1 billion.[153] Total also announced a collaboration with the automaker Opel, on EV battery manufacturing, potentially investing as much as $5.5 billion of up to 47 GWh of manufacturing capacity.[154] It has also announced acquisition of Blue Point London (EV charging network).[155]

Similarly Repsol-Ibil[156] partnership could be mentioned as well as ENI and IONITY.[157] These examples illustrate how oil and gas companies are regarding their future role in the transportation sector and how they are planning for GHG reductions addressing scope 3 emissions.

The Norwegian company, Equinor (formerly Statoil and StatoilHydro), has tended towards wind generation with a

[144] https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/oil-and-gas-mergers-and-acquisitions.html
[145] https://assets.kpmg/content/dam/kpmg/ru/pdf/2019/12/ru-ru-renewable-energy-sources-for-oil-and-gas.pdf
[146] https://www.theguardian.com/business/2021/jan/25/shell-agrees-deal-to-buy-electric-car-charging-company-ubitricity
[147] https://www.reuters.com/article/us-newmotion-m-a-shell/shell-buys-newmotion-charging-network-in-first-electric-vehicle-deal-idINKBN1CH1QV
[148] https://www.ft.com/content/12f343d6-3100-11e9-8744-e7016697f225
[149] https://www.nytimes.com/2017/12/15/business/energy-environment/bp-lightsource-solar.html
[150] https://www.lightsourcebp.com/us/about/
[151] https://www.theguardian.com/business/2018/jun/28/bp-buys-uks-biggest-electric-car-charger-network-for-130m
[152] https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-invests-in-ultra-fast-charging-battery-company-storedot.html
[153] https://www.saftbatteries.com/media-resources/press-releases/total-takes-control-saft-groupe-after-successful-tender-offer-which
[154] https://www.oilandgas360.com/woodmac-energy-storage-to-accelerate-global-energy-transition-in-2020s/
[155] https://www.total.com/media/news/news/united-kingdom-total-acquires-londons-largest-electric-vehicle-charge-points
[156] https://www.repsol.com/en/press-room/press-releases/2019/repsol-and-ibil-strengthen-their-position-in-electric-vehicle-charging.cshtml
[157] https://www.eni.com/en-IT/media/press-release/2018/10/eni-and-ionity-sign-framework-agreement-to-install-high-power-chargers-for-electric-cars-at-eni-service-stations.html

floating offshore wind farm Hywind Scotland,[158] 50% in Polish offshore Bałtyk Środkowy III and Bałtyk Środkowy II[159]; 50% in German Arkona, 40% in Sheringham Shoal[160] in the North Sea, and other assets. The company's new CEO has also voiced his intention to enhance portfolio items related to renewables. "I am willing to reallocate capital between oil and gas and renewables. It will depend on the opportunities we will have at that point in time."[161]

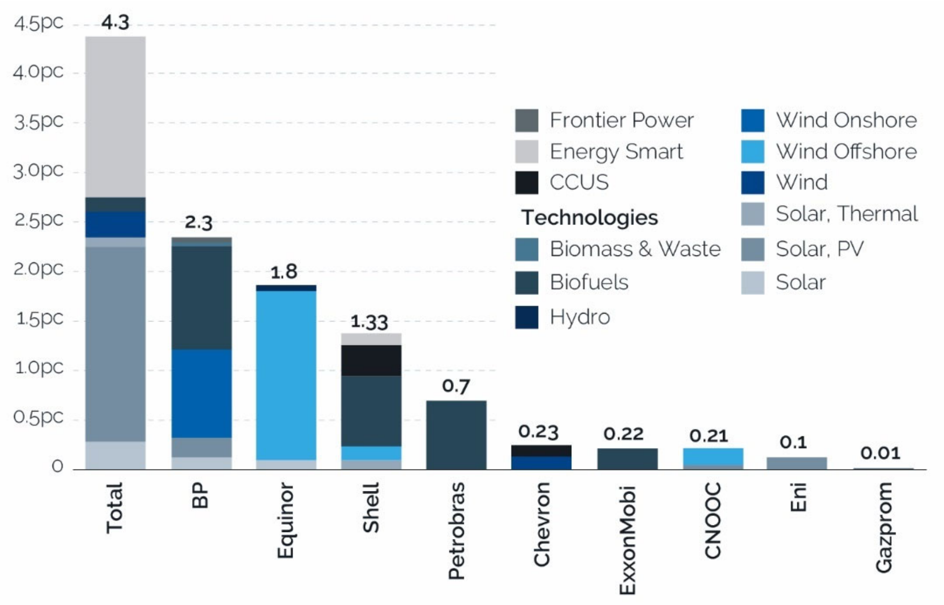
One of the most impressive examples of a dramatic change in oil and gas company's profile is that of the Danish company, *Ørsted* (Oersted) (formerly Danish Oil and Natural Gas), which completely overhauled its development strategy in 2012. *Ørsted* has completely revised its strategy and key business aspects from being one of the blackest European power generators to one of the most sustainable companies in the world, according to the Corporate Knights 2020 Global 100 ranking.[162] The company is planning to completely transition to almost 100% green energies by 2025.

At 0.5-4.2%, the proportion of investments going to renewable energy sources is just a sliver of the total investments of leading oil and gas companies between 2016 and 2019.

However, for the most part, carbon footprint changes are not very fast and not large-scale. According to 2019 data, though leading global oil and gas companies did allocate and spend money on the implementation of low-carbon technologies, it was only to the tune of an unimpressive 0.5-4.2% of their total investments (Fig. 25). The majority of these investments are aimed at solar, wind, and bio energy generation, storage, and distribution. According to the IEA, the average data for the whole oil and gas industry shows an even lower investment percentage allocated to green projects (typically solar and wind power generation) - just 1%.[163]

[158] https://www.bbc.com/news/uk-scotland-scotland-business-34694463
[159] https://cleantechnica.com/2018/03/06/statoil-acquires-50-interest-1-2-gw-polish-offshore-wind-farms/
[160] http://sheringhamshoal.co.uk/
[161] https://www.reuters.com/article/us-equinor-ceo-idUSKCN2560B4
[162] https://orsted.com/en/sustainability/our-stories/worlds-most-sustainable-company-2020
[163] The Oil and Gas Industry in Energy Transitions / International Energy Agency, 2020.

Fig. 25 - Proportion of leading oil and gas companies' investments in low-carbon technologies



Source: https://www.petroleum-economist.com/articles/low-carbon-energy/energy-transition/2020/dividing-lines-appear-in-transition-approaches

Restructuring

Major oil and gas companies continue to focus on hydrocarbon upstream, midstream, refining and trading activities. However, the scale of renewable projects calls for the establishment of separate divisions and subsidiaries. For example, Shell, Total, and Eni have established separate departments for project management and investing in renewable and low-carbon power generation. We believe more of this restructuring will take place in the future.

Development of the petrochemical business

International oil and gas companies are paying more and more attention to diversifying their businesses, strengthening the role of the petrochemical sector, which uses hydrocarbons not as fuel, but as feedstock with potentially very high value added and fast-growing demand. Oil and gas companies see an opportunity in oil and gas chemistry for reducing the risks of price volatility by diversifying their product portfolios, increasing business margins, and increasing synergy effects. However, with the strengthening of the climate agenda, the development of the petrochemical sector creates additional opportunities and benefits in terms of decarbonization. More detailed analyses are provided in the petrochemical chapter.

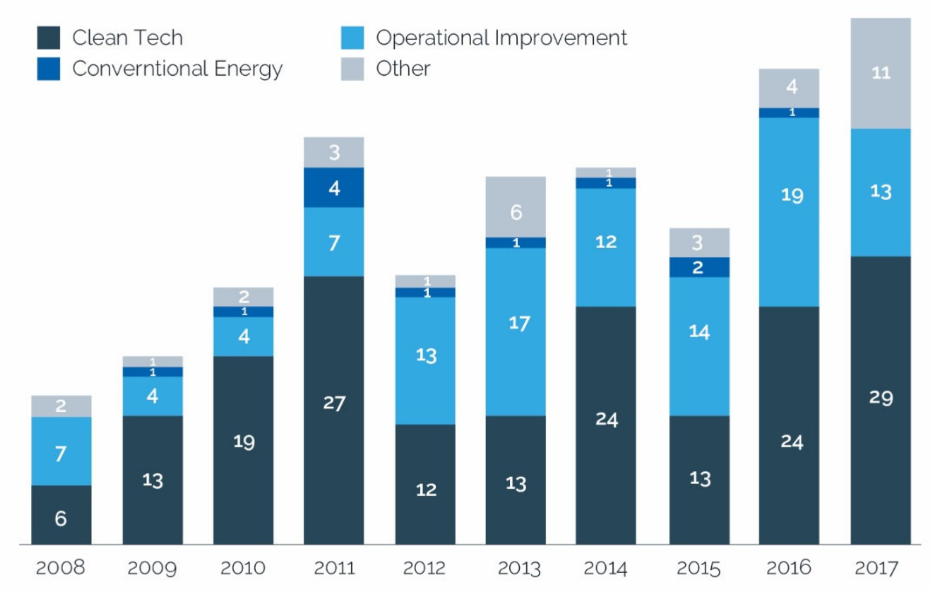
Corporate funds

Corporate venture capital (VC) investments are often concentrated in corporate VC funds. Almost all major companies have such funds (Shell Technology Ventures, Chevron Technology Ventures, Energy Technology Ventures (ConocoPhillips), AE Ventures (BP), Total Energy Ventures, etc.).

The interest on these types of funds covers alternative fuels and increasing operational efficiency, in particular, due to digital technologies.

According to CB Insights, from 2008 to 2017, integrated oil companies accounted for about 80% of industry startup funding. The remaining 20% included independent exploration companies, oil service suppliers, and independent oil processing companies (Fig. 26).

Fig. 26 - Corporate venture capital investments of oil and gas corporations from 2008 to 2017



Source: CB insights.

Many companies create venture capital funds focused on innovations in the fields of methane leakage reduction, operational efficiency, CCS, hydrogen technologies, etc.

Corporate non-VC funds may be allocated directly to carbon footprint reduction. Thus, in March 2019 BP announced the fund (new Upstream Carbon Fund) that is supposed to finance new emission reductions projects in upstream oil and gas operations for the proceeding three years in the total amount of $100 million.[164]

A few important emerging aspects of corporate funds development include industrial cooperation on R&D, venture investments, and the piloting of deep decarbonization projects in order to increase the quality and speed of these new technologies' developments. OGCI investments are a good example of joint corporate venture fund investment. The recently approved Northern Lights open-source CCUS project[165] is an example of joint piloting of a major deep decarbonization project.

[164] https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-commits-100-million-to-fund-new-emissions-reductions-projects.html
[165] https://northernlightsccs.com/what-we-do/

Carbon allowances and carbon credits trading

Carbon allowances and credits tradingstimulate investments in decarbonization technologies and in zero-carbon energy sources. These tools give a price signal that serves as a basis for companies to make decisions on carbon footprint reduction strategies.

There are different options of carbon markets organization around the world, and oil and gas companies use all of them. Carbon allowances and credits trading, as well as taxes on GHG emissions, stimulate investments in decarbonization technologies or in zero-carbon energy sources. These tools give a price signal that serves as a basis for companies from different sectors to make decisions on carbon footprint reduction strategies. The different CO2 pricing options are discussed in more detail below.

First segment is represented by carbon allowance under the cap-and-trade mechanism. It is a regulated market trading GHG emission allowances granted pursuant to the Kyoto Protocol. Allowances are distributed among countries and among companies within a country engaged in industries included in the list of regulated industries. Distribution may be free or auctioned. Companies must measure GHG emissions and provide a sufficient number of allowances for their emissions volumes. The volume of allowances is annually decreased to motivate companies to either reduce their emissions or purchase additional allowances from other companies that may have extras after initial distribution. The list of regulated industries has been extended. At first, it included only power generation and extractive industries, but in recent years, it has come to include airlines, lumber processors, and transporters.

Along with the development of intergovernmental regulation of GHG emissions over the past decade, the practice of using national and regional emissions trading systems (ETS) is expanding rapidly. According to the World Bank, by 2020, over 30 ETSs were developing, which together with 30 carbon taxes initiatives are covering about 22% of global GHG emissions.[166] Prices per MT of CO_2e were ranged from $1 to $127. However, over 51% of emissions were priced at less than $10 per MT of CO_2e.

In March 2021 in mandatory markets (consisting of European Union Allowances (EUA), California Carbon Allowances (CCA), Regional Greenhouse Gas Initiative (RGGI), North American Pricing and ICE Futures Pricing), weighted carbon price was $28,2 per MT of CO_2e.[167] (Fig. 27).

[166] State and Trends of Carbon Pricing Initiatives 2020. World bank, 2020. https://openknowledge.worldbank.org/handle/10986/33809
[167] https://indices.ihsmarkit.com/Carbonindex

Fig. 27 - Averageweighted carbon price, $ per MT of CO2e

Source: IHS Markit Global Carbon Index.

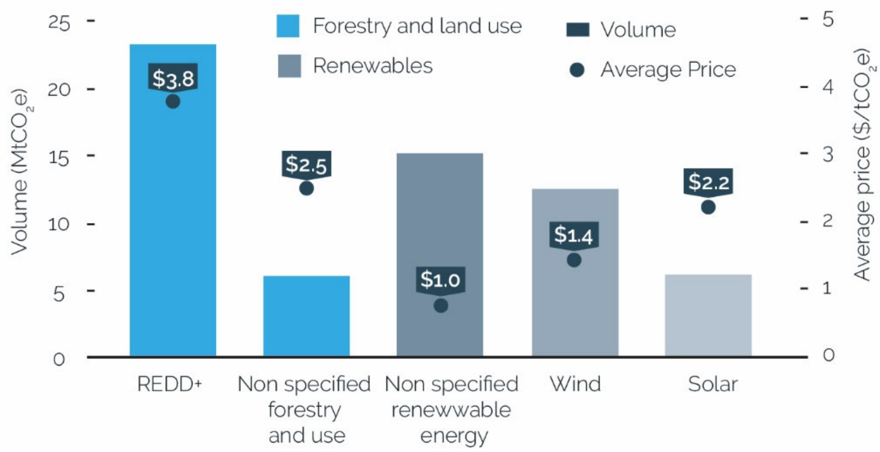
Carbon markets are also developing outside of government regulation. The role of voluntary emission reduction offsetting schemes based on investment projects is growing. Carbon offsetting establishes a voluntary market in which companies from different industries (including non-regulated ones) can act as either issuers of credits (thus implementing carbon emission reduction projects) or purchasers of credits for compensation of their own carbon footprints. Companies are eager to take part in these schemes, driven by the desire to reduce GHG emissions for reasons of corporate responsibility, as well as to reap the associated benefits, including obtaining long-term competitive advantages through the earlier development of advanced green technologies compared to their competitors.

The implementation of voluntary projects to reduce emissions is controlled by a set of international standards for the verification of reduction units (the Verified Carbon Standard, Gold Standard, etc.), which vary depending on the type and geography of the project activities, as well as on the methodology for counting the reductions. Projects cover various areas of activity, from agriculture to improving the energy efficiency of production and transitioning to clean energy sources.[168]

Due to differences between various projects, sales volumes and average sale prices of credits from different types of projects may substantially differ depending on geography, type of certification and project types. In 2020, prices were mainly in the range of $ 1-13 / Mt CO_2e (Fig. 28).

[168] https://russiancouncil.ru/analytics-and-comments/analytics/evolyutsiya-uglerodnykh-rynkov-est-li-mesto-dlya-rossii/

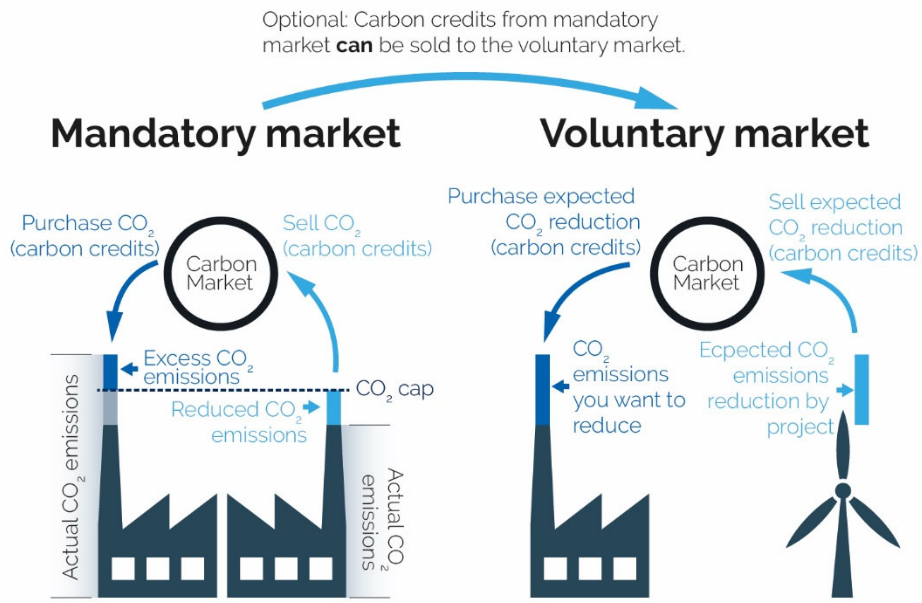
Fig. 28 - Transacted voluntary carbon offset volumes and average prices by project type, 2019



Source: Forest Trends' Ecosystem Marketplace, State of Voluntary Carbon Markets Report, Special Climate Week NYC 2020 Installment. Washington DC: Forest Trends Association, 21 September 2020.

The line between the two markets (the regulated market of carbon allowances and the voluntary market of carbon credits) starts to blur as the regulated market borrows the mechanisms of the voluntary market to improve transaction quality (Fig. 29).

Fig. 29 - Mechanisms of mandatory and voluntary markets



Source: Sustainalize.

The mandatory market beats the voluntary market hundredfold in annual sales, though historically it showed very volatile prices because of the excessive volume of mandatory allocations.

Both markets include some inefficiencies that have continued to be gradually eliminated. Thus, the volume of regulated emissions and the procedure of their distribution among industrial companies were criticized as poorly performing. The problem of the excessive offer of carbon allowances became most acute during the economic recession. In 2018-2019, the problem was partially solved with the withdrawal of some allowances to the reserve fund and the extension of the regulated industries perimeter.

As for the voluntary market of carbon credits, its early stages witnessed abuse upon issuing credits to projects that failed to comply with qualifications, such as permanent emission reduction, incrementality (i.e., no project would be feasible without proceeds from carbon credit sales), impossibility of credit transfers to other sectors or locations, and the accuracy of effects measurements).

It is also very difficult to avoid double accounting between regulated and non-regulated markets and cross-border transactions with allowances or credits. Now, these problems are partially solved due to broader implementation of project certification standards.

The carbon trading mechanisms are also criticized because companies would buy cheap (and not always reliable) carbon credits instead of engaging in a real GHG emission reduction in the course of their operations (the term "greenwashing" has even been used). However, studies by the CDP, one of the leading non-profit organizations in the field of carbon footprint reduction, have revealed that the companies involved in the purchasing of carbon credits practice tougher approaches to carbon footprint reduction than those that do not engage in voluntary carbon credits trading.[169]

Together with power generators, oil and gas companies account for 30% of all offset traded volumes.[170] The major purchasers are ExxonMobil, Eni, Shell, ConocoPhillips, and OMV. The proportion of purchases in mandatory markets differs greatly from one market player to another, thus reflecting the uneven distribution of credits among different countries within the same industry. For example, in the European emission market, EU ETS (the largest and the most liquid mandatory market), the extra volume of purchased allowances in 2019 varied from 20% (ConocoPhillips) to 45% (Equinor) (Table 8).

Table 8 - Share of carbon allowances purchased by oil and gas companies on the EU ETS market in the total volume of regulated GHG emissions

Company	Share of carbon allowances purchased on the EU ETS market in the total volume of regulated GHG emissions
ConocoPhillips	20%
Shell	24%
Repsol	28%
OMV	41%
Equinor	45%

Source: Energy Centre, Moscow School of Management SKOLKOVO based on company data.

[169] https://www.ecosystemmarketplace.com/articles/debunked-eight-myths-carbon-offsetting/
[170] data https://www.forest-trends.org/wp-content/uploads/imported/Buyers%20Report-2016%20FINAL.pdf of 2012-2014 surveys.

The leading corporations are increasingly introducing their own internal carbon prices independently of any government regulation.[171] Many large companies, including the oil and gas giants ExxonMobil, Royal Dutch Shell, Equinor, ConocoPhillips, Total and others have already set prices for themselves. Internal carbon prices are used when making investment decisions: an estimated volume of emissions within the framework of a planned project, multiplied by the price, is included in the planned costs and, alongside the traditional financial indicators, affects the assessment of the project's potential and, as a result, the decision on whether or not to launch the project in the first place. Generally speaking, internal carbon pricing is, first of all, a way to manage the risks associated with regulating emissions at the international, national and industry level; second, it is a tool for these companies to position themselves in a world where increasing attention is being paid to green development issues.

It should be stressed that most carbon pricing mechanisms do not adequately reflect the social cost of carbon which internalizes the cost of GHG emissions associated with a business activity by assigning a monetary value to each ton emitted. Actually social cost of carbon in itself is a metric that is a topic of continued conversation, currently estimated in the range of $50-417/ Mt CO_2e.[172]

When comparing different price sygnals and options for carbon footprint reduction, in general, the purchasing and offsetting of carbon credits ($1-13/ Mt CO_2e), are actually cheap options. Voluntary (trading average prices are materially lower than major carbon taxes, many companies' internal carbon prices (approximately $25/ Mt CO_2e [173]) and the "social" carbon price ($50/ Mt CO_2e), calculated pursuant to the World Bank's methodology),

This is a serius obstacle for the large-scale decarbonization. The High-Level Commission on Carbon Prices estimated that carbon prices of at least $40–80/ Mt CO_2e by 2020 and $50–100/ t$CO_2$e by 2030 are required to cost-effectively reduce emissions in line with the temperature goals of the Paris Agreement.[174] As of today, less than 5% of GHG emissions are currently covered by a carbon price are within this range and moreover the IMF calculates the global average carbon price is only $2/ Mt CO_2e.[175]

Looking ahead to 2030, forecasts for CO_2 prices vary greatly from one source to another, but all are in the higher price range of

[171] https://www.c2es.org/site/assets/uploads/2017/09/business-pricing-carbon.pdf
[172] https://www.edf.org/true-cost-carbon-pollution
[173] https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-state-of-internal-carbon-pricing
[174] CPLC, Report of the High-Level Commission on Carbon Prices, May 29, 2017. https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f26b3c91f1bb0de2e41a/1505227373770/CarbonPricing_EnglishSummary.pdf
[175] IMF, Putting a Price on Pollution, Finance & Development 56(4), December, 2019. https://www.imf.org/external/pubs/ft/fandd/2019/12/the-case-for-carbon-taxation-and-putting-a-price-on-pollution-parry.htm

$30-95/ Mt CO_2e (Table 9). So it can be assumed that in the near future, companies in the sector will have to pay much more attention to carbon markets and set higher internal prices for CO_2.

Table 9 - Comparative forecasts of CO2 pricing

Source:	CO_2 price forecast
International Emissions Trading Association (IETA)	2020-2030: $32/MT, on average
Zero Carbon Commission, U.K.	2025: €60/MT 2030: €81/MT
Carbon Tracker, Institute of Analytics	€50/MT (computed value necessary to reach the target emission reduction)
Carbon market watch	€40-80 by 2030 is necessary to reach the Paris Agreement goals

Source: Energy Centre, Moscow School of Management SKOLKOVO based on the think-tank's outlooks.

In general, most oil and gas companies stick to passive trading strategies in carbon trading markets:

- purchase the necessary volumes to cover obligations within a regulated market,
- purchase on a voluntary market for offset of emissions related to employees' traveling (Equinor), and
- some companies also issue credits related to their projects (e.g., the West Arnhem Land Fire Abatement Project (WALFA) ConocoPhillips - 100,000 t) and Quest CCS by Shell -500,000 t).
- Using carbon credits to offset emissions associated with individual LNG and oil cargos[176].

The following principle applies: first, reduce all you can in your own operations and then compensate for the rest with carbon credits.

GHG reduction due to investments in regenerative land use (projects related to reforestation, natural sinks, and agricultural lands)

Forests and soils are natural absorbers and storers of carbon (Table 10). The UNFCCC estimates that regenerative use will account for about 30-50% of potential carbon emission reductions from 2030 to 2050.

[176] https://www.poten.com/wp-content/uploads/2020/09/Carbon-Neutral-LNG-Offerings-LNGWM-Aug-2020-1.pdf

Table 10 - Global carbon stocks in vegetation and sold carbon pools to the depth

Biome	Area (10^9 ha)	Global carbon stocks (GT C)		
		Vegetation	Soil	Total
Tropical forests	1.76	212	216	428
Temperate forests	1.04	59	100	159
Boreal forests	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grasslands	1.25	9	295	304
Desert ana semi-deserts	4.55	8	191	199
Tundra	0.95	6	121	127
Wetlands	0.35	15	225	240
Crop lands	1.60	3	128	131

Source: IPCC 2000.

Nature-based projects are usually a cheaper (compared to the average price of carbon) way to get carbon credits. Increasingly, oil and gas companies are looking into these projects, albeit with apprehension in the selection of the project and of the project partners due to the inherent difficulty of measuring the impact of nature-based carbon sinks, as well as the negative publicity associated with not yet matured projects.

Human impact and climate change materially influence the condition of these eco systems. Soil forms 20-100 times more slowly than it erodes. Deserts extend, droughts become more and more frequent and influence more and more people. Agriculture, lumber processing, and other land use industries account for 23% of anthropogenic GHG emissions.[177]

As both soil and forests absorb and emit GHG of both natural and anthropogenic origin, it is very difficult to reliably identify a purely anthropogenic impact. There are considerable divergences between different patterns of carbon buildup. Models of new forest creation projects and deforestation results are more aligned with each other, while managed forest project results are the worst (with the greatest divergences between the models).

As carbon production mostly takes place in distant areas unrelated to agricultural operations, projects for the recovery of forests and natural sinks are the most relevant. Besides, companies may gain carbon credits in the course of implementing regenerative land use projects.

The UN Food and Agriculture Organization estimates that the total carbon reserves in forests all over the world shrunk from 668 Gt in 1990 to 662 Gt in 2020. While the specific storage intensity had grown from 159 to 162 t/hectare of forest.[178]

In different climate conditions and at different stages of a forest's life cycle, the ability to both build up and store carbon varies. Young forests are the quickest to build up carbon, while mature, old growth forests provide for the maximum carbon storage volume. The maximum storage is reached in a warm, moderately humid climate. Carbon rests not only in land-based biomasses but also in dead woods, forest floors, and litter. In northern boreal forests, storage in land-based biomasses, dead woods, and forest floors are comparable, while in southern rain forests, the

[177] IPCC Climate and Land; Summary for policy makers 2019. https://www.ipcc.ch/srccl/chapter/summary-for-policymakers/
[178] http://www.fao.org/3/CA8753EN/CA8753EN.pdf

majority of carbon is stored in the land-based biomasses of trees.[179]

Deforestation is the second largest anthropogenic source of GHG in the world (17% according to IPCC (2007) Climate Change: Synthesis Report).[180] Since 1990, the world has lost 178 million hectares of forest. However, the rate of reduction has gradually decreased from 7.8 hectares per year on average between 1990 and 2000 to 4.7 hectares per year on average between 2010 and 2020. Most of this loss has taken place in Africa and South America, i.e., those rain forests that include the most specific carbon stocks.[181]

There are several types of projects for carbon footprint reduction with the help of forests and natural sinks:

- conservation of forests and elimination (decrease the volume) of deforestation in the course of operations,
- preservation and rehabilitation of peat bogs,
- fire protection activities,
- partial-load forestry regime (minimal harm to soil),
- decrease of felling waste (use of pulpwood, processing of 100% of felled trees),
- effective forest rehabilitation (substitution of slow-growing single crops for fast-growing diverse crops), and
- planting of high trees of equivalent quality on areas equal in size to deforested areas.

It is notable that forestry projects are rather complex for certification under programs for carbon credits acquisition, and they cause most of the disputes in the course of negotiations on climate issues. Firstly, methods of assessment for carbon stock volumes in forests and soil are complex from a scientific standpoint and call for rather accurate descriptions of forest ecosystems for proper application. Furthermore, it has turned out to be difficult to prove the incremental nature of carbon buildup in forests and long-term nature of its storage. Has the forest actually been designated for cutting? If the field had not been artificially planted, would a forest have grown on its own? In view of climate and social changes, can it be guaranteed that the forest would exist long enough? Further still, in many countries this sector lacks transparency, which leads to material abuse.

All of this is why nature-based projects were not represented for a long time in mandatory trading markets, though they have started to claim their place in voluntary markets.

[179] https://www.researchgate.net/publication/258726470_The_Role_of_Forests_in_Carbon_Cycle_Sequestration_and_Storage
[180] Intergovernmental Panel on Climate Change (2007) Climate Change: Synthesis Report. Cambridge University Press, Cambridge, U.K.
[181] http://www.fao.org/3/CA8753EN/CA8753EN.pdf

According to the World Business Council for Sustainable Development, worldwide, only 2-3% of financing allocated to climate change resolution is allocated to regenerative land use projects. Only 67 out of the 783 of these projects (less than 1%) registered with the UNFCCC for emission reduction certificates (CER) are related to forestry projects.[182]

In 2013, under the UNFCCC, criteria and mechanisms for calculating carbon volumes in forests were developed, as well as mechanisms for verifying REDD+ (reducing emissions from deforestation and forest degradation, plus forest enhancement) forestry projects. Upon REDD+ project implementation, companies gain carbon credits that are offset against total emissions.[183]

In 2016, the distribution of carbon credits in mandatory carbon credit trading markets began. Australia, California, China, and New Zealand started to include nature-based projects into the programs of mandatory carbon credit markets. The largest forestry carbon credits market is the auction of projects in Australia. In combination with those volumes, carbon credits trading related to forestry projects held the largest proportion of volumes and prices in voluntary carbon trading markets.

Table 11 - Summary of types of forest carbon finance, 2009 and 2009-2016 cumulative

Type of Finance	Name of Finance	2016	All Years*
Market	Voluntary forest carbon offset transactions	$74.2M	$996.6M
	Compliance forest carbon offset transactions**	$551.4M	$1 573.9M
Non-Market	Payments for REDD+ programs	$36.5M	$218.0M
Total		**$662.1M**	**$2 788.5M**

*Ecosystem Marketplace has been tracking forest carbon finance annually since 2009 but our data goes back as far as the early 2000s, when payments for forest-based emissions reductions were just beginning. "All years" refers to the total finance that we know of to date.

**This compliance market value includes Australia's Emissions Reduction Fund's payments for land-use offsets, worth an estimated $1.2B across all years, and $509.5M in 2016. We counted this finance as market-based because contracts are awarded through a competitive auction; however, there is currently only one buyer: the government. Without the Australia value, compliance market payments in 2016 were $41.9M.

Source: http://www.fao.org/3/CA8753EN/CA8753EN.pdf)

Nature-based projects are usually a cheaper (compared to the average price of carbon) way to get carbon credits (Table 12).

[182] https://cdm.unfccc.int/Statistics/Public/index.html
[183] https://redd.unfccc.int/fact-sheets/warsaw-framework-for-redd.html

Table 12 - Transacted voluntary carbon offset volume, value, and weighted average price by project category, 2019

	VOLUME $MtCO_2e$	AVERAGE PRICE	VALUE
RENEWABLE ENERGY	42.4	$1.4	$60.1 M
FORESTRY AND LAND USE	36.7	$40.3	$159.1 M
WASTE DISPOSAL	7.3	$2.5	$18.0 M
HOUSEHOLD DEVICES	6.4	$3.8	$24.8 M
CHEMICAL PROCESSES/INDUSTRIAL MANUFACTURING	4.1	$1.9	$7.7 M
ENERGY EFFICIENCY/ FUEL SWITCHING	3.1	$3.9	$11.9 M
TRANSPORTATION	0.4	$1.7	$0.7 M

In 2019, the volume of renewable energy transactions exceeded that of nature-based solutions in forestry and land use, but the prices garnered for nature-based solutions averaged more than three times those of renewable energy.

Source: State of forest carbon finance 2019
https://app.hubspot.com/documents/3298623/view/88656172?accessId=b01f32

In 2019, some major oil and gas companies, such as Shell, BP, Total and Eni, announced their carbon footprint reduction strategies, which provided for the use of carbon credits from forestry projects, or, Nature-Based Solutions (many different projects, like planting trees and preserving forests, not just carbon credits). Additionally, some companies (Repsol and ConocoPhillips) implemented forestry projects in order to get carbon credits, though they have not voiced any specific strategic goals in this respect. Some market players (Saudi Aramco and Equinor) implemented forestry projects due to the support and statutory requirements for forest rehabilitation of their local communities (Table 13).

Table 13 - Sample projects

Company	Project	Partners
Shell	Allocated about 50% of carbon emission reductions to nature-based projects. Between 2019 and 2021, invested $300 million into 18 projects for conservation, forests rehabilitation, and the creation of new forested areas with carbon credits of more than 15 Mt implemented annually. Credits are offered to purchasers of Shell products to reduce their carbon footprints. Shell's forestry projects are aimed at scope 3 reductions.	The projects have been implemented with the help of the professional funds Acre Investment, WildLife Alliance, Permian Global, TIST, and Althelia Funds
ConocoPhilips	Since 2005, has been investing $1 million annually into fire-protection projects (West Arnhem Land Fire Abatement Project) in Australia and getting carbon offsets in the amount of 100,000 $MTCO_2$	Municipal authorities and local rangers (foresters) Northern Land Council Arnhem Land Rangers

Company	Project	Partners
Repsol	Buys project-related carbon credits from the relevant organization engaged in forest rehabilitation and management of growing forests in Spain	Proyecto Forestal CO2CERO
LUKOIL	Like other Russian oil and gas companies, engages in forests rehabilitation in the regions of its operations. Since 2009, over 1 million seedlings of Siberian cedar pine (cedrine) and common pine have been planted in Western Siberia.	Not included
Saudi Aramco	Program for planting 1 million trees by 2025 to fight deforestation and decrease desertification. Carbon goals of the project have not been articulated.	Not included
Equinor	Supports the development of Emergent, a non-profit organization focused on the acceleration of rain forest conservation, certified under ART (REDD+) standards.	Emergent

Sources: Energy Centre, Moscow School of Management SKOLKOVO based on corporate data, CDP reports.

In general, the apprehension of international oil and gas companies to use this tool stems from the criticism of emerging forestry projects at earlier stages of the carbon credits market and from the complexity of such projects for incidental organizations. Furthermore, some regulators and non-profit organizations believe that any carbon credits, including the ones from forestry projects, should be purchased only by companies that have exhausted all other methods for reducing their carbon footprints.

Carbon capture, utilization, storage and removal

Technologies for carbon capture, storage and utilization, are high-tech solutions providing the reduction of GHG emissions.

A number of scientific associations, research institutes, and laboratories recognize the introduction of carbon capture, utilization, and storage (CCUS) technologies as the critical step towards decarbonization.

There are three approaches to CO_2 capture: capture directly at the emission sources, capture on the consumption sites or capture from the atmosphere (removal).

The key advantages of CCUS technologies are:

- continued diversity of the power supply, which envisages long-term and environmentally-friendly use of conventional fossil fuels,
- support for long-term operation and investment appeal to industrial production facilities with high GHG emissions,
- maintaining the efficiency of capital investments into power engineering and the power industry,
- expanded technological opportunities to control electricity generation, and
- production of hydrogen fuel based on fossil fuels, with low emission levels.

Carbon capture, utilization and storage

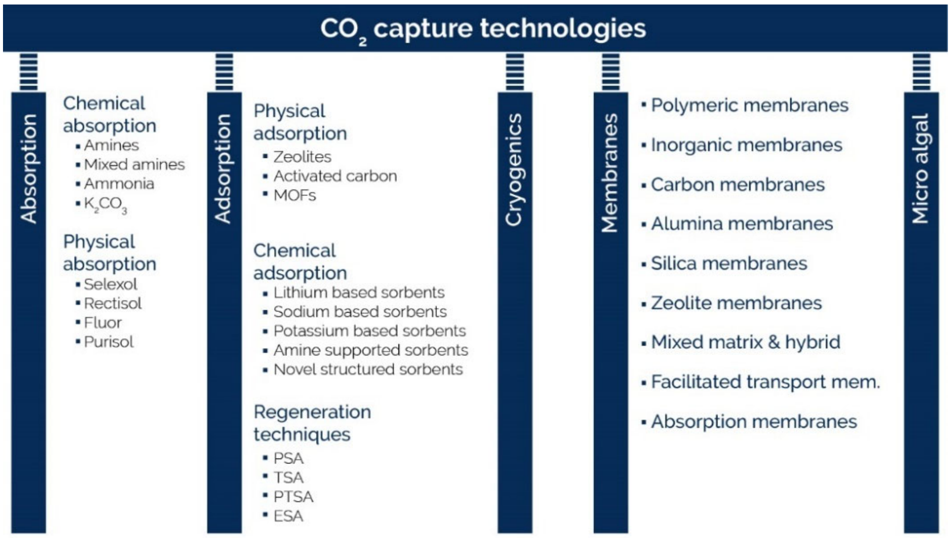
The approach of capturing CO_2 directly at emission sources on the production facilities comprises CCS (Carbon Capture and Storage), CCU (Carbon Capture and Utilization) and CCUS (Carbon Capture, Utilization and Storage) process solutions. This technology involves capturing CO_2 that is emitted as a result of fuel burning or other industrial processes (it may capture up to 90% of GHG emissions, with the remaining CO_2 able to be buried or reused), further transportation, and, consequently, the use of these resources to create new productsor temporary storage in geological formations.

By 2050, the annual volume of CO2 capture and storage in volumetric equivalent may reach the scale of today's global annual oil production thus representing a new, major diversification opportunity for the oil and gas industry.

According to the IEA, in order to achieve climate targets in the Sustainble Development Scenario by 2050 the annual volume of CO_2 capture and storage in volumetric equivalent may reach 4,6GtCO_2 per year, which is comparable with the scale of today's global oil industry annual production.[184][185] This means that a new, huge CCUS industry, with competences similar to those of the oil and gas industry, should be created within the next 30 years (of course, if the proper regulation and carbon pricing will be in place). It is representing a new, major diversification opportunity for the oil and gas industry.

There is a wide variety of CCUS technologies currently under development (see Fig. 30-31 and Table 14). CCUS utilizes different process solutions, with the application of membrane technologies and the use of sorbent.

Fig. 30 - Overview of carbon dioxide capture technologies



Source:
https://www.researchgate.net/publication/257760384_Carbon_capture_from_stationary_power_generation_sources_A_review_of_the_current_status_of_the_technologies

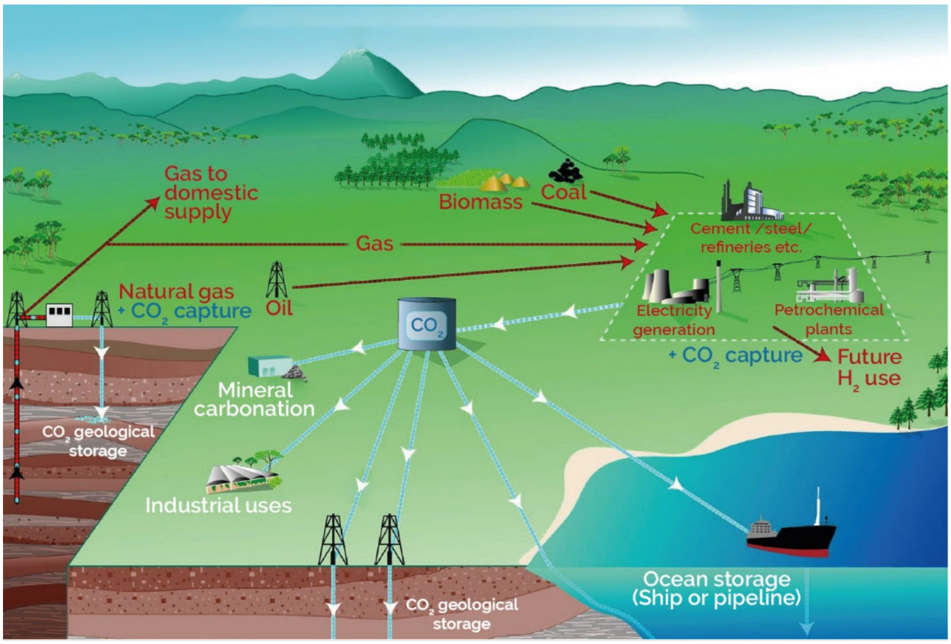
[184] CCUS in Clean Energy Transitions. IEA Flagship report, September 2020. https://www.iea.org/reports/ccus-in-clean-energy-transitions
[185] BP statistical review 2020.

Table 14 - CO2 capture technologies

Technology	Advantages	Implementation difficulties
Chemical absorption	Appropriate technology for natural gas processing and post-combustion; high capture efficiency and selectivity; low hydrocarbon losses	High capture heat ratio; risks of corrosion, emissions, and solvent degradation; challenges with new solvents to increase thermochemical stability; reducing capture and heat ratio and stripping temperatures allows use of waste heat
Physical absorption	Appropriate technology for natural gas processing and post-combustion; high capture efficiency; low heat ratio for regeneration	Low selectivity; hydrocarbon losses
Membrane technology	Technology is used in the natural gas processing of large-scale floating production storage and off-loadings; no regeneration; no chemicals; low footprint	Requires compression of fed natural gas and permeable membranes hydrocarbon losses; trade-off permeability-selectivity; low CO_2 partial pressure forbids it in post-combustion
Pre-burning capture	Potential lower cost technology; commercial for H_2 production; high efficiency; large-scale H_2 production	Complex scheme novel materials for high temperature CO_2 capture; high capital expenditure; insufficient, large-scale H_2-fired power plant experience
Cryogenic distillation	Appropriate technology for processing natural gas with high CO_2 content; high selectivity; low hydrocarbon losses; CO_2 obtained as liquid with benefits in CO_2 transport (no compressors needed; pumps used instead); appropriate for high CO_2 content	Avoidance of CO_2 freeze-out required

Source: https://static.clearpath.org/2019/12/191206-npc-roadmap-at-scale-deployment-of-ccus.pdf

Fig. 31 - Different carbon dioxide handling technologies and their readiness for industrial implementation



Source: https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_spm_ts_ru-1.pdf

To drive innovation in CCUS technology, investments from operators, oilfield services, and equipment and energy technology companies and cooperation between them are vital in overcoming the practical, real-world challenges and accelerate momentum toward decarbonization goals. For example, Baker Hughes recently acquired Compact Carbon Capture (3C), a pioneering technology development company specializing in carbon capture solutions. 3C's technology differs from traditional carbon capture solvent-based solutions in that it uses rotating beds instead of static columns, effectively distributing solvents in a compact and modularized format. The rotating bed technology enhances the carbon capture process resulting in an up to 75% smaller footprint and lower capital expenditures.[186]

So far CCUS represents quite a controversial business-model (Table 15). It provides for GHG emission reduction but is not regarded as a green technology; it is associated with high CapEx but does not generate good returns on investments. Nevertheless, it is already considered a critical component of all decarbonization efforts.

[186] https://investors.bakerhughes.com/news-releases/news-release-details/baker-hughes-signs-agreement-acquire-compact-carbon-capture

Table 15 – SWOT analysis of CCUS

Strengths	**Threats**
Reduction in GHG emissions, mitigation of adverse environmental impact, and prevention of climate changes Avoids the need to pay the carbon tax imposed on exporters of industrial and carbon products Compliance with the Paris Agreement and national regulations High demand among exporters of hydrocarbon products or metallurgical, chemical products, which affirm the need for greenhouse gas emissions	No approved methodological framework for designing and implementing process solutions No legal/regulatory framework Lack of voluntarily obligations on CCUS development High reliance on the market: enterprises transporting carbon dioxide and accepting it for storage and disposal Low interest among most branches of industry in the technology, due to the lack of commitments to introduce these processes
Weaknesses	**Opportunities**
High cost of equipment Long project payback periods Complex and multi-component process chain, which comprises different chemical, physical, and other processes No certified technologies that enable the comprehensive implementation of the capture, transportation, utilization, and burial processes No certifying enterprises, lack of unified requirements for certification No specialized transport facilities, available pipeline networks are intended for captured gas transportation Heterogeneity of facilities, lack of critical volume of primary stock (CO_2), for which capture technologies are necessary	Expansion onto new markets and to consumers who are interested in consuming low-carbon products Likelihood of high demand for the technologies in the transitional period of the change in energy resources due to the complexity of drastic transitioning to other fuel types and to the impossibility of promptly giving up using conventional fuel types (e.g., natural gas) Conformity to the closed-loop (circular) economic strategies as applicable to the CO_2 zero emission concept Conformity to European energy shifting and economic decarbonization programs

Source: Energy Centre, Moscow School of Management SKOLKOVO

These are some measures that could promote investing in the implementation of CCUS projects:

- purposeful governmental efforts to support the initiatives in the creation and development of CCUS projects, supported with promoting policy that comprehensively assesses the capital and operating costs of these projects,
- large-scale geological research, which would substantiate the opportunity to keep CO_2 in particular layers, given information on their dimensional features and the review of the options of CO_2 injection into the layer, to improve operating performance within the oil and gas sector,
- the possibility of tracking the income portion of the CO_2 capture and utilization projects, in particular, in the projects for pumping into oil-bearing formations,
- introduction of the industry carbon tax, an incentive to reduce CO_2 emissions,

- designing, development, and improvement of CCUS technologies, implementation of pilot projects, and
- raising awareness of CCUS technologies, advantages, and additional options available to enterprises from the implementation of CCUS technologies.

Most leading oil and gas companies invest already into large-scale CCUS projects, independently and jointly. These projects are mostly at the initial stages of implementation (Table 16).

Table 16 - Examples and features of CCUS projects implemented by oil and gas companies

Company name	Technology, project description, emission reduction, costs
Norske Shell, Total E&P Norge, and Eqinor[187]	Carbon storage on the Norwegian continental shelf is under development. The storage project will store CO_2 captured from onshore industrial facilities in Eastern Norway. This CO_2 will be transported by ship from the capture facilities to a receiving terminal located onshore on the west coast of Norway. At the receiving terminal, CO_2 will be transferred from the ship to intermediate storage tanks, prior to being sent through a pipeline on the seabed to injection wells east of the Troll field on the Norwegian continental shelf.
BP, ENI, Equinor, Shell, and Total, with BP leading as operator, Net Zero Teesside, U.K.[188]	Net Zero Teesside is a CCUS project, based in Teesside in the North East of England. Stage 1 Consultation on the Net Zero Teesside Project (NZT) was completed in fall 2019 and Net Zero Teesside was introduced to the local community. Following Stage 1 Consultation, further technical and environmental work was underway on Net Zero Teesside.
Equinor	In the U.K., Equinor's H2H Saltend project involves the production of blue hydrogen using CCS.[189] Below are some examples of pre-combustion CCS. Since 1996, 1 $MtCO_2$ per year have been separated during natural gas production from the Sleipner West field and stored in the Utsira Formation. Since 2008, the *Snøhvit* (Snoehvit) facility has been separating CO_2 from the well stream before cooling the gas to produce LNG. CO_2 is transported back to *Snøhvit* by pipeline and injected into the subsea reservoir. During normal operation, it stores up to 700,000 $MTCO_2$ per year.[190]
Chevron, Australia[191]	The Gorgon LNG project being developed in Western Australia is among the largest global LNG projects. It includes the world's largest CCUS operation, which captures 3-4 $MtCO_2$ each year assisted by a \$60 million government grant and delivered thanks to the multistage projects' pioneering carbon dioxide sequestration powered by compressions trains from key technology partner, Baker Hughes, which also supplied subsea equipment and LNG refrigeration trains.[192]

[187] https://www.total.com/media/news/press-releases/statoil-shell-and-total-enter-co2-storage-partnership
[188] https://www.netzeroteesside.co.uk/
[189] https://www.equinor.com/en/what-we-do/h2hsaltend.html
[190] https://www.norskpetroleum.no/en/environment-and-technology/carbon-capture-and-storage/
[191] https://australia.chevron.com/news/2019/carbon-dioxide-injection
[192] https://www.businesswire.com/news/home/20091021006630/en/GE-Oil-Gas-Awarded-400-Million-Contract-for-Gorgon-One-of-the-World%E2%80%99s-Largest-Natural-Gas-Projects

Company name	Technology, project description, emission reduction, costs
Shell, Quest, Canada[193]	This integrated CCS facility, designed to capture, transport, and store CO_2 deep underground has a scale of 1 $MtCO_2$ annually. By May 2019, less than four years after its startup, Quest had captured and safely stored more than 4 $MtCO_2$. The project is funded by CAN $745 million and CAN $120 million, from Shell and Quest respectively.
Qatar Petroleum	The company has commissioned a carbon capture and storage plant and aims to capture 5 million tonnes of carbon dioxide at its liquefied natural gas (LNG) facilities by 2025. The company is also considering the possibility of using CO2-EOR technology[194].

Source: Energy Centre, Moscow School of Management SKOLKOVO

The economic efficiency of CCUS projects directly depends on two parameters: the price of carbon (or carbon tax) and costs related to these projects.

So far, all these projects are more of a pilot nature, they require state support and are not a profitable business for companies in the oil and gas sector. In the long term, the economic efficiency of the implementation of CCUS will depend on two factors: on the rigidity of carbon regulation and the resulting size of price or tax on CO_2, as well as on progress in technology development and reduction of capital and operating costs of CCUS projects.

Table 17 - Carbon capture, transportation, utilization, and storage costs

Process	Price range ($/MT)	Energy resource source:	Reference to the source:
Capture			
	93	Oil and gas production	https://static.clearpath.org/2019/12/191206-npc-roadmap-at-scale-deployment-of-ccus.pdf
	37-74	Oil and gas production	https://www.osti.gov/servlets/purl/1170620
	40-140	Refinery	https://www.bcg.com/publications/2019/business-case-carbon-capture
	70-84	Refinery	https://www.sciencedirect.com/science/article/pii/S175058361730289X
	120	Oil and gas production	https://www.resourcesmag.org/resources-radio/going-deep-carbon-capture-utilization-and-storage-ccus-julio-friedmann/
	15-25	Oil and gas production	https://ccsknowledge.com/pub/documents/publications/2019May_IEA_Transforming_Industry_CCUS.pdf
Transportation	14		https://static.clearpath.org/2019/12/191206-npc-roadmap-at-scale-deployment-of-ccus.pdf
	4,3-7,2	$/MT CO_2/250 km	https://www.hindawi.com/journals/geofluids/2017/6126505/
Utilization (pumping)	0,5–8	$/MT	https://www.sciencedirect.com/science/article/pii/S2211339817300126
Storage	1-12	N/A	https://www.hindawi.com/journals/geofluids/2017/6126505/

Source: Energy Center, Moscow School of Management SKOLKOVO

[193] https://www.shell.ca/en_ca/about-us/projects-and-sites/quest-carbon-capture-and-storage-project.html
[194] https://www.aljazeera.com/economy/2019/10/8/qatar-building-large-co2-storage-plant

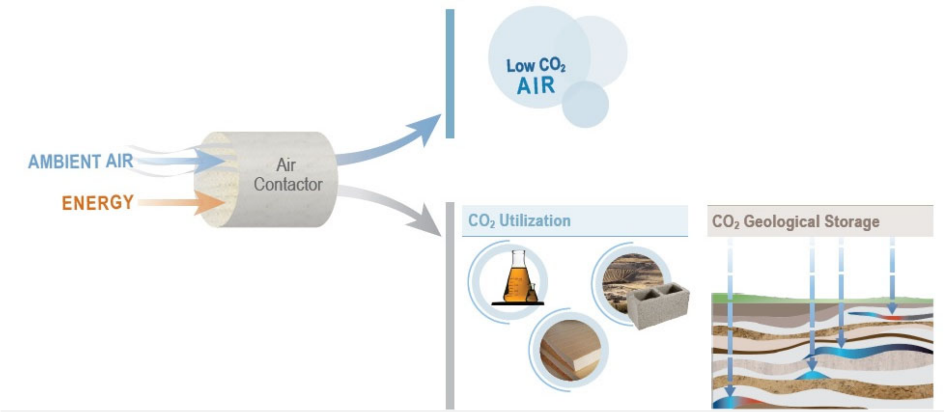
The assessment of specific costs for CCUS projects suggests that in the oil and gas industry, the carbon capture, transportation, and storage would cost approximately \$100/MtCO_2e.

Carbon removal

Carbon removal technologies involve extracting CO_2 from the atmosphere, directly or indirectly (via the absorption of CO_2 in biomass), and permanently storing it. The main attraction of carbon removal technologies is their potential to offset residual emissions from sectors where emissions are hard to abate, to achieve net-zero emissions across the energy sector.[195] They include direct CO_2 capture from the atmosphere (DAC) and Bio-energy with carbon capture and storage (BECCS). Both these technologies are enabling carbon dioxide removal making them negative emissions technologies, and both are currently only in the experimental phase.

Direct CO_2 capture from the atmosphere (DAC) is a process of capturing directly from the ambient air and generating a concentrated stream of CO2 for sequestration or utilization or production of carbon-neutral synthetic fuel.

Fig. 32 - Direct air capture of carbon dioxide



Source: Innovation for Cool Earth Forum (ICEF) Roadmap 2018. https://www.globalccsinstitute.com/wp-content/uploads/2020/06/JF_ICEF_DAC_Roadmap-20181207-1.pdf

According to the ICEF, there are currently three main process flows in CO_2 direct air capture:

- chemical, which uses liquid solvents or solid sorbents,
- cryogenic, which uses low temperatures and CO_2 freezing in the air, and
- membrane-based, which using membranes for ion exchange and reverse osmosis.

There are currently no commercial, scalable DAC projects, though there are already numerous experimental projects.

[195] CCUS in Clean Energy Transitions. IEA Flagship report, September 2020. https://www.iea.org/reports/ccus-in-clean-energy-transitions/ccus-in-the-transition-to-net-zero-emissions#removing-carbon-from-the-atmosphere

These projects involve not only tech startups but also major oil and gas companies and infrastructural corporations, of which there are several examples below.

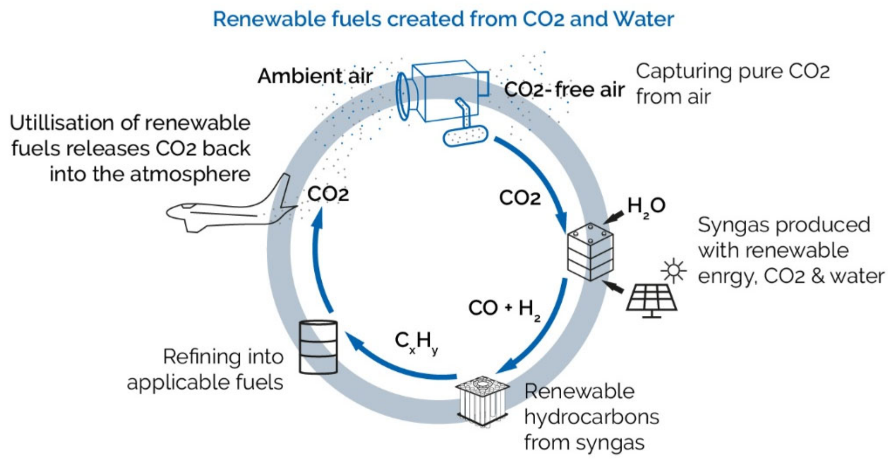
In May 2019, Oxy Low Carbon Ventures, a subsidiary of Occidental Petroleum, and Canadian Carbon Engineering, which provides clean-energy solutions, announced the development of the world's biggest project of direct carbon capture in the Permian oil and gas basin.[196] The plant is supposed to capture 500,000 $MTCO_2$ from the atmosphere annually. After being captured, the CO_2 will be used to increase oil recovery from formations in Occidental's licensed fields. In the future, the company plans to build more plants with the aim of capturing 1 $MtCO_2$ from the atmosphere annually (which is the equivalent of the annual CO_2 absorption of 40 million trees). Construction is scheduled to begin in 2021 and the facility is to be commissioned two years after construction start.

Eni and Zurich Polytechnic University's tech startup, Synhelion, announced the implementation of the captured CO_2 use project. They're working on a plant, which is to be commissioned in 2025, that use solar panel energy to produce methanol from CO_2 and water.[197]

ExxonMobil and the U.S. tech startup, Global Thermostat, investigate into the opportunities to use its direct CO_2 capture technology to reduce the massive carbon footprint of the U.S.

A project that uses solar energy to manufacturing synthetic fuel from CO_2 caught in the atmosphere, is to be implemented at the Rotterdam The Hague Airport. The project will be implemented using technologies from the Swiss company, Climeworks, and aims to manufacture 1,000 L of aviation fuel daily[198]. This project would enable the complete closure of the carbon cycle (Fig. 33).

Fig. 33 – Closing the carbon cycle



Source: Climeworks

[196] https://www.oxy.com/News/Pages/Article.aspx?Article=6095.html
[197] https://www.eni.com/en-IT/media/press-release/2019/06/eni-and-synhelion-team-up-to-produce-low-emission-fuel-using-renewable-energy.html
[198] https://climeworks.com/news/renewable-jet-fuel-from-air

The main obstacle to implementing direct CO_2 capture projects is their cost. For instance, Climeworks Technology ensures CO_2 capture at $600/MT$CO_2$e, with plans to reduce this to $100/MT$CO_2$e by the end of the decade. GlobalThermostat announced that the reduction in CO_2 price to $100/MT$CO_2$e is possible if a cheap, or free, heat and energy source become available.[199]

Another promising carbon removal technology is bio-energy with carbon capture and storage (BECCS) which is the process of extracting bioenergy from biomass and capturing and storing the carbon, thereby removing it from the atmosphere. The carbon in the biomass comes from CO_2 which is extracted from the atmosphere by the biomass when it grows. Energy is extracted in useful forms (electricity, heat, biofuels, etc.) as the biomass is utilized through combustion, fermentation, pyrolysis or other conversion methods. Some of the carbon in the biomass is converted to CO_2 or biochar which can then be stored by geologic sequestration or land application, respectively.

The IPCC states that estimations for BECCS cost range from $60-$250 per ton of CO2.[200] There are just few projects in this area, in particular just recently Chevron, Microsoft and Schlumberger have announced their collaboratin on carbon negative bioenergy project designed to produce carbon negative power in Mendota, California.[201] The BECCS plant will convert agricultural waste biomass, such as almond trees, into a renewable synthesis gas that will be mixed with oxygen in a combustor to generate electricity. More than 99% of the carbon from the BECCS process is expected to be captured for permanent storage by injecting CO_2 underground into nearby deep geologic formations. The plant, when completed, is expected to remove about 300,000 MTCO_2e annually.

CO_2-EOR

There are excellent prospects for CO_2 capture technology for injecting the captured CO_2 into exhausted oil-bearing formations for oil recovery enhancement. This method is called CO_2-EOR.

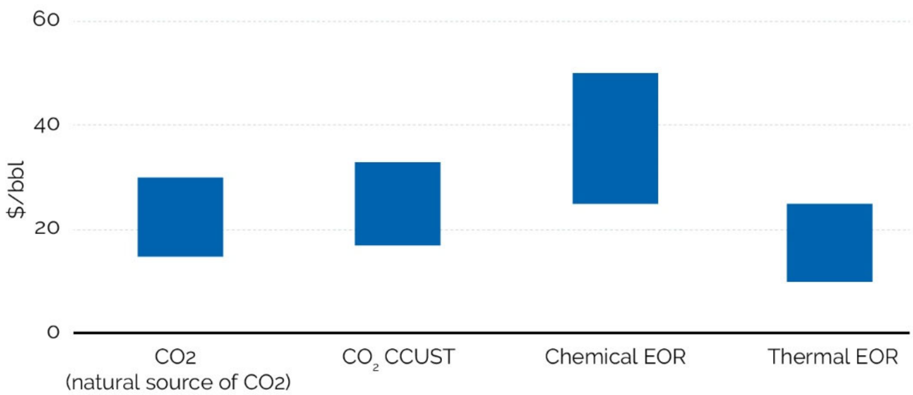
Boundary Dam is among the major projects for injecting captured CO_2 into formations. Boundary Dam Power Station is the biggest coal power plant owned by Sask Power, located in Saskatchewan, Canada.[202] Investments into upgrading the power plant and CCS plant are estimated at $354 million and $1.2 billion, respectively. The Canadian Government invested $240 million into the project. The captured CO_2 volume amounts to 1

[199] http://www.geoengineeringmonitor.org/2019/07/direct-air-capture-recent-developments-and-future-plans/
[200] https://www.reuters.com/article/us-climatechange-ccs-idUSBREA2P1LK20140326
[201] https://www.chevron.com/stories/chevron-microsoft-and-schlumberger-partner-on-carbon-negative-bioenergy
[202] Proceedings of the International Conference on Industrial Engineering and Operations Management Rabat, Morocco, April 11-13, 2017 An Overview of Power Plant CCS and CO2-EOR Projects, Saber Kh. Elmabrouk, Husen E. Bader, Walid Mohamed Mahmud.

million tons per annum (Mtpa).[203] Of the captured CO_2, 90% is compressed and transported via the 66 km long pipeline to the Weyburn field, where the oil recovery enhancement project with CO_2 injection is being implemented.[204] The remaining 10% is channeled to the Aquistore Project, 2 km from the station, which is supported by the Petroleum Technology Research Centre. Aquistore works on measuring and monitoring CO_2 to verify the hypothesis that storing carbon dioxide 3.4 km underground a water environment with a salt solution and sandstone is a safe and efficient solution for GHG emission reduction.[205]

CO_2-EOR is one of the tertiary oil recovery methods which are characterized by high operating costs. For CO_2 injection, operating costs account for up to 55% of total costs and include the costs of CO_2 purchasing and separation from oil and well maintenance[206]. In general, tertiary oil recovery methods make oil production $10-50 bbl more expensive (Fig. 34), which means that, at the current prices, such methods cannot be applied everywhere.

Fig. 34 - Comparison of oil production cost breakdowns (pre-tax)



Source: https://irp-cdn.multiscreensite.com/5b322158/files/uploaded/Subtask5_3.pdf,

https://www.elsevier.com/__data/assets/pdf_file/0017/230831/RDS_OG_EP_WP_-EOR-Right-Strategy_DIGITAL.pdf, Evaluation of Three Large Scale ASP Flooding Field TestNormal access, Hu Guo, Y. Q. Li, R.C. Ma, F. Y. Wang, and Z. Shihu, IOR 2017 - 19th European Symposium on Improved Oil RecoverySession: Poster Introductions 3, Publication date: 24 April 2017, DOI: 10.3997/2214-4609.201700257, Liu K., Wei X. (2017) Oil Recovery: Experiences and Economics of Microbially Enhanced Oil Recovery (MEOR). In: Lee S. (eds) Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Production of Fuels and Chemicals. Handbook of Hydrocarbon and Lipid Microbiology. Springer, Cham

The cost of CO_2 is a key factor in the success of carbon taxing because it has a major impact on the economy of this method of oil recovery enhancement. In general, the cost of CO_2-EOR operations varies with in three main parameters: oil prices, CO_2 cost, and various, if any, benefits. Purchasing CO_2 is the biggest cost item when applying CO_2-EOR. CO_2-related costs, including

[203] https://www.power-technology.com/projects/sask-power-boundary/
[204] https://sequestration.mit.edu/tools/projects/boundary_dam.html
[205] https://ptrc.ca/projects/co2-eor-and-storage/aquistore
[206] Carbon Dioxide Enhanced Oil Recovery. Untapped Domestic Energy Supply and Long Term Carbon Storage Solution, NELT, DOE, 2010.

the CapEx of CO_2 transportation, injection, and separation from oil, may be as high as 25-50% of the produced oil price per bbl.[207] Companies using carbon taxes do not normally publish CO_2 prices. However,the CO_2 price for carbon tax purposes is usually linked to the oil price. An operator is usually ready to pay approx. 2% of WTI oil price/bbl per million cubic feet CO_2.[208][209] Though before the oil crisis, the average price of CO_2 was $20-30/ton, it is currently estimated at $10-15/ton, with oil prices at $40-55/bbl.[210] Thus, the development and cost-lowering of CCS technologies are the main factors in successful CO_2-EOR application.

In addition to high costs, there are some other constraints for CO_2 capture and injection projects for enhance oil recovery. These constraints are related to technical solutions, business environments, and legal/regulatory issues. The key technical challenges for CO_2-EOR are whether a tank is suitable for storing CO_2 (not all collectors are suitable for storing CO_2).and whether there are requirements for monitoring and accounting for CCS and CO_2 leaks. [211]

Hydrogen

Even though oil and gas companies around the world have been using hydrogen in their processes at refineries and petrochemical plants for several decades already, the use of hydrogen for decarbonization is a relatively new approach for the industry and the global economy in general. The essence of this approach is the potential to produce hydrogen with almost zero GHG emissions and to use it as a global all-purpose, low-carbon energy carrier. It may enable deep decarbonization even in those sectors that are poorly adapted for that purpose (e.g., energy intensive industry, heavy-freight, and long-distance transportation).[212]

According to IEA Sustainable Development Scenario, as early as 2040, the annual consumption of low-carbon hydrogen may reach 75 Mt worldwide,[213] provided the consumption of such hydrogen was near-zero level in 2020. In this case, by 2040 , the

[207] Kuuskraa, V., Ferguson, R., and Van Leeuwen, T. (2009). Storing CO2 and Producing Domestic Crude Oil with Next Generation CO2-EOR Technology, Report DOE/NETL2009/1350 prepared by Advanced Resources International, Inc. for Department of Energy, Pittsburgh, PA: National Energy Technology Laboratory.
[208] Middleton, R. S. (2013). A new optimization approach to energy network modelling: anthropogenic CO2 capture coupled with enhanced oil recovery. Int. J. of Energy Res. 37, 1794–1810. doi: 10.1002/er.2993
[209] Kuuskraa, V. A., Van Leeuwen, T., and Wallace, M. (2011). Improving Domestic Energy Security and Lowering CO2 Emissions with "Next Generation" CO2-Enhanced Oil Recovery (CO2-EOR). Pittsburgh, PA: National Energy Technology Laboratory.
[210] https://s1.q4cdn.com/594864049/files/doc_presentations/2020/03-2020-Credit-Suisse-Presentation-Final.pdf
[211] Technical aspects of CO2 EOR and associated carbon storage, Global CCS Institute, 2013
[212] For more details on hydrogen as a low-carbon energy carrier and the "hydrogen economy" concept please refer to: Hydrogen Economy: Path to Low Carbon Development. /T.A. Mitrova, Yu.V. Melnikov, D.A. Chugunov, Moscow School of Management SKOLKOVO, June 2019. - Access mode: https:// energy.skolkovo.ru/downloads/documents/ SEneC/ Research/ SKOLKOVO_EneC_Hydrogeneconomy_Rus.pdf
[213] Sustainable Development scenario, World Energy Outlook 2020

amount of energy carried and stored in hydrogen be more than the global output of wind and solar energy today.

In this vein, oil and gas companies have two options:

a) develop projects for producing low-carbon hydrogen, then transfer and sell it to end-consumers to diversify business and to develop low-carbon products in the company's portfolio (scope 3 emission reduction);

b) consume low-carbon hydrogen for inter-company needs to reduce GHG emissions classified under scopes 1 and 2.

Companies such as Shell, Equinor, Total, Sinopec, PetroChina, Aramco, BP, OMVAG, Chevron, Gasunie, Snam, Petroleum Development Oman, Indian Oil, and Idemitsu Kosan are already involved in various pilot hydrogen-related projects. Below there are some examples of these pilot projects within the two options mentioned above.

Hydrogen production, transportation, and sales

Oil and gas companies are producing hydrogen using methane steam reforming technology. Oil and gas are used as raw materials and CO_2, amounting to at least 9 kg per 1 kg of hydrogen (according to the IEA), is a by-product. Such hydrogen is often called "gray" in public discussion, emphasizing its relation to GHG emissions. Its applicability as an energy carrier is limited. Even though gray hydrogen is often used in pilot projects to fine tune technologies and value-adding chains, the demand for it will dissipate over time. The reason for this is that the expanded use of gray hydrogen does not quickly reduce, but rather increases, GHG emissions.

Below are a few examples of some oil and gas companies' promising research and projects focused on "blue" and "green" hydrogen production.

- "Blue" hydrogen is derived by methane steam reforming, which must occur in combination with the CCUS technologies described above.

  For example, the Japanese oil company, Idemitsu Kosan, is fine tuning its blue hydrogen production technology at the Tomakomai refinery (Hokkaido Island, northern Japan). After capture, CO_2 is injected into two underground storage units located 1-3 km under the sea floor. The project's target CO_2 storage level of 300,000 MT was achieved between April 2016 and November 2019. Then the project turned to the monitoring phase.[214]

- "Green" hydrogen is derived from water through electrolysis, which uses the electricity generated from renewables.

[214] Tomakomai CCS Demonstration Project. https://www.japanccs.com/en/business/demonstration/

For example, Shell, in partnership with Gasuine, is developing the NortH2 Project, the world's biggest project on green hydrogen. The project concept is to set up a green hydrogen plant in the northern Netherlands, using electricity from offshore wind clusters (North Sea). The project's targets are 800,000 MT of hydrogen and a 10-GW wind cluster capacity by 2027. Hydrogen is to be delivered to consumers in the Netherlands via the gas supply system. The Project feasibility study is set to be finalized by the end of 2020.[215]

- "Turquoise hydrogen" is a product of methane pyrolysis, a high-temperature process to convert methane into hydrogen gas and solid carbon in the presence of a catalyst.

  For example, Eni Next (the venture investing arm of Italian oil company Eni) together with Breakthrough Energy Ventures, AP Ventures and Mitsubishi Heavy Industries are investing in hydrogen startup C-Zero, which is approaching from lab tests to pilot plant scale of turquoise hydrogen production.[216]

In addition to hydrogen production, oil and gas companies are also quite interested in the development of hydrogen transportation. It can be transported via existing gas transport infrastructure, and pilot projects in this field are already being implemented by gas companies in Europe. For example, the Italian company, Snam, was the first company in Europe to conduct successful tests of hydrogen injection into the gas distribution system, with up to 10% of hydrogen in the gas mix.[217] In August 2020, British companies, National Grid and Northern Gas Networks in partnership with Equinor, announced the construction of a testing ground in northwestern England for testing the opportunities and limitations of hydrogen use for heating houses and industrial buildings.[218][219] The project investments will exceed €10 million, and the testing ground is set to be launched in 2022.

The sale of hydrogen to end consumers, e.g., owners of electric cars with fuel components, can be implemented by oil and gas companies via their filling stations networks. The European H2Mobility Project, intended to develop hydrogen filling related infrastructure, involves Total, Shell, and OMV AG. As of October 2020, as part of this project, 115 hydrogen filling stations are in operation and 50 more are expected to be commissioned.[220]

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[215] Europe's largest green hydrogen project starts in Groningen. Cited by: https://www.gasunie.nl/en/news/europes-largest-green-hydrogen-project-starts-in-groningen
[216] https://www.greentechmedia.com/articles/read/c-zero-raises-11.5m-to-scale-up-turquoise-hydrogen-technology
[217] https://www.snam.it/en/energy_transition/hydrogen/snam_and_hydrogen/
[218] https://www.nationalgrid.com/5-aug-2020-national-grid-launch-ps10m-trial-project-test-if-hydrogen-can-heat-homes-and-industry
[219] https://www.northerngasnetworks.co.uk/event/h21-launches-national/
[220] https://h2.live/en/tankstellen

Hydrogen consumption for inter-company needs

Oil and gas companies already consuming hydrogen for inter-company processes may substitute the current grey hydrogen with carbon-free hydrogen, thereby reducing the carbon footprints of their products. These projects are more often implemented in downstream operations at petrochemical plants. For example, BP, in partnership with Uniper energy company, is going to create a 15-MW electrolysis plant at the Lingen Refinery in Germany, which will generate electricity from renewables and produce green hydrogen to substitute the gray hydrogen being consumed at the plant.[221]

Another possible application is substituting natural gas by hydrogen as fuel for the oil and gas companies' internal needs. Snam (Italy) is implementing such a project in partnership with the energy technology company, Baker Hughes. In July 2020, the two companies announced the completion of tests of the world's first hybrid hydrogen turbine for gas transportation grids.[222] The NovaLT12 turbine can be fueled by a methane and hydrogen mixture (MHM), with up to 10% hydrogen content, which will enable Snam to reduce up to 5 $MtCO_2$ per year. The turbine is to be installed in Snam's compressor station in Istrana Commune (Veneto, Italy) by 2021. Similar projects can be implemented in upstream or downstream sectors where gas turbines are used.

Hydrogen can be used in the marine transportation of hydrocarbons, too, by converting a tanker's power plant to partial hydrogen use. This is similar to the process tested in gas turbine drives of stationary compressors in gas pipelines. Based on the unique features of marine transportation (the limited weight and dimensions of the vessels' fuel storages, etc.), the combination of carbon-free hydrogen and ammonia can be considered.[223] For more details see chapter on "GHG emission reductions during oil and gas marine transportation by shifting to low-carbon fuel types".

The key barriers fot the hydrogen economy development today are:

- insignificant global production volumes of carbon-free hydrogen,
- demand uncertainty and lack of market framework, including regulation, standard contracts and transpsrent pricing, etc.;
- high costs of green and blue hydrogen production (gray hydrogen costs start from \$1/kg; blue hydrogen is

[221] https://www.carboncommentary.com/blog/2020/11/13/bp-and-synthetic-fuels-at-the-lingen-refinery
[222] https://www.bakerhughes.com/company/news/snam-and-baker-hughes-test-worlds-first-hydrogen-blend-turbine-gas-networks
[223]https://www.ajudaily.com/view/20200924125922807

estimated to be at least 30% more expensive; green hydrogen is at least 4x the cost of gray hydrogen),

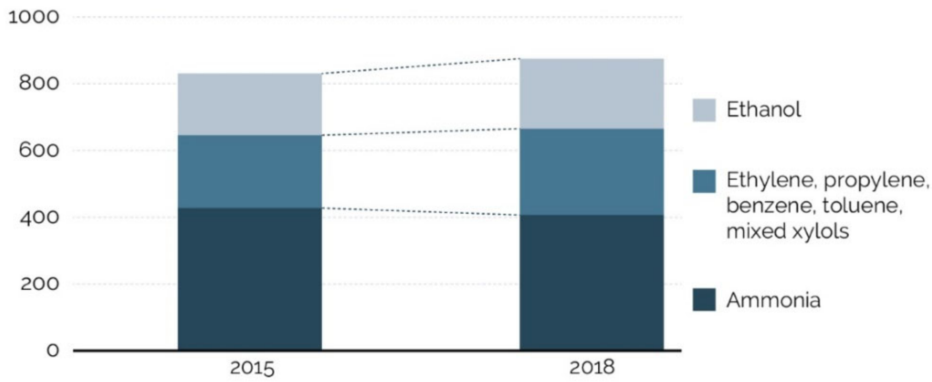
- insufficient technological maturity/readiness of other promising technologies (such as methane pyrolysis), and
- insignificant scaling and high cost of hydrogen storage and transportation (especially over long distances).

Together, these barriers make it nearly impossible to launch pilot projects and scale them without policy support measures such as carbon pricing, subsidies, and tax breaks.

Decarbonization of the petrochemical sector

According to the IEA, global direct CO_2 emissions from primary chemical manufacturing facilities[224] reached 880 Mt[225] in 2018, making them the leading producers of CO_2 emissions within the processing industry. Of these emissions, 24%, 46%, and 30% accounted for the production of methanol, ammonia, and other products, respectively (Fig. 35). The growing demand for these products in recent years has also added to the increase in GHG emissions (6% carbon dioxide emission growth since 2015).

Fig. 35 - CO2 direct emissions from primary chemical manufacturing facilities in 2015 and 2018, Mt

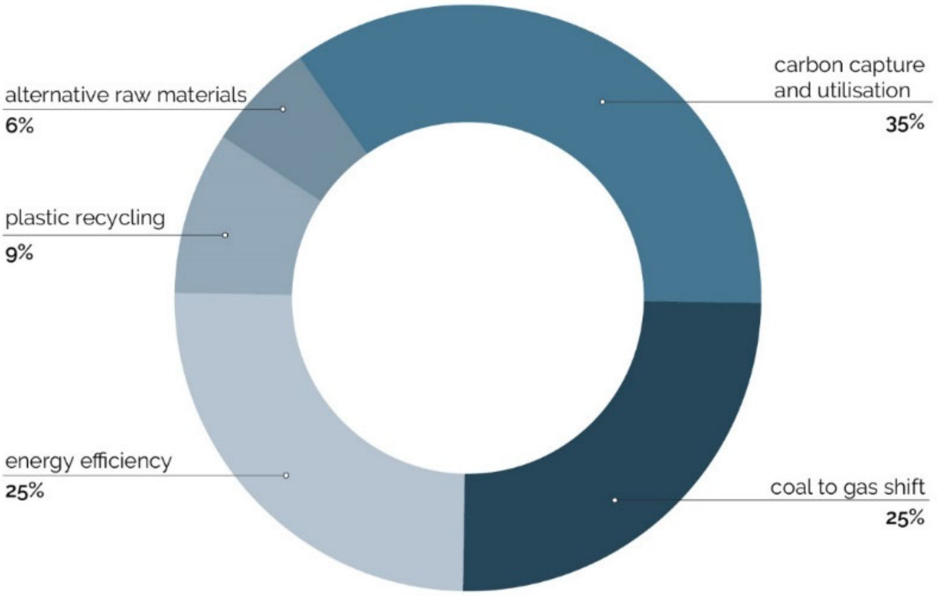


Source: IEA.

Compared to 2017, CO_2 direct emissions from manufacturing chemicals and petrochemicals may decrease by 45% by 2050, despite the projected 40% growth in demand for petrochemical products, according to IEA. This will be mostly facilitated by carbon capture and utilization technologies, a coal-to-gas shift in the industry, and energy efficiency improvement (Fig. 36).

[224] Ethylene, propylene, benzene, toluene, mixed xylols, ammonia and methanol are classified by IEA as primary chemicals and account for approx. two thirds of the chemical and petrochemical sector energy consumption.
[225] P. Levi, T. Vass, H. Mandová, A. Gouy. Chemicals. Tracking report – IEA, June 2020// https://www.iea.org/reports/chemicals

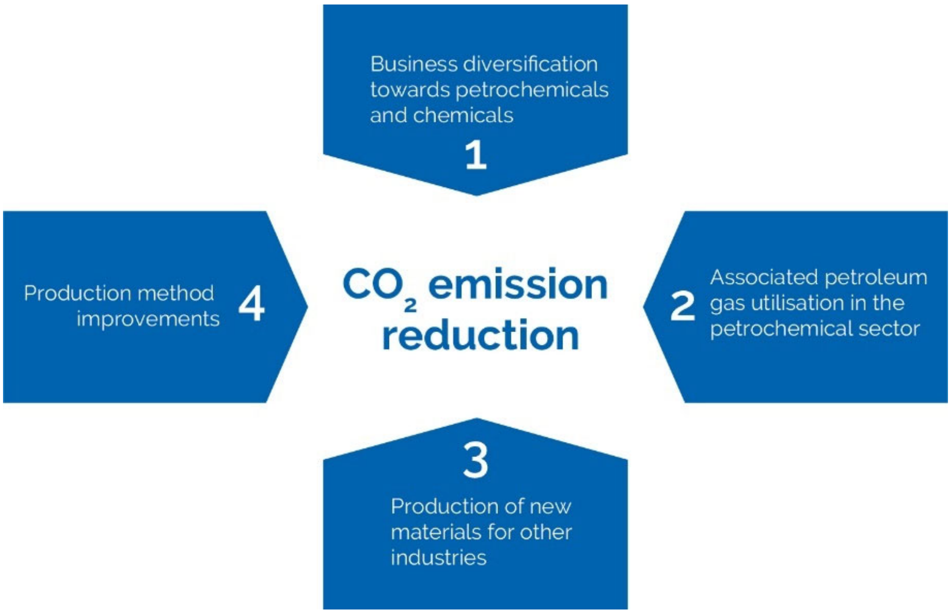
Fig. 36 - Contribution of different factors to reducing direct greenhouse gas emissions in primary chemical manufacturing by 2050



Source: IEA.

By 2050, the whole global chemical industry will directly and indirectly contribute to a 5-10 $GtCO_2e$ annual reduction of emissions (approx. 15-30% of total current global CO_2 emissions),[226] according to the International Council of Chemical Associations' study. There are currently four distinguishable areas of decarbonization areas within the petrochemical sector (Fig. 37).

Fig. 37 - Areas of CO2 emission reduction by petrochemical sector enterprises



Source: Energy Centre, Moscow School of Management SKOLKOVO.

Business diversification towards petrochemicals, chemicals, and APG utilization are regarded by oil and gas companies as a way

[226] Avoiding Greenhouse Gas Emissions. Enabling the Future. Chemistry innovations for a low-carbon society - International Council of Chemical Associations (ICCA), 2020.

to monetize produced resources. These business areas are becoming increasingly important for oil and gas companies looking towards decarbonization and more sustainable development with the raising climate agenda. These same areas are important for petrochemical/chemical enterprises within oil and gas corporations and independent, specialized petrochemical companies looking towards decarbonization and more sustainable development.

Business diversification towards the petrochemical and chemical industry

Oil and gas companies' portfolio diversification towards petrochemicals

The global chemical sector is the leading industrial consumer of oil and gas (15% and 9% of global consumption, respectively). Major oil and gas corporations are becoming increasingly interested in the petrochemical and chemical industry because of the potential synergy they see through integration with oil refining systems, as well as the potential for the monetization of available raw hydrocarbons, improvement of output marginality, and, increasing also presented as part of ESG agenda and decarbonization goals.

More and more oil and gas and petrochemical companies are shifting from basic petrochemical products to more deeply processed ones, seeking to enter high-margin product sectors to enhance the monetization efficiency of the resources these companies produce. Meanwhile, as the role of decarbonization and environmental impact reduction policies starts to grows, a more comprehensive use of produced hydrocarbons, particularly in the petrochemical sector, seems to hold promise not only in resource monetization but also in subsequent tax burden reduction and raising funds for business development.

For example, Total is including low-carbon economy development plans (production of biofuel and bioplastics, processing of plastics, etc.)[227] into its processing and chemical unit strategies. Shell's strategy is focusing increasingly on natural gas (the most environment-friendly hydrocarbon), chemical sector development, and a broad product range within that sector.[228] And Chevron is accounting for the risks and market changes associated with climate change when making its business development decisions. The company plans to expand its oil refining and petrochemical/chemical units (boosting profits across the entire value chain), implement biofuel production projects, and step up investments into closed-cycle project within its petrochemical businesses.

[227] 2019 Strategy & Outlook Presentation Total, 2019// URL: https://www.total.com/media/news/press-releases/2019-strategy-outlook-presentation
[228] Shell website// https://www.shell.com/investors/shell-and-our-strategy/our-strategy.html

Product portfolio diversification in favor of oil and gas chemicals

Compared to the power industry, the oil and gas chemicals industry generates a more sustainable demand for raw hydrocarbons. More than half of the hydrocarbons consumed in this industry are used as raw materials rather than combusted energy resources. The industry's aggregate contribution to generating direct GHG emissions per unit of raw hydrocarbons used is less than that of the fuel and energy industries that fully combust raw hydrocarbons to produce energy.

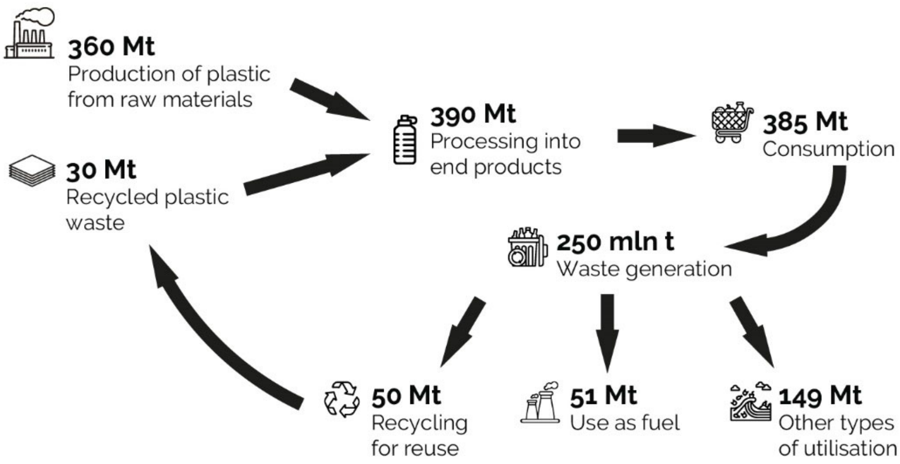
In terms of indirect GHG emissions, oil and gas chemicals have some advantages over the conventional product range of oil and gas companies. The end products made from naphtha, LNG, and ethane result in less GHG emissions than fuel combustion made from a similar volume of raw hydrocarbons for electricity or thermal energy generation.

If the environmentally responsible approach to the lifecycle of oil and gas chemicals is taken, these products also have obvious advantages over other refined products, like transport fuels. The making of bioplastics by including renewable biological raw materials into manufactured products is one such approach within the chemical industry. In recent years, BASF, Dow, Cargill, Evonik, BioAmber, and others have been actively developing technologies for chemical product manufacturing with the use of mill cake, corn, sawdust, soybeans, and other types of biological raw materials. Bioplastics, nitric fertilizers, lubricants, detergents, ink, and other products can comprise biological raw materials. For example, BASF produces the biomaterial, Ecovio, a bioplastic for package manufacturing, use of which reduces one's carbon footprint. The company also produces 1.4-butanediol from renewable raw materials, which is used for producing plastics, solvents, chemical substances, and elastic fibers.[229]

Carbon footprint mitigation can also be achieved in the industry by reducing the share of plastic waste burned or delivered to landfills, as these increase GHG emissions. Thus, plastic waste recycling is another way to improve the environmental sustainability of oil and gas chemicals. In 2018, 30 Mt of recycled plastic were used for manufacturing 390 Mt of plastic products[230] (Fig. 38).

[229] Basf website// https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy/dedicated-bio-based-production.html
[230] Global Plastics Flow 2018 - Conversion Market & Strategy GmbH.

Fig. 38 - Global plastic product handling flows in 2018



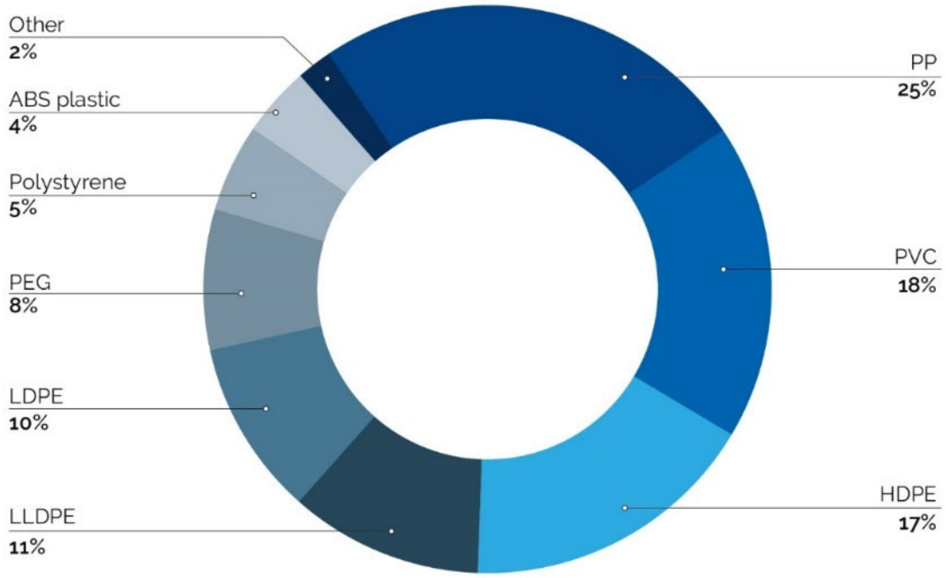
Source: Energy Centre, Moscow School of Management SKOLKOVO based on Global Plastics Flow 2018.

Plastics can be recycled through thermomechanical, chemical, or biological methods. Thermomechanical recycling is the most common and long-established method. However, it is associated with numerous limitations on types of recycled plastics and the products made of them. With chemical recycling, the chemical structure of plastic waste can be modified, which allows for the manufacturing of products with similar qualities to those of the products manufactured from primary raw materials. This recycling type is less common now but is actively being developed and is the most promising. Bio-recycling (using bacterial, fungal, worm, and insect enzymes to degrade plastics) is also a potentially promising but not yet commercially implemented type of plastic recycling.[231]

Wood Mackenzie[232] estimates that, currently, the bulk of global polymer recycling is accounted for by polyethylene terephthalate (PET), which represents approx. 8% of polymer production structure (Fig. 39), and, to a lesser extent, by polyethylene. Polypropylene, polyvinyl chloride, and polystyrene account for less than 1% of recycling (Table 18).

[231] A. Shartogasheva. Closed circle of recycling – Sibur, 2020//URL: https://www.sibur.ru/press-center/publications/Zamknutyykrugresayklinga/
[232] A. Gelder, G.Haire. Energy Transition & Circular Economy. Friend or foe to the Middle East chemicals sector?// Wood Mackenzie, November 2018.

Fig. 39 - Global plastic product handling flows in 2018



Source: Wood Mackenzie

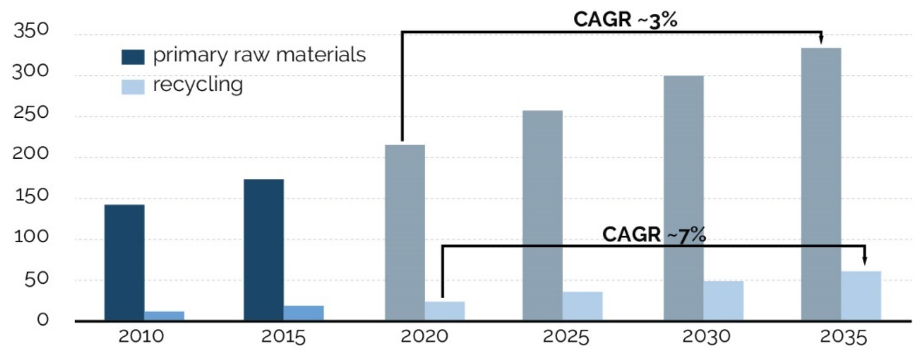
Table 18 - Polymer product recycling share

Polymer type	Recycling share
PET	>50%
PE	<7% (mostly HDPE)
PP	<1%
PVC	<1%
Polystyrene	<1%

Source: Wood Mackenzie

However, PE, PP, and PET recycling is expected to increase in the near future and to surpass the growth in the demand for primary raw materials used in the manufacturing of these products (Fig. 40). The changing consumer preferences and the global environmental and climate agenda, which influence public authorities and product manufacturers, help solve the problem of environmentally harmful plastic waste disposal.

Fig. 40 - Demand for primary raw materials in PE, PP, and PET manufacturing and their recycling in 2010/2035, Mt



Source: Wood Mackenzie

Many chemical companies are developing plastic recycling. BASF is implementing a comprehensive plastic recycling project called ChemCycling.[233] Dow Chemical Company, as part of a comprehensive strategy, is working on integrating recycled plastic into its products.[234] By 2030, the company intends to scale up its plastic recycling volume to over 1 Mt a year.[235] The Norwegian company, Quantafuel, supported by BASF, is expanding a technology for converting mixed plastic waste into liquid.

Oil and gas companies are also involved in plastic waste recycling. BP is developing the BP Infinia technology, which will be used for recycling PET into premium quality raw material for manufacturing new packages.[236] Shell is developing new process flows for recycling plastic waste into liquids that can be used as fuel or raw material for new products. By 2025, the company plans to recycle up to 1 Mt of plastic waste at its chemical enterprises.[237]

APG utilization in the oil and gas chemicals industry

A separate chapter in this paper is devoted to APG utilization. Here we highlight only that APG use in the manufacturing of oil and gas chemicals is an excellent alternative to APG flaring.[238] As technologies evolve, the concept of APG processing in the field becomes more prevalent worldwide, thanks to mobile modular solutions for raw material recycling.

Production of new materials for other industries

Oil and gas enterprises manufacturing new materials for other industries make an indirect contribution to combating climate change. This manufacturing limits GHG emissions in other industries indirectly and, consequently, is a factor of sustainable business development for oil and gas chemicals companies.

The development of chemicals and oil and gas chemicals has resulted in the creation of new product types, which has enabled energy savings and, thus, mitigated growth in carbon dioxide emissions by households, vehicles, industrial enterprises, and infrastructure. These product types include the entirely new construction materials that have made a significant contribution to energy savings in buildings and structures. Materials such as window system Styrofoam and PVC insulation, which enhance

[233] BASF website// URL: https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy/mass-balance-approach/chemcycling.html
[234] https://corporate.dow.com/en-us/science-and-sustainability/plastic-waste.html
[235] Dow website// URL: https://corporate.dow.com/en-us/news/press-releases/dow-sets-targets-to-reduce-ghg-emissions--stop-plastic-waste--an.html
[236] BP website// URL: https://www.bp.com/en/global/bp-petrochemicals/sustainability/infinia-recycling.html
[237] Shell website// URL: https://www.shell.com/sustainability/environment/plastic-waste.html
[238] D.A. Siginevich, A.N. Efimova. APG recycling as the petrochemical industry development resource in the Russian Federation // Eurasian Science Messenger, No. 5, 2018.

energy efficiency within buildings, are widely used in today's construction industry.

The use of polymer materials in utilities piping, buildings, and structures has ensured increased energy savings by reducing heat conduction in heating systems. Conventional steel pipes are susceptible to corrosion, which limits their service life to approx. 20-30 years. Polymer pipes have a longer service life of approx. 50 years.[239] Therefore, use of polymer materials in piping has enabled the reduction of heat losses and improvement of repair processes.

Composite materials that reduce product weight, fuel additives, and a number of other products of the industry have supported energy efficiency progress in land, water, and air transportation. For instance, use of composite materials in car making helps decrease vehicle weight by 20-25%,[240] which leads to lower fuel consumption.

In the future, polymer materials may also contribute to RES development, in particular, the manufacturing of solar batteries and the accumulators necessary for their efficient use. For instance, polymers are applied in the manufacturing of the photoelectric elements of solar power plants, though this type is now less common than silicon solar batteries.[241] Lithium-polymer batteries, which are not currently very widespread, have potential for expansion in the future. Japanese APB has developed manufacturing technologies for a new type of lithium-polymer battery that may become a serious product competitor for a lithium-ion battery in 5-10 years.[242]

Thus, when drafting development strategies and making investment decisions, oil and gas companies and relevant chemical companies need to pay attention to the carbon footprint of the entire lifecycle of their products and assess the indirect effects of their business on the decarbonization of the global economy.

Production method improvements in the industry of oil and gas chemicals

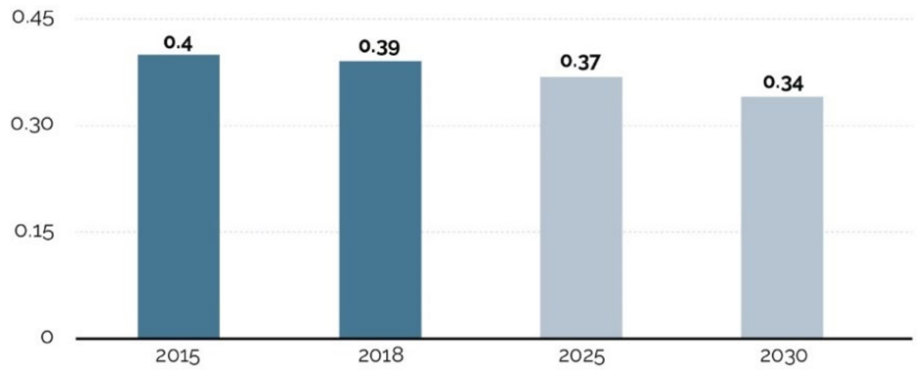
Oil and gas companies with integrated chemical facilities and specialized chemical companies are actively reducing carbon intensity in production by improving process flows. The greater impact of worldwide environmental and climate policies encourages them to develop this line of business more purposefully and to implement innovation projects that enable

[239] Pipe polymers in municipal utility systems in 2015/2025. RUPEC information and analytical center, URL: http://rupec.ru/analytics/32317/
[240] P.N. Timoshkov, A.V. Khrulkov, L.N. Yazvenko. Composite materials in car making. – E-scientific journal, VIAM PAPERS, No. 6, 2017.
[241] How have polymers managed to become another step in the solar energy evolution? – Forbes//URL: https://www.forbes.ru/tehnologii/344223-kak-polimery-stali-eshchyo-odnim-shagom-v-razvitii-solnechnoy-energetiki
[242] Japan's APB develops new polymer battery – Argus, 2020//URL: https://www.argusmedia.com/en/news/2122571-japans-apb-develops-new-polymer-battery

adaptation of current operations to new public demands. These include:

Enhancing energy efficiency and saving resources when manufacturing oil and gas chemicals. Oil and gas chemicals companies, just as enterprises in a number of other industries, are developing projects to upgrade process flows and technical facilities to reduce the energy intensity of their production processes. The prospects of energy efficiency improvement by using catalysts to accelerate and enhance the efficiency of chemical reactions are worth noting separately. According to a joint study conducted by IEA, the International Council of Chemical Associations, and the German Chemical Engineering and Biotechnology Society, the energy savings potential from the application of catalysts may amount to 13 exajoules by 2050, which is comparable to the annual consumption of primary energy in Germany.[243] Energy efficiency is regarded by oil and gas chemicals companies as a priority for reducing GHG emissions. For instance, from 1990 to 2018, BASF was able to halve GHG emissions mostly due to energy efficiency efforts and improving production processes, while, in the same period, doubling its output.[244] IEA estimates that the energy intensity potential in the manufacturing of primary chemicals (per unit of manufactured products) can add extra 13% of what is was in 2018 by 2030 (Fig. 41).

Fig. 41 - Energy intensity of manufacturing primary chemicals under the sustainable development scenario, 2015/2030



Source: IEA.

Introducing carbon capture and storage technologies. So far, this effort is not very common. However, there are several examples of applying this technology, particularly at coal chemical enterprises. For instance, such projects are being implemented at two Yangchang Petroleum coal chemical plants in China.[245]

[243] Technology Roadmap Energy and GHG Reductions in the Chemical Industry via Catalytic Processes – IEA, ICCA, DECHEMA, 2013
[244] BASF website// URL: https://www.basf.com/global/en/who-we-are/sustainability/we-produce-safely-and-efficiently/energy-and-climate-protection/carbon-management/energy-and-process-efficiency.html
[245] Yanchang Petroleum's large-scale CCUS facility enters construction in China – Hydrocarbon Processing// URL: https://www.hydrocarbonprocessing.com/news/2017/03/yanchang-petroleum-s-large-scale-ccus-facility-enters-construction-in-china

Using CO_2 as raw material for producing oil and gas chemicals. The application of CO_2 in the production of different chemicals (e.g., methanol) and polymers is a new and innovative area of CO_2 use. One project using this method is being implemented by Saudi Aramco (Converge product), which acquired license of this technology from Novomer, Inc. in 2016. The technology envisages deriving convergent polyols from CO_2 reaction with oil refining products, while using a catalyst. The products are used in coatings for home appliances, glues, packages, medical devices, car components, and many other things. SK Innovation Co., Ltd (Green Pol product), Covestro AG (Cardyon product), Empower Materials Inc (QPAC product), Cardia bioplastics (Biohybrid product), and Asahi Kasei Advance Corporation (Wonderlite, Infino product)[246] also possess technologies for using CO_2 in manufacturing their products.

Using RES in production processes. There are many RES enterprises using oil and gas chemicals as energy resources for conventional production processes in the industry and as tools for innovative production. For example, BASF, Adani, and ADNOC plan to implement a $4 billion project to establish a chemical facility where 100% of the energy needs will be satisfied by renewables.[247] Projects on deriving ammonia using green hydrogen generated from solar or wind energy are further RES use examples from within the industry. One such project is being implemented in Australia by Yara Pilbara Fertilizers.[248]

[246] K. Vilcinskas. Carbon dioxide-based polymers: Turning carbon emissions into plastic. PreScouter, 2020 //URL: https://www.prescouter.com/2020/03/carbon-dioxide-based-polymers-turning-carbon-emissions-into-plastic/

[247] BASF eyes wind and solar stake for 'world-first' chemicals plant – Recharge News// URL: https://www.rechargenews.com/transition/basf-eyes-wind-and-solar-stake-for-world-first-chemicals-plant/2-1-693920

[248] Yara website// URL: Ca https://www.yara.com/news-and-media/news/archive/2020/arena-announces-funding-for-yara-pilbara-and-engies-feasibility-study-on-a-renewable-hydrogen-to-ammonia-solution-in-fertiliser-production/

ECONOMICS OF DECARBONIZATION IN OIL AND GAS SECTOR

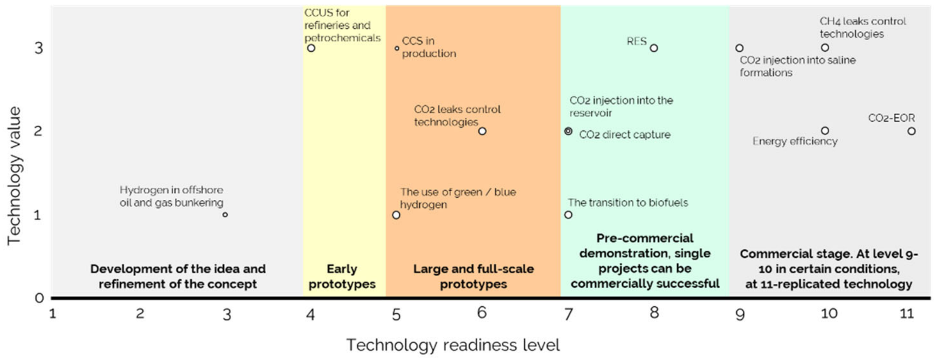
Economics of decarbonization projects could be assessed differently depending on the maturity of the given decarbonization strategy and type of decarbonization project. At early stages of implementing decarbonization projects, companies use sensitivity analyses to evaluate the impact on major investment projects and overall financial results of various scenarios of CO_2 pricing.

At further-advanced stages of GHG reduction, companies use several other tools, such as:

- models to estimate the minimal costs for achieving target GHG reductions,
- business cases to assess the optimal emission dynamics that will minimize GHG reduction costs, while taking into account an increase in social and country-level benefits of reducing emissions, and
- total marginal CO_2 social costs - evaluating damage caused by marginal ton of CO_2 emission[249]

Decarbonization technologies differ significantly in both maturity and importance for the oil and gas industry. In terms of potential volume of emission reductions, the most important technologies and methods are renewables, controlling methane leaks controls, energy efficiency, and CCUS in refining. However, only technologies at maturity stages 9 to 11[250] are available for commercial use (Fig. 42).

Fig. 42 - Matrix of several decarbonization technologies in oil and gas sector



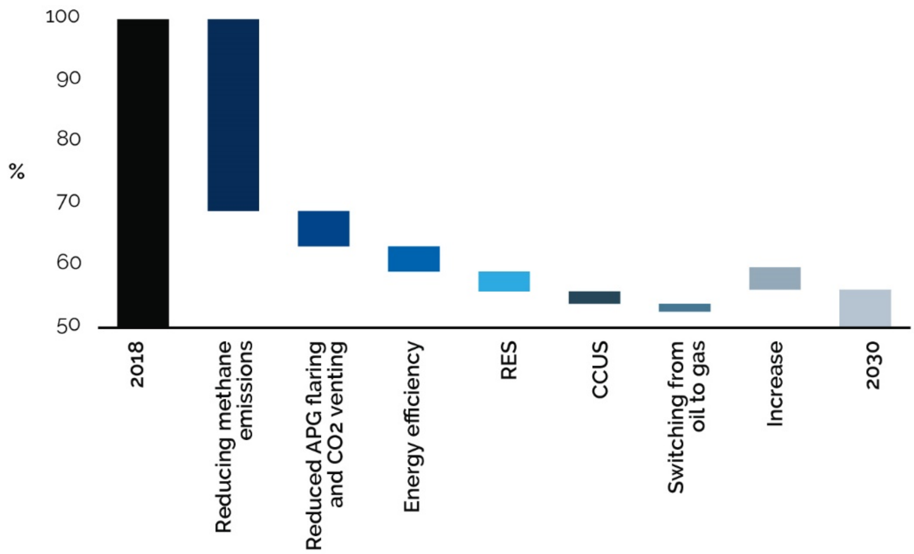
Source: Energy Centre, Moscow School of Management SKOLKOVO, IEA database on prospective technologies

Energy efficiency, avoidance of APG flaring, and methane leaks reduction are the three main areas with the largest potential for GHG emissions reduction by 2030 (Fig. 43). According to expert interviews with sustainability managers of the leading oil and gas

[249] https://www.edf.org/true-cost-carbon-pollution#:~:text=The%20social%20cost%20of%20carbon%20is%20a%20measure%20of%20the,per%20ton%20in%20today's%20dollars
[250] https://www.iea.org/reports/clean-energy-innovation/innovation-needs-in-the-sustainable-development-scenario

companies, up to 40% of initiatives in those areas can be realized with neutral or even positive impact to the bottom line, when taking into account production cost reductions or additional revenues from selling saved methane (at the current price level).

Fig. 43 - The role of key technologies in the reduction of average GHG emissions intensity of oil and gas production in the IEA Sustainable Development Scenario in 2018-2030



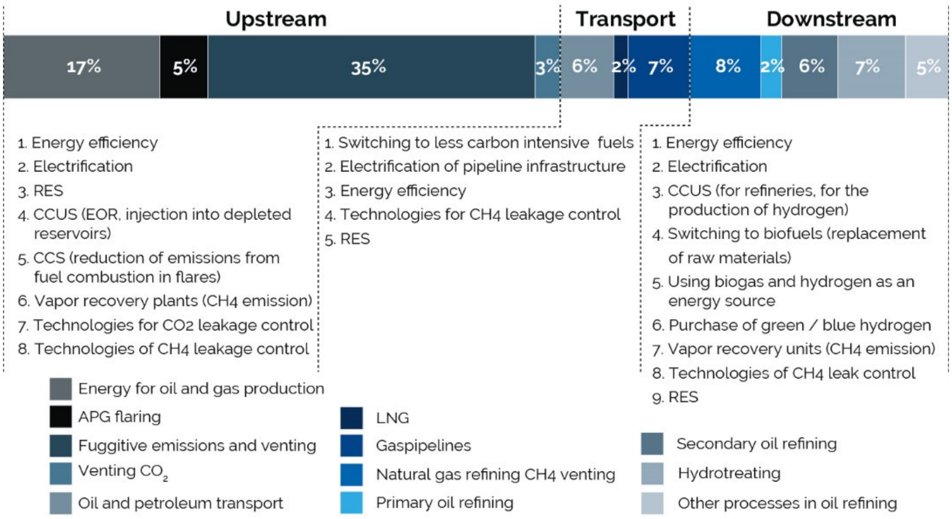
Source: IEA (2020), The Oil and Gas Industry in Energy Transitions, IEA, Paris https://www.iea.org/reports/the-oil-and-gas-industry-in-energy-transitions

Another group of technologies comprises carbon capture, utilization and storage. These technologies require large scale capital expenditures and are currently mostly at pilot stages, realized only with significant infrastructural and financial government support. This is why they represent relatively a small share of forecasted GHG emissions reduction through 2030. They are mostly evaluated in the frameworks of public-private partnerships.

Finally, there is a wide variance in the technological and commercial maturity of using renewables for production processes and low-carbon fuels for production, refining and operational transportation. In many regions, there are strong governmental incentives for negative emissions projects. In other regions, RES has to compete with the lower costs of coal and gas. This is why, in the short term, renewables and biofuels remain relatively small. Some of these projects are still viewed through the framework of venture capital investment, while others are structured as public-private partnerships.

If decarbonization opportunities are split by sector, value chain, energy efficiency, CCUS, and methane reduction remain main technologies in all three sectors – upstream, midstream and downstream (Fig. 44).

Fig. 44 - Main technological options for GHG emissions reduction along the value chain of the oil and gas sector



Source: Energy Centre, Moscow School of Management SKOLKOVO based on The future is now: How oil and gas companies can decarbonize January 7, McKinsey and Company, IEA WEO 2018.

Overall, a marginal cost analysis by technology (Table 19) shows that there can be a GHG emissions reduction of about 900 $MtCO_2e$ for close to zero, or slightly negative costs. Energy efficiency is a big part of this, which is still representing huge opportunities in the reduction of both GHG emissions and operating costs.

There can be a further reduction of 1,400 $MtCO_2e$ for as low as $5/$MTCO_2$. These numbers may change if carbon were priced more than it arguably is today. Overall, these two groups represent about 50% of the sector's emissions over the next 20 years.

Please note, that the data summarized in the table below is far from being complete. At this point, the marginal cost analysis of decarbonization methods is still at its early stages.[251] However, even from this data, it is clear that reaching net zero objectives requires further technological development and the piloting and scaling up of new technologies. This is impossible without regulatory, and potentially, financial, support from the government.

[251] Friedmann S. J., Fan Z., Z. Byrum et al. Levelized cost of carbon abatement: an improved cost-assessment methodology for a net-zero emissions world by S. Julio Friedmann, Zhiyuan Fan, Zachary Byrum, Emeka Ochu, Amar Bhardwaj, and Hadia Sheerazi, October 2020.

Table 19 - – Evaluation of costs and volume of GHG emissions reduction by technological method

	Volume $MtCO_2e$	marginal costs $2,009/MT	Comments	Source for volumes	Source for price
Effective planning and forecasting	20	-$111.20	The abatement cost curve displays the reduction potential of measures that cost less than €60/$MtCO_2e$ by 2030	https://www.mckinsey.com/industries/oil-and-gas/our-insights/co2-abatement-exploring-options-for-oil-and-natural-gas-companies	https://www.mckinsey.com/industries/oil-and-gas/our-insights/co2-abatement-exploring-options-for-oil-and-natural-gas-companies
Change in consumer behaviors	31	-$109.81			
Energy efficiency from maintenance and technological process management	52	-$1,091.15			
Energy efficiency from behavior change, technical maintenance, and process controls	27	-$107.03			
Energy efficiency that requires additional CapEx for technological units	100	-$58.38			
New, energy-efficient buildings	80	-$55.60			
Inspection and maintenance of compressors	27	-$13.90			
Replacement of compressor seals	23	-$13,205			
Energy efficiency requiring CapEx for modernizing technological units	20	-$1.39			
Inspection and maintenance of distribution networks	55	-$1.39			
Co-generation	120	-$11.12			
Reduction of continuous, remote flaring	70	-$41.70			
RES (monetization)	70	-$50.00	by 2040	World Energy Outlook 2018, 496	World Energy Outlook 2018, 496
Energy efficiency	300	-$100-15	by 2030	The Oil and Gas Industry in Energy Transitions | IEA 2020, p. 154	https://www.mckinsey.com/industries/oil-and-gas/our-insights/co2-abatement-exploring-options-for-oil-and-natural-gas-companies
Methane (monetization)	897	-$1.32-0	by 2040	https://www.iea.org/data-and-statistics/charts/marginal-abatement-cost-curve-for-oil-and-gas-related-methane-emissions-globally	https://www.nrel.gov/docs/fy16osti/62818.pdf
RES	280	$0-50	by 2040	World Energy Outlook 2018, 496	World Energy Outlook 2018, 496
RES	400	$50-300	by 2040	World Energy Outlook 2018, 496	World Energy Outlook 2018, 496
Methane	1514	$0-15	by 2040	World Energy Outlook 2020, p 106, https://www.i	World Energy Outlook 2020, p 106

	Volume $MtCO_2e$	marginal costs $2,009/MT	Comments	Source for volumes	Source for price
				ea.org/data-and-statistics/charts/marginal-abatement-cost-curve-for-oil-and-gas-related-methane-emissions-globally	
CCUS processing of natural gas	110	$25-30	by 2040	World Energy Outlook 2018, 501, https://www.bcg.com/publications/2019/business-case-carbon-capture	World Energy Outlook 2018, 501, https://www.bcg.com/publications/2019/business-case-carbon-capture
CCUS refining	140	$30-50	by 2040	World Energy Outlook 2018, 501, https://www.bcg.com/publications/2019/business-case-carbon-capture	World Energy Outlook 2018, 501, https://www.bcg.com/publications/2019/business-case-carbon-capture
CCUS refining, CHP, Fluid catalytic cracking (FCC)	450	$50-150	by 2040	World Energy Outlook 2018, 501, https://www.bcg.com/publications/2019/business-case-carbon-capture	World Energy Outlook 2018, 501, https://www.bcg.com/publications/2019/business-case-carbon-capture

Source: Energy Center, Moscow School of Management SKOLKOVO.

CONDITIONS FOR DECARBONIZATION IN RUSSIA AND DECARBONIZATION PRIORITIES OF THE RUSSIAN OIL AND GAS COMPANIES

Conditions for decarbonization in Russia – positions of the main stakeholders regarding climate change

Unlike many other countries of the world, in Russia the problem of climate change is still of low priority for the population, business, financial institutions and government, which hinders the process of decarbonization.

Public attitude towards climate change issues

According to opinion polls published in September 2020[252], 40% of Russian adults believe that the problem of global warming is far-fetched and exaggerated. The opposite opinion is held by 52% of Russians: they believe that global warming is a really significant problem. However, the majority (62-76%) of the respondents are not ready to pay more for goods or services - even if the funds will be used to introduce alternative energy sources or improve energy efficiency. Thus, voters' attitude to the climate is ambiguous. At the same time, since the institutions of civil society and the activities of climate NGOs are not well developed in the country[253], there is no noticeable pressure on the authorities and on companies with climate requirements (as is the case in other regions of the world) in Russia.

State position regarding climate and GHG regulation in Russia

Russia`s emissions targets declared under the Paris Agreement have already been met and more ambitious targets have not yet been discussed. .

In the state policy of the country, there is a low priority of climate challenge.[254] Decarbonization in Russia has not yet been included in the list of top priority tasks monitored by the state. So far, the policy of the Russian government in this matter is mainly demonstrative and does not see the need for significant changes.[255]

Russia's Nationally Determined Contributions (NDC), under the Paris Agreement, envisaged a 25-30% reduction in emissions by 2030 from 1990 levels, including LULUCF. Against the backdrop of a profound transformation of the economy, this commitment was fulfilled in the early 1990s and has now been surpassed. The government has not yet discussed any further ambitious goals.[256] As for the longer-term beyond 2030, even the most

[252] https://wciom.ru/analytical-reviews/analiticheskii-obzor/izmenenie-klimata-i-kak-s-nim-borotsya
[253] https://www.csis.org/analysis/environmental-activism-russia-strategies-and-prospects
[254] https://www.csis.org/analysis/who-responsible-mitigating-effects-climate-change-russia
[255] https://www.ifri.org/sites/default/files/atoms/files/bobolo_russia_climate_change_2021_ru.pdf
[256] For more information on climate regulation in Russia, please, see e.g.: Global Climatic Threat and the Russian Economy: Searching for the Way / Mitrova T.A., Khohlov A.A., Melnikov Yu.V.,

ambitious Intensive Scenario in the draft of Russia's low-carbon development strategy published in March 2020, sets the goal of reducing GHG emissions by 2050 by 52% of 1990 levels, which substantially differs from the goals announced by the European Union, Japan, South Korea, Canada (net-zero by 2050).

It's also worth noting that the nationally approved target for GHG emissions by 2030 of 75% of the level of 1990 most likely will not to be exceeded even in the situation of non-action in the area of GHG regulation for the following Russia-specific reasons:

- currently GHG emissions are ~50% of 1990 level.
- the statistics of the economically prosperous 2000-2010s show that during the period of active economic growth the volume of GHG emissions (excluding forests) in Russia increased by only 8% in 10 years. Even in the most aggressive scenario if we assume that the economy will develop at a similar pace during the next 10 years (2021-2030), and nothing will happen with the absorbing capacity of forests, by 2030 Russian emissions will be about 60-62% of the level of 1990.
- Over the past seven years of the reporting period (2011-2017), which was accompanied by serious external constraints on the national economic growth, GHG emissions grew by about 0.7% per year. With no changes in conditions and with moderate economic growth, Russian GHG emissions may reach 57-60% by 2030.
- Regardless of the rate of economic growth, Russia has a certain potential for increasing the level of absorption of forests and ecosystems. First of all, this may be due to the increase in the number of regulated forests, the completion of forest inventory and the intensification of the fight against illegal logging and fires. If this potential is realized, net emissions in Russia, taking into account the absorptive capacity of forests and ecosystems, may appear to be below 60% of the level of 1990 by 2030.

Obviously, in this situation there are no reasons for the Russian government to introduce additional regulations (carbon tax, GHG allowances, emission penalties) in the period before 2030. If the carbon border tax is introduced on export markets, it could probably lead to the intensification of the Russian GHG regulatory activity. But it could lead to the final abandonment of the idea of introducing the carbon tax or its derivatives in Russia in order to exclude double taxation of domestic exporters. In this case, the Government will have to take urgent incentive measures to accelerate the reduction of export product carbon

etc. Moscow School of Management SKOLKOVO, May 2020. — Access mode: https://energy.skolkovo.ru/ downloads/ documents/SEneC/Research/SKOLKOVO_EneC_Climate_Primer_RU.pdf footprint. This will primarily affect oil and gas producers, metallurgical enterprises and fertilizer producers.

GHG regulation

Carbon regulation in Russia is in its early stages of development. In 2021 the first key regulatory documents will enter into force,

In Russia, GHG emission regulations are still in the initial stages therefore, while the oil and gas sector does not receive incentives and signals aimed at decarbonization. It is expected that in 2021, the first regulatory documents will enter into force, which will govern enterprises' reporting on GHG emissions. The main structural elements of thyye currently evolving Russian regulation on GHG emissions are (Table 20):

1. Long-term goal of the Russian Federation for GHG emissions.
2. The strategy of social and economic development of Russia, providing for economic growth with account taken of the long-term goal for GHG emissions.
3. Introduction of the necessary regulations for greenhouse gas emissions, ensuring the implementation of the strategy of social and economic development of Russia.

The current status of the development and approval of each of the above elements is presented in the table below.

Table 20 - Current status of the main elements of the GHG emission regulation system

Element of the of GHG emission regulation	Document	Document status
1. Long-term goal of the Russian Federation for GHG emissions.	Decree of the President of the Russian Federation No. 666 dated November 4, 2020 [257]	**Approved.** The national target for emissions of 70% from the level of 1990 by 2030 has been set. Therewith, in 2017, emissions amounted to 50.7% of the level of 1990[258].
2. The strategy of social and economic development	Long-term development strategy of the Russian Federations with low GHG emissions by 2050	**In progress.** The draft Strategy was submitted by the Ministry of Economic Development to the Government in March 2020.[259] Obviously, this Strategy will be adjusted before approval, taking into account the Presidential Decree No. 666 dated November 4, 2020. Expected to be approved in 2021.
3. Introduction of the national regulation on GHG emissions.	Federal Law "On Limiting GHG Emissions"	**In progress.** The draft law has been submitted to the State Duma[260]. It conceptually corresponds to Presidential Decree No. 666 dated November 4, 2020. It includes vocabulary, obligation to monitor GHG emissions and mechanism for voluntary climate projects. No regulation is introduced as such, since it is not required to achieve the national goal by 2030. Expected to be approved in 2021.

Source: Energy Center, Moscow School of Management SKOLKOVO.

[257] Available at: http://docs.cntd.ru/document/566191878
[258] Fourth report of the Russian Federation submitted in accordance with resolution 1/CP.16 of the Conference of the Parties to the United Nations Framework Convention on Climate Change, Roshydromet, Yuri A. Izrael, Institute of Global Climate and Ecology, Moscow, 2019. Available at: http://downloads.igce.ru/publications/Two_years_Doklad_RF/124785_Russian%20Federation-BR4-2-4BR_RUS_rev.pdf
[259] Available at: https://economy.gov.ru/material/file/babacbb75d32d90e28d3298582d13a75/proekt_strategii.pdf
[260] Decisions of the Russian Government dated February 17, 2021. Available at: http://government.ru/news/41576/

The main document that will regulate the sphere of GHG emissions will be the federal law "On Limiting GHG Emissions". From November 2018 to February 2021, this law was a subject to numerous discussions and approvals, therefore, it was amended considerably. Now, the draft law has been submitted by the Government of Russia to the State Duma. According to the Ministry of Economic Development of Russia, this law will be adopted in the first half of 2021[261].

In less detail, the draft law consists of three blocks introducing:

- The vocabulary;
- The system for monitoring GHG emissions by the largest emitters;
- The arrangement for the implementation of voluntary climate projects.

The following describes the characteristics of each of these blocks in more detail.

Vocabulary

At present, the Russian legislation does not include such concepts as: "GHG", "anthropogenic emissions of greenhouse gases", "absorption of GHG", "carbon unit", "carbon footprint", etc. The draft law fills this gap, and introduces about two dozens of new concepts. The new research vocabulary will allow building the necessary system for regulating GHG emissions, and will also allow all stakeholders to have an unambiguous interpretation of the basic concepts.

GHG Emission Monitoring System

Organizations with annual GHG emissions of 150,000 tons or more until 2024 and 50,000 tons or more after 2024 will fall under the new regulations. Obviously, the largest oil and gas companies and industrial enterprises will fall under these criteria. Regulated entities will be required to submit annual reports on GHG emissions to a designated government agency. The procedure and terms for submission, as well as the form of such reports and responsibility for failure to submit thereof will be provided later.

Other organizations and individual entrepreneurs will have the right either to submit reports or not to report on GHG emissions.

Based on the collected information on GHG emissions, a GHG state accounting system will be created. This system will:

- check reports on greenhouse gas emissions;
- maintain a register of greenhouse gas emissions;
- store and analyze information;
- inform government agencies, businesses and citizens about GHG emissions.

[261] https://sozd.duma.gov.ru/bill/1116605-7%EF%BF%BC

Arrangement for the Implementation of Climate Projects

A climate project is a project that reduces (prevents) GHG emissions or increases their absorption. The draft law provides for the voluntary nature of climate projects implementation.

The draft law and subsequent regulations are necessary to unambiguously formulate the rules for the implementation of such projects and the requirements for verifying their results, as well as to report on project results through the product carbon footprint, and to provide non-financial reporting.

In particular, the form and procedure for submitting a report on the implementation of a climate project will be unified. When implementing such a project, it will be necessary to go through the procedure to verify the achieved results.

Following the verification of the project results, carbon units will be issued. These carbon units are to be credited to the account of the climate project executor in a special register of carbon units. Hereafter, the owner of carbon units may decide to offset them to reduce their own emissions or to transfer them to another business entity.

The draft law does not regulate the conditions under which the exchange of carbon units between economic entities will be performed. The transparent and understandable procedure is not configured for setting the price for carbon units to be transferred between economic entities. This could potentially lead to the manipulation of carbon offsets between economic entities.

In 2021, the draft law will pass three readings in the State Duma, and then will be examined by the Federation Council. It is possible that there will be additional amendments.

Additional restrictions will be imposed on oil and gas companies if they decide to implement climate projects with the subsequent inclusion of the project results in a special state register of carbon units. The limitations will be associated with the need to comply with climate projects implementation and verification requirements.

In connection with the adoption of the law "On Limiting GHG Emissions" and the corresponding secondary legislations, the number of instruments for oil and gas industry decarbonization is most likely to increase. This will be facilitated by a more accurate understanding of the sources and volumes of emissions generated by oil and gas companies due to the obligation to introduce the monitoring and reporting system for enterprises with annual emissions of more than 50,000 tons per year. Also, there will be developed more clear rules for the implementation, verification and accounting of the climate project results. It will be possible to reduce carbon footprint of products through voluntary climate projects, including forest projects. The possibility of using carbon units by economic entities will appear, although it is not yet clear how the price for these carbon units will be established.

Besides the initiatives related to the development of the regulatory scope for greenhouse gas emissions, Russia has environmental legislation. This legislation already offers elements for the regulation on certain greenhouse gases emissions, which are pollutants.

Futhermore, special arrangements are already in place in Russia, allowing oil and gas companies to enjoy exemptions and subsidies, as well as to attract additional financing for the implementation of energy-efficient projects and activities aimed at introducing the best available technologies and reducing emissions of APG.

Methane emissions regulation

From as early as the 1980s, Russia recognizes methane as a pollutant regulated by separate legislation. The current regulatory framework for methane emissions is represented by:

- Federal Law No. 7-FZ "On Environmental Protection" dated January 10, 2001[262];
- Order of the Government of the Russian Federation No. 1316-р "On Approval of the List of Polluting Substances in Respect of Which State Regulation Measures in the Field of Environmental Protection Are Applied" dated July 8, 2015[263];
- Decree of the Government of the Russian Federation No. 913 "On Rates of Payment for the Negative Impact on the Environment and Additional Factors" dated September 13, 2016[264].

The mentioned above documents created a regulatory framework for charging industrial enterprises for the negative impact on the environment from methane emissions[265]. The fee rate is 108 rubles per ton of methane.

Since methane is the main component of APG, the Decree of the Government of the Russian Federation No. 1148 "On Specifics of Calculation of Fees for the Negative Impact on the Environment of Emissions of Polluting Substances When Flaring and(or) Dispersion of Associated Petroleum Gas"[266] dated November 8, 2012 is also of particular importance for oil and gas companies.

This decree introduced the maximum permissible volume of flared APG of no more than 5% of the produced APG volume. Thus, oil and gas companies need to utilize 95% of produced APG. In the case of failure, oil and gas companies are obliged to pay a fee for the negative impact on the environment when

[262] Available at: http://docs.cntd.ru/document/901808297
[263] Available at: http://docs.cntd.ru/document/420286994
[264] Available at: http://docs.cntd.ru/document/420375216
[265] https://www.sciencedirect.com/science/article/abs/pii/S1352231014002982?via%3Dihub
[266] Available at: http://docs.cntd.ru/document/902379207

emitting gas into the atmosphere. Herewith, the cost of APG utilization is taken into account when calculating a fee. That is, the more the company spends on the APG utilization system, the less it pays for the negative impact on the environment. The utilization system may include:

- Systems for APG collection, preparation and transportation;
- Plants for generating heat and electricity from APG;
- APG processing units;
- Facilities for APG injection into formation, gas caps;
- Natural and artificial underground gas storage sites;

During the period from 2010 to 2019, the level of APG utilization in Russia increased from only 74.3% to 81.5%, which indicates either insufficient incentives or low rates of payment for the negative impact on the environment in case of gas emission.

Introducing the Best Available Technologies

Currently, Russia has been developed a regulatory framework for the introduction of the best available technologies at industrial enterprises including oil and gas companies. As a rule, the introduction of the best available technologies is accompanied by an increase in energy efficiency, and, therefore, a reduction in greenhouse gas emissions and a decrease in negative impact on the environment.

The list of the best available technologies and their criteria are described in detail in the Best Available Technologies (BAT) References. For example, directories:

- Oil Production[267];
- Natural Gas Production[268];
- Oil Refining[269].

When introducing BAT at production facilities, companies are entitled to subsidies from the federal budget. The subsidy is provided to reimburse for paying the coupon yield on bonds issued as part of the implementation of projects on the introduction of the best available technologies. In general, the subsidy amounts to 70% of the coupon yield on issued bonds. If the introduced BAT is based on equipment produced in the Russian Federation, the subsidy amounts to 90% of the coupon yield.

[267] Information and technology guide on the best available technologies, ITS 28 "Oil production", Federal Agency for Technical Regulation and Metrology, BAT Bureau, 2017. Available online: http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1112&etkstructure_id=1872
[268] Information and technology guide on the best available technologies, ITS 29 "Natural gas production", Federal Agency for Technical Regulation and Metrology, BAT Bureau, 2017. Available online: http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1114&etkstructure_id=1872
[269] Information and technology guide on the best available technologies, ITS 30 "Oil refining", Federal Agency for Technical Regulation and Metrology, BAT Bureau, 2017. Available online: http://burondt.ru/NDT/NDTDocsDetail.php?UrlId=1116&etkstructure_id=1872

The procedure for providing such a subsidy is regulated by Decree of the Government of the Russian Federation No. 541 dated April 30, 2019[270].

Companies that switch to BAT receive a complex environmental permit. The procedure for issuing such permits was approved by Decree of the Government of the Russian Federation No. 143 "On Approval of the Rules for Examining Applications for Complex Environmental Permits, Issuance, Re-issuance, Revision, Revocation and Amendments Thereto" dated February 13, 2019[271]. Companies can obtain such permits from January 1, 2019. Currently, a list of 300 enterprises has been formed, which are required to apply for such permits by December 31, 2022, which means they must comprehensively switch to BAT. The list of these enterprises was approved by Order of the Ministry of Natural Resources of Russia No. 154 dated April 18, 2018[272]. This list includes, among other things, oil and gas companies, for example:

- Kharyaga Oil Field;
- Astrakhan Gas Processing Plant;
- Syzran Refinery JSC;
- Orenburg Gas Production Complex;
- Oil and Gas Production Facility of the ES OOGCF;
- Ryazan Oil Refining Company;

The remaining enterprises of the first category (enterprises creating significant environmental impact) must apply for the IEP (Integrated Environmental Permits) until December 31, 2024. There are about 7,000 such enterprises in Russia. Enterprises of the second category can obtain the IEP on a voluntary basis.

Upon receipt of IEPs, obligations arise to achieve certain technological standards, and to reduce negative impact on the environment. But at the same time, companies are entitled to a number of different benefits:

- Offsetting the costs of reducing negative impact and introducing BAT against payments for the negative impact on the environment;
- Cancellation of payments for the negative impact on the environment for enterprises of the first category that switched to BAT;
- Investment tax credit to introduce BAT;
- Application of increased depreciation rate for energy-efficient equipment and BAT equipment (Article 259.3. of

[270] Available at: http://docs.cntd.ru/document/554440902
[271] Available at: http://docs.cntd.ru/document/552405898
[272] Available at: http://docs.cntd.ru/document/542623710

the Tax Code of the Russian Federation, Application of increasing (decreasing) factors to the depreciation rate[273]);

- Application of a new method of fundraising by issuing green bonds for BAT projects, as well as obtaining a subsidy of up to 90% of the coupon yield (Decree of the Government of the Russian Federation No. 541 dated April 30, 2019[274]).

Basically, the use of economic and tax instruments that are already available in Russia allows oil and gas companies to launch activities aimed at decarbonizing their core operations. These instruments include:

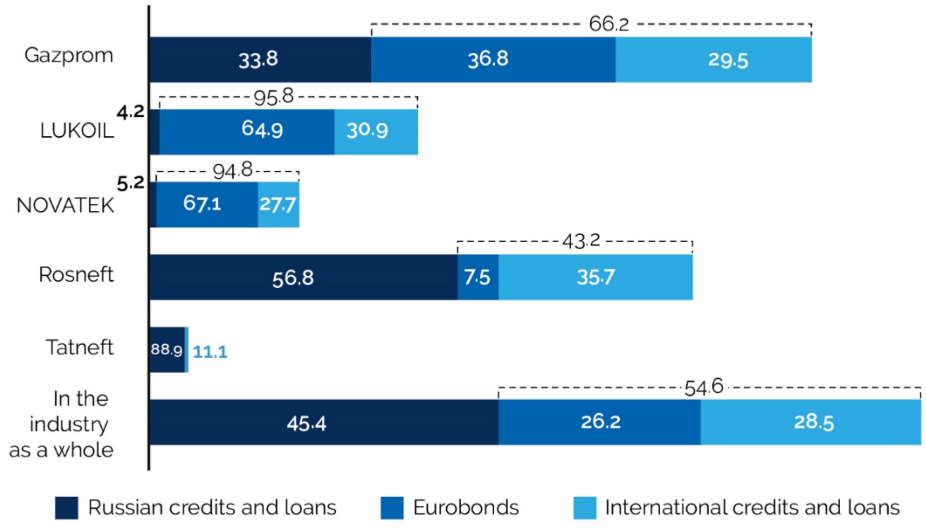
- Offsetting the costs for the APG utilization system against payments for the negative impact on the environment;
- Offsetting the costs of reducing the negative impact and introducing BAT against payments for the negative impact on the environment;
- Cancellation of payments for the negative impact on the environment for enterprises of the first category that switched to BAT;
- Application of increased depreciation rate for energy-efficient equipment and BAT equipment;
- Investment tax credit to introduce BAT;
- Obtaining a subsidy of up to 90% of the coupon yield on bonds issued as part of projects to introduce the best available technologies;
- Application of the new method for raising fund for projects aimed at reducing GHG emissions by placing green bonds that meet the requirements of the VEB.RF guidelines.

Position of the financial sector and green financing

Globally financial sector is extremely influential in promoting decarbinization agenda and putting pressure on the oil and gas companies to reduce their carbon footprint. In Russia oil and gas business of the key vertically integrated oil companies mainly rely on the international financing – it represents 54,6% in the debt capital of the leading Russian oil and gas companies (Fig. 45), forcing them to get involved on an equal footing with international companies in investor disclosure initiatives, focus on climate strategy and climate risk management. This is currently one of the main drivers of decarbonization of Russian oil and gas companies.

[273] Available at: http://docs.cntd.ru/document/901765862
[274] Available at: http://docs.cntd.ru/document/554440902

Fig. 45 -Share of international credits and loans in the debt capital of individual Russian oil and gas companies



Source: CSR, 2021. https://www.csr.ru/ru/news/klimaticheskaya-povestka-rossii-reagiruya-na-mezhdunarodnye-vyzovy/

It can be expected that the leading Western financial and investment organizations will continue to develop the principles of sustainable financing – so Russian oil and gas companies that do not meet the standards may be deprived of foreign loans and borrowings. Sanctions could also play their role in restricting access of the Russian companies to the financing.

For the Russian financial institutions currently, the agenda of sustainable development, climate change and the need for decarbonization is getting more important.

In particular, the Bank of Russia issued the Regulation[275] on December 19, 2019, which provided for issuing green bonds. The Bank of Russia has also prepared and published principles of responsible investment for institutional investors[276].

VEB.RF (Vnesheconombank of the Russian Federation) State Development Corporation, which is the largest development institution in Russia, has been designated by the Russian Government as a methodological center for the development of investment activities in Russia in the field of sustainable (including green) development and fundraising. The powers of VEB.RF are established by Order of the Government of the Russian Federation No. 3024-p dated November 18, 2020.

In 2020, VEB.RF prepared the first edition of guidelines for the development of investment activities in the field of green finance[277] in the Russian Federation and the first version of the directions for the implementation of green projects in the Russian Federation (taxonomy)[278]. These documents were

[275] Available at: http://docs.cntd.ru/document/564112335
[276] Available at: http://docs.cntd.ru/document/565313944
[277] Available at: https://veb.ru/files/?file=1cc7ffec701762260d130988dafca0cf.pdf
[278] Available at: https://veb.ru/files/?file=3c88641bf666e0d8b2609488ed24d511.pdf

developed taking into account the experience of the largest international organizations in the said area, CBI, ICMA, IDFC, and using the experience of China, which was the first country to develop and implement a similar document. The update of the guidelines and taxonomy is currently under development.

Based on the methodological recommendations of VEB.RF, in 2020, Russian Railways JSC issued perpetual green bonds series 001B-03 worth 100 billion rubles to finance green projects, as well as refinance costs incurred under green projects.

It's worth noting that the Moscow Exchange offers the Sustainable Development Sector[279] for bonds aimed at financing projects in the field of ecology, environmental protection and socially desirable projects.

Thus, at the moment, any oil and gas company can raise funds for projects aimed at reducing GHG emissions by placing green bonds that meet the requirements of VEB.RF guidelines.

Position of the business

In general, Russian business is in no hurry to move to active climate action: the absence of pressure from public opinion and the regulator allows companies to maintain their traditional approach to business within the country. For example, the Russian Union of Industrialists and Entrepreneurs (RSPP), which includes the largest Russian companies from the energy sector (including a number of oil & gas companies), the chemical, metallurgical industry, mechanical engineering, etc., is among the consistent opponents of toughening carbon regulation in Russia. Arguments against a domestic carbon pricing introduction include concerns about overburdening the economy and business, and rising energy costs for businesses and households. RSPP considers it expedient to focus on preventing the growth of greenhouse gas emissions (instead of reducing them)280, and considers the creation of an integrated GHG accounting system (both for emission and sinks) to be a key area281 in the Russian climate policy development.

However, on the international markets, exporting companies are increasingly faced with new requirements for disclosure of information on their GHG emissions. This is especially true for the key export market - the European one. The European "Green Deal" and related new regulatory initiatives - border carbon regulation, the "EU Methane Strategy", recommendations for

[279] Sustainable Development Sector of the Moscow Exchange. Available at: https://www.moex.com/s3019

[280] RSPP position paper on the concept draft of Federal Law on GHG Emissions Regulation in Russia -April 2018. Available at: http://media.rspp.ru/document/1/8/a/8a57f55cc17707234e2558e0624e23e5.pdf

[281] RSPP position paper 'About measures for the Russian economy adaptation to climate change' – December 2020. Available at: http://rspp.ru/activity/position/pozitsiya-rspp-o-meropriyatiyakh-po-adaptatsii-rossiyskoy-ekonomiki-k-izmeneniyam-klimata

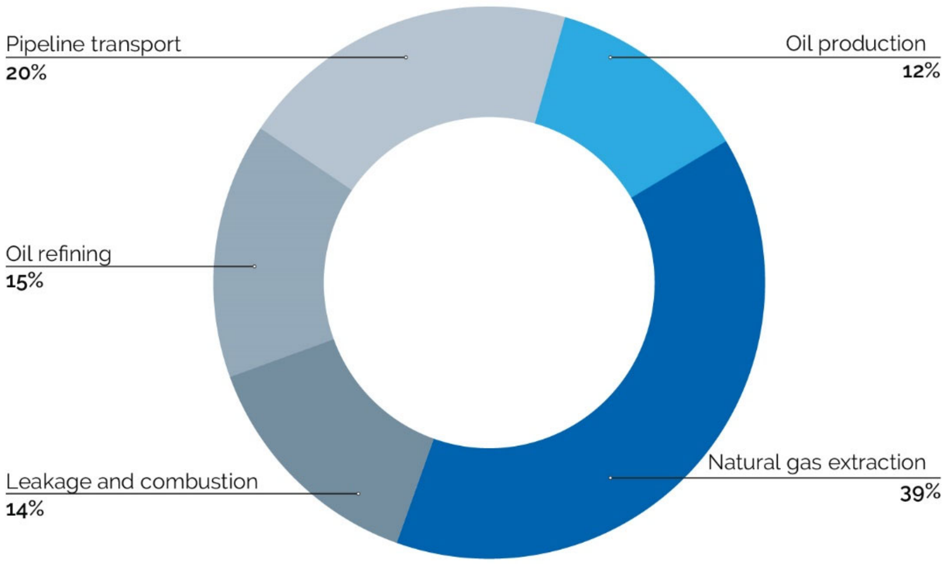
financing projects within the taxonomy - will have a direct impact on Russian exports.

Export-oriented Russian business in general and oil and gas companies in particular are gradually beginning to realize that more active decarbonization measures are needed to maintain a strong market position and attractiveness in the eyes of international investors.

Decarbonization priorities of the Russian oil and gas companies

As for the oil and gas business, GHG emissions here are estimated at 355 MtCO2e, which accounts for about 24% of total emissions (1.5 BtCO2e, including land use, land use changes, and forestry (LULUCF) in 2017, of which 47% came from electricity and heat generation). Natural gas extraction accounts for up to 40% of all emissions coming from the oil and gas industry (Figure 46), with a further 20% coming from pipeline transport.282

Fig. 46 - Breakdown of oil-and-gas industry GHG emissions in the RF in 2018



Source: Russian GHG inventory, https://unfccc.int/documents/227987

So the share of GHG emissions coming from the oil and gas industry in Russia is nearly twice as high as the global average, accounting for about a quarter of total emissions.

While domestic carbon regulation has not yet encouraged decarbonization of oil and gas companies, many of them are ahead of the political agenda in preparing voluntary reporting and disclosures, proactively adopting decarbonization strategies, and even employing internal carbon pricing for investment projects.

While domestic carbon regulation has not yet encouraged decarbonization of oil and gas companies, many of them are ahead of the political agenda in preparing voluntary reporting and disclosures, proactively adopting decarbonization strategies, and even employing internal carbon pricing for investment projects.

[282] https://unfccc.int/documents/226417

In 2020, Russia's oil and gas leaders (Gazprom,[283], Rosneft,[284] LUKOIL,[285] Gazprom Neft,[286] Tatneft,[287] and NOVATEK[288]) mentioned sustainability in their corporate reports (both stand-alone sustainability reports and sections within annual reports). Key decarbonization measures mentioned in these reports include organizing a system of accounting for GHG emissions, energy efficiency, using APGs, and further developing their gas business (as opposed to their oil business). Additionally, renewables development and reforestation are mentioned. At the same time, most of these activities have been implemented for many years without any accounting of GHG emissions coming from inter-company processes (e.g., working on increasing energy efficiency for cost reduction).

As of December 2020, several Russian oil and gas companies have published long-term targets (with a 2024 horizon) to reduce GHG emissions (Table 21). Two companies (LUKOIL and Tatneft) publicly declared their strategic commitment to carbon neutrality by 2050. Representatives of two companies (LUKOIL and Tatneft) in public speeches mentioned that they are striving for carbon neutrality by 2050 (although they did not formally set such a target).

CDP voluntary climate reporting data[289] shows that Russian oil and gas companies are gradually improving their ratings. In 2020, five companies (Gazprom, Gazprom Neft, LUKOIL, Nizhekamskneftikhim, and Tatneft) improved their CDP ratings compared to 2019. The 2019-2020 period also includes the declarations of companies (like Tatneft, LUKOIL, Rosneft, NOVATEK, and others) and their management personnel regarding their pursuit of long-term reductions in GHG emissions or even carbon neutrality.

[283] Environmental report of PJSC Gazprom for 2019: https://www.gazprom.ru/f/posts/77/885487/gazprom-environmental-report-2019-ru.pdf
[284] Sustainability report of PJSC Rosneft for 2019 / https://www.rosneft.ru/upload/site1/document_file/Rosneft_CSR2019_RUS.pdf
[285] Sustainability report of PJSC Lukoil for 2019 https://lukoil.ru/InvestorAndShareholderCenter/ReportsAndPresentations/SustainabilityReport
[286] Sustainability report of PJSC Gazprom Neft for 2019 / https://csr2019.gazprom-neft.ru/
[287] Annual report of PJSC Tatneft for 2019 / https://tatneft.ru/storage/block_editor/files/ff073d3c825320e4709391e336c0ec350e599b49.pdf
[288] http://www.novatek.ru/common/tool/stat.php?doc=/common/upload/doc/NOVATEK_FULL_RUS_2019.pdf
[289] The CDP (Carbon Disclosure Project) is an international non-profit organisation based in the United Kingdom, Germany and the United States of America that helps companies disclose their environmental impact. It aims to make environmental reporting and risk management a business norm. It collects self-reported data from thousands of companies - CDP's climate change program aims to reduce companies' greenhouse gas emissions and mitigate climate change risk. CDP requests information on climate risks and low carbon opportunities from the world's largest companies on behalf of over 800 institutional investor

Table 21 - Russian oil and gas companies' long-term targets for reducing GHG emissions (as of January 2021)

Company	Target	Target Year	Base Year	Reduction, %
Gazprom	Specific GHG emissions from natural gas transportation, total CO_2e per billion m³ per km	2024	2018	3.8%
Gazprom Neft	No published GHG emissions reduction targets			
Zarubezhneft	No published GHG emissions reduction targets			
Irkutsk Oil Company	No published GHG emissions reduction targets			
LUKOIL	Official long-term targets are being expanded. The company is reportedly targeting carbon neutrality by 2050.			
NOVATEK	GHG emissions per unit of production in the Upstream segment	2030	2019	6%
	Methane emissions per unit of production in the Production, Processing and LNG segments	2030	2019	4%
	GHG emissions per ton of LNG produced	2030	2019	5%
Rosneft	Carbon intensity in upstream sector	2035	2019	30%
	Methane emissions intensity	2035		0.25%
Russneft	No published GHG emissions reduction targets			
Sakhalin Energy	No published GHG emissions reduction targets			
Sibur	Specific GHG emissions from gas processing	2025	2018	5%
	Specific GHG emissions from petrochemistry	2025	2018	15%
Surgutneftegaz	No published GHG emissions reduction targets			
Tatneft	Carbon intensity	2025	2019	10%
		2030	2019	20%
	*strategic target: carbon neutrality by 2050			

Source: Energy Center, Moscow School of Management SKOLKOVO based on companies` data.

In the most recently reported CDP rankings of 2020, one of Russia's oil and gas companies scored a "B", while two others were given a "C", making them competitive with their international peers. However, the development stages of these decarbonization strategies vary greatly, and some are still in the early stages of structuring their goals and methods for decarbonization with no ostensible industry cooperation yet achieved. Let us consider further which of the decarbonization methods are prioritized by the Russian oil and gas companies.

Operational methods

Russian oil and gas companies are quite actively introducing all methods of increasing operational efficiency, but the main priority and the greatest potential, both in terms of reducing GHG emissions and increasing their commercial efficiency, is associated with energy efficiency.

Energy efficiency

For many years, Russian oil and gas companies have experienced a steady growth in energy efficiency indicators, at the rate of about 1-2.5% a year. The gained momentum and accumulated experience will be useful if the regulatory environment makes it possible to monetize the resulting reduction of GHG emissions.

In the draft of Russia's low-carbon development strategy, increasing energy efficiency by 2050 is considered the key to curtailing the growth of GHG emissions in the Russian economy.[290] In the past, Russian oil and gas companies associated energy efficiency nearly exclusively with the task of operational cost cutting. However, with the development of climate regulation, the use of this proven tool for business decarbonization becomes particularly important.

The Ministry of Economic Development names the following energy efficiency technologies and methods in the Russian oil and gas sector:

- turbo-expanders at gas distribution stations,
- technologies for utilizing exhaust gas heat,
- increase in operating pressure at gas export line sections,
- use of large-diameter pipes with internal smooth coating,
- application of gas pumping units with a nigh nominal efficiency factor,
- increase in degree of compression,
- raise in oil recovery coefficient of benches,
- processing of interlayers formed at oil treatment facilities,
- modernization of production equipment, and
- utilization of flare gases.291

Due to their universality, the technologies mentioned above are applicable to the upstream, midstream, and downstream sectors.

According to the Ministry of Economic Development, from 2015 to 2018, energy efficiency indicators at Gazprom, Surgutneftegaz, Tatneft, and Transneft (in oil and gas production, transportation of gas, oil, and refined products, and processing

[290] Draft strategy of development of the Russian Federation with low level of greenhouse gas emissions till 2050. / RF Ministry of Economic Development, December 2019. Access mode: https:// economy.gov.ru/ material/ file/ babacbb75d32d90e28d3298582d13a75/proekt_strategii.pdf
[291] State report on the condition of energy supply and energy efficiency increase in the Russian Federation in 2018. / RF Ministry of Economic Development, December 2019. Access mode: https://www.economy.gov.ru/material/file/d81b29821e3d3f5a8929c84d808de81d/energyefficiency2019.pdf

of gas, condensate, and oil) demonstrated a variety of trends, without any clear-cut improvement. In production, energy consumption was growing, probably, as a result of the field maturation and the necessity to spend more energy on the same amount of oil or gas produced.[292]

According to Rosneft data, the company's energy efficiency indicators within the last two years have improved by 14%, with the result being an avoidance of 3.1 $MtCO_2e$ over the period. Between 2021 and 2023, according to the 2019 report, RUR 16 billion in investments in energy efficiency were planned.[293]

According to LUKOIL data,[294] the key activity for increasing energy efficiency in the upstream sector was the replacement of asynchronous motors with PMSM ones, used as the driver for ESP units of mechanical well stock. Additionally, the pumps of the reservoir pressure maintenance system are being upgraded. In 2019, 3,885 PMSM units were implemented in the company.

Gazprom Neft is focusing on the following main directions of energy efficiency improvement within the upstream sector:[295]

- application of energy-efficient electric centrifugal pump units,
- implementation of PMSM motors,
- operation of submersible equipment and optimization of its planned maintenance,
- reduction of produced water and its injection (stoppage of non-profitable well stock and performance of geotechnical jobs),
- selection of optimal unit size and replacement of pumping units at water-injection pumping stations and booster pump stations, as well as preliminary water removal units,
- installation of variable-frequency drives on pumping equipment, and
- optimization of electric heating systems (installation of temperature regulators).

According to its data, in 2019 the company managed to save 5.3 million gigajoule (GJ) as a result of energy efficiency programs.

According to Tatneft, as result of implementing the corporate energy conservation program for 2017-2019, the reduction of inter-company energy resource needs (in tons of oil equivalent) on average amounted to 1% a year, or 2 billon RUR of accumulated effect.

[292] Ibid.
[293] Sustainability report of PJSC Rosneft for 2019. https://www.rosneft.ru/upload/site1/document_file/Rosneft_CSR2019_RUS.pdf
[294] Sustainability report of PJSC Lukoil for 2019. https://lukoil.ru/InvestorAndShareholderCenter/ReportsAndPresentations/SustainabilityReport
[295] https://www.gazprom-neft.ru/social/energy-efficiency/

In 2008, for the purpose of energy efficiency enhancement, Transneft adopted the Program of Energy Saving and Energy Efficiency Increase. Within the scope of that program, the below technologies and approaches were implemented to enhance oil transportation energy efficiency.

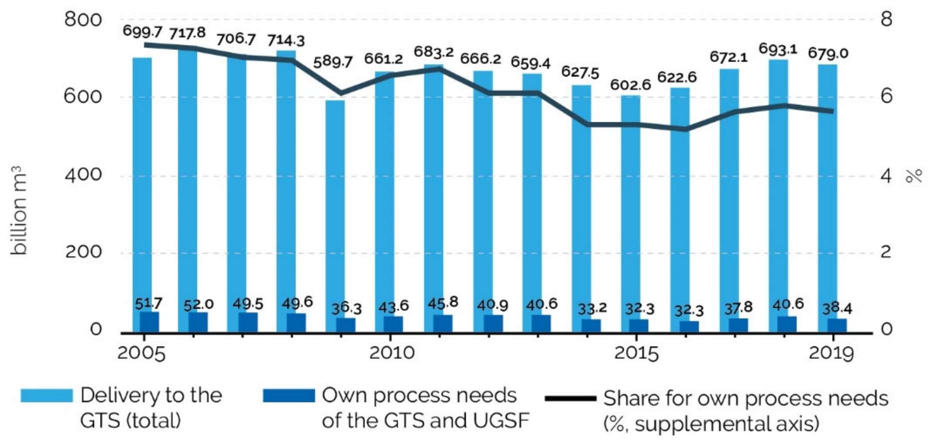
- Chemical agents were utilized to increase pipeline throughput. For this purpose, suspension-type anti-turbulence additives are used to reduce oil flow friction in the pipeline.[296]
- Optimal oil pumping modes were developed.
- Pumping equipment and boiler houses were modernized.
- Power was generated from renewables. According to the 2019 results, Transneft achieved 507 kWh of renewable electric power energy. The energy is generated by three photovoltaic power stations: JSC Transneft – Sibir (Tymen), JSC Transneft – Ural (Tchelyabinsk), and JSC Transneft – Privolga (Samara). Additionally, at Chernomortransneft facilities, a solar water-heating station has been mounted to meet the needs of heating and hot water supply using mirror heat boosters.[297]

According to Gazprom, in 2019 the company achieved a 2.9% total reduction of the amount of consumed fuel and energy resources, and their specific consumption in the most energy-intensive activity, gas transportation, decreased by 3.2%. The key activities that determined these indicators were optimization of the operating mode of electric equipment at processing facilities and the reduction of the volume of bleeding gas from out of service gas pipeline sections. In compliance with the report, specific consumption of natural gas for inter-company processing needs during transportation reduced by 22% from 2011 to 2019, with the target indicator of no less than 11.4% within the period of 2011-2020.

In Russia, which has the world's longest gas transportation system, fuel consumption for GTS own needs accounts for 5-7% of the total amount of gas delivery in the system. At the same time, in the recent years, there is a trend towards reduction of the gas share used for company`s pown needs (Fig. 47).

[296] https://niitn.transneft.ru/sustainable_development/ecology/
[297] Sustainability report 2019, PJSC Tatneft.

Fig. 47 - Operation of Gazprom GTS and gas consumption for GTS processing needs



Source: Gazprom in Figures Statistical Yearbook 2005-2019

For the last two decades, Russian oil and gas companies have experienced a steady growth in energy efficiency indicators, at the rate of about 1-2.5% a year (though from a very low base). The gained momentum and accumulated experience will be useful if the regulatory environment makes it possible to monetize the resulting reduction of GHG emissions.

Efficient monetization of methane and APG

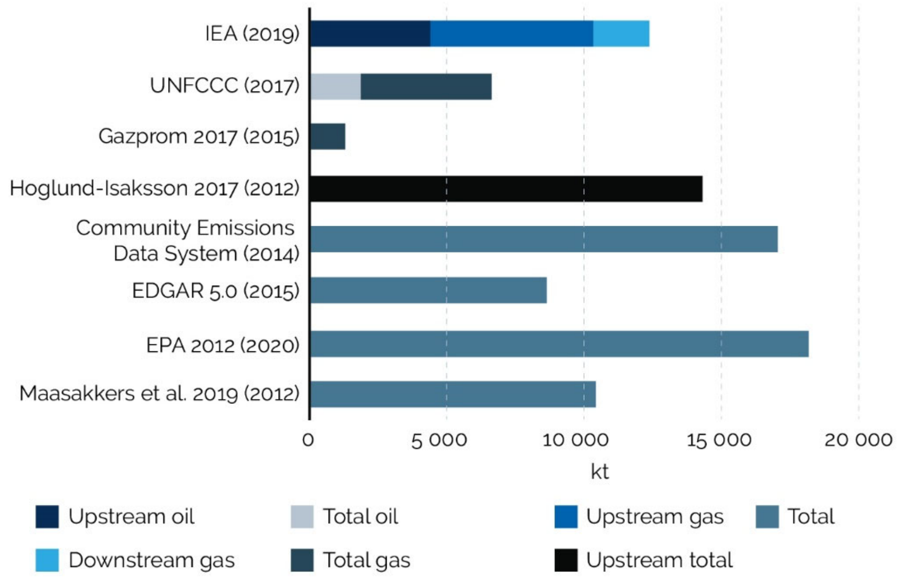
Reduction of methane emissions

Methane emissions management is a significant challenge for Russian oil and gas companies, which usually underestimate the scale of the problem and the potential for reducing methane emissions.

Methane emissions management is a significant challenge for Russian oil and gas companies, which usually underestimate the scale of the problem and the potential for reducing methane emissions. First of all, the data problem is worth noting: as shown in Fig. 48, different sources give significantly different estimates of methane emissions in Russia.

According to the Russian official data, the majority of methane emissions in the national oil and gas sector are accounted for by gas transmission, storage, and distribution – approximately 70% of all methane emissions in the industry. This is explained by the unique length of the gas transmission network, large volumes of gas transported (both Russian and Central Asian), and the size of the internal Russian market.

Fig. 48 - Estimations of methane emissions in Russia



Source: International Energy Agency, 2020.

According to the environmental reports of the Russian oil and gas companies, in the recent years they have stabilized or reduced atmospheric methane emissions. Main activities of the Russian oil and gas companies in this area include measures aimed at reducing the consumption of fuel gas and preventing natural gas blowing during gas pipeline repairs. For oil companies, such activities include outfitting production facilities with monitoring equipment for detection of methane leakages during oil production.

With the existing structure of methane emissions, one third of them may be reduced without any additional investment outlays (strictly by means of production process streamlining). The reduction of methane emissions may be facilitated by introducing monitoring systems and implementing equipment repair programs for the reduction of gas emissions or leakages, modernization of technologies and equipment for minimizing or eliminating gas emissions or leakages, optimized maintenance and modernization of equipment for more precise measuring and control of methane emissions or accompanying parameters, and utilization of methane collection and methane utilization systems, in particular, as a part of oil-well gas.[298]

Implementation of cost-efficient technologies for the detection, measurement, and minimization of methane emissions at oil and gas enterprises is currently an outstanding issue. The existing technologies for preventing dispersal methane and fugitive single emissions still need a number of measures for scaling up their implementation in Russia – update of operations standards, technical regulations, etc.

[298] Role of methane in climate change, edited by Doctor of Chemistry Profession A.G. Ishkov. NIIPE, 2018. http://www.vernadsky.ru/files/Publishing/rol_metana_v_izmenenii_klimata.pdf

Additional measures for methane emission reduction could be as follows:

- enhancement of the regulatory/legal framework in terms of its requirements for capital construction processes and technologies applied, updating provisions on equipment certification, technology conditions aimed at reducing GHGs emissions, including methane, as well as switching to the best available and environmentally-safe technologies,
- organization of R&D establishments for development of the best available and environmentally-safe technologies, inter alia, those aimed at reducing atmospheric emissions of GHG and pollutants,
- provision of economic conditions for operating commercially viable producers of equipment that meets the standards of the concept of minimal GHG emissions, including methane, as well as the best available and environmentally-safe technologies,
- simplification of procedures for governmental and environmental review of facilities/technologies that meet the standards for minimizing atmospheric GHG emissions,
- official certification of equipment and technological units, which meet GHG emission reduction standards,
- allow for third party measurement and verification of data, in order to convince others that the data are reliable.

Methane emission management is becoming even more important in view of the requirements for methane emission certification from buyers, in particular the European Union, and this may become a very serious challenge for the Russian oil and gas industry in the coming years.

Utilization of APG

Despite a number of adopted external (regulatory) and internal (corporate) measures for increasing beneficiary use of associated petroleum gas, Russia remains well below the 95% utilization target.

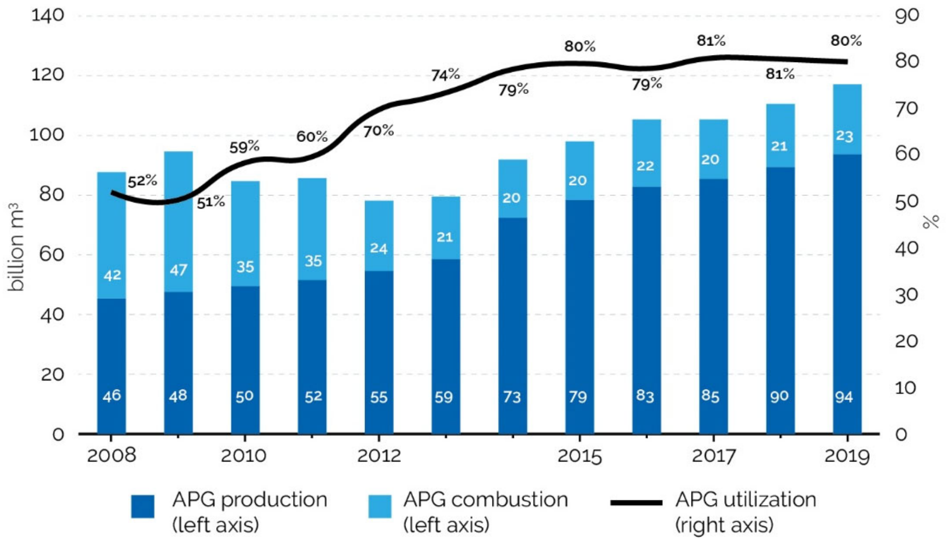
The reduction in the volume of APG combustion is directly related to the minimization of atmospheric emissions of pollutants and GHG. However, despite a number of adopted external (regulatory) and internal (corporate) measures for increasing beneficiary use of APG, Russia remains well below the 95% utilization target.

In Russia, the volume of APG production is growing. (Fig. 49). According to the Ministry of Energy, this indicator is heavily impacted by the total growth of oil and APG production in the country, as well as the geographic expansion of the production territory into eastern Siberia and Far East fields, which are far from the main infrastructure and gas processing centers in European Russia and Western Siberia.[299]

[299] Final report on the results and main directions of activity of the RF Ministry of Energy and FEC in 2019, Moscow 2020, Ministry of Energy.

On the whole, APG utilization in Russia in the last five years has remained at the average level of 80%. It should be specifically noted that official statistics on combustion volumes and, consequently, on the indicator of APG utilization in Russia and international statistics differ, in particular, in the early years. In the present paper, international data on APG combustion was used, namely, that of the Global Gas Flaring Reduction Partnership, the World Bank, and National Centers for Environment Information (U.S.). According to the 2019 results, the combustion volume was 23 BCM.

Fig. 49 - APG production, combustion, and utilization in Russia



Sources: Operation and development of the Russian FEC in 2019, Ministry of Energy, 2020, https://minenergo.gov.ru/node/1215, Global Gas Flaring Tracker Report JULY 2020, Global Gas Flaring Reduction Partnership,

https://www.worldbank.org/content/dam/photos/419x440/2016/oct/flaring_data.JPG, https://ngdc.noaa.gov/eog/interest/gas_flares.html

Below are the most popular directions for APG utilization in Russia.

APG provision to local consumers or pumping to GTS

- Srednevolzhskaya Gaz Company Ltd. implemented a project for the renewal of oil-well gas intake from RITEC-Samara-Nafta, a regional industrial enterprise in the gas transmission network. For this, Srednevolzhskaya Gaz Company constructed 14.5 km of high-pressure gas pipeline and built a gas discharge unit and four underwater crossings in the Grachevka and Kutuluk rivers.[300]
- Gazpromneft-Vostok put into operation a network of gas pipelines in the Urmano-Archinsky fields and Southern Pudinsky licensed site in the Tomsk Region. This project allowed the company to increase the volume of gas delivered to the network fourfold and increase the level of

[300] https://svgk.ru/company/press-center/news/2019/8793/

oil-well gas to 95%. For successful implementation of this project, an 18 km gas pipeline was constructed.[301]

Reinjection into the reservoir

- Gazprom Neft is implementing a project for gas reinjection into the reservoir at the Novoportovsky field.[302] Due to this, the company managed to achieve 95% APG utilization.[303]
- In eastern Siberia, Rosneft is reinjecting APG into a temporary underground storage in the reservoir at the Verkhnechonsky field. This technology makes it possible to store APG for subsequent rational use without maintaining the reservoir pressure. With this technology, the level of APG utilization at the Verkhnechonsky oil and gas condensate field has reached 97%.[304] [305]

APG processing at gas processing plants (GPP)

- In 2019, Tatneft upgraded its Minnibaevsky GPP, which has been intended for APG processing since Soviet times. This enabled a reduction in the volume of APG flaring and an APG utilization at most Tatneft fields to reach 96%. The company also plans to produce maleic anhydride (an expensive product of natural gas conversion).[306]

Electric power generation for the own needs

- In 2019, at the Roman Trebs field developed by PJSC Rosneft Oil Company, the first stage of a 22 MW energy center was put into operation. It comprises 20 gas generator plants. This completely covers the current power needs of the enterprise. In the near future, the energy center capacity will be increased to the scheduled 46 MW. For comparison, the capacity of the local power station providing electricity to the city of Naryan Mar and adjacent settlements is 38 MW.[307]
- LUKOIL has been using APG to supply power to its production facilities for a long time. In 2015, one of the largest gas turbine plants was put into operation in Perm, at the LUKOIL-Permneteorgsintez Ltd. oil refinery. The plant was commissioned for inter-company needs and has an electric capacity of 200 MW and a heat capacity of 435 Gcal/hour. Before that, the facility received electric power only from the nearby Permsky CCPP-9, owned by KES Holding, which provided both electric power and heat energy. As of September 2020, LUKOIL Group was using 75 gas turbine plants made in Perm, with a total capacity

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[301] https://vostok.gazprom-neft.ru/press-center/news/57732/
[302] https://www.gazprom-neft.ru/press-center/sibneft-online/archive/2018-june/1715824/
[303] https://sever-press.ru/2019/12/27/novoportovskoe-mestorozhdenie-poleznoe-ispolzovanie-png-dostiglo-95/
[304] https://www.rosneft.ru/press/news/item/198509/
[305] Ecological and environmental approaches to assessment of the processes of combustion and utilization of oil-well gas. Sheveleva, N.A. Scientific Journal of the Russian Gas Society, 02/25/2020, pp. 48-54.
[306] https://rg.ru/2019/10/10/reg-pfo/minnibaevskij-gpz-sokratit-vybrosy-v-25-raza.html
[307] https://www.rosneft.ru/press/news/item/194399/

of 850 MW. For the creation and implementation of Ural GTPP and for working with APG from fields with various compositions of oil and gas, the LUKOIL and ODK-Aviadvigatel team of designers was awarded a prize in the area of science and technology by the Russian government. According to ODK, taking into account the generation cost, electric power energy produced by Ural GTPP is 30-40% cheaper than purchased energy. Simultaneously, APG utilization and a reduction in CO_2 emissions is achieved.[308]

Shifting to low-carbon energy sources

Russian oil and gas companies are increasingly testing switching to less carbon-intensive fuels for inter-company electric and heat supply and for fueling the maritime and pipeline transportation of their hydrocarbons. But, so far, these projects represent a marginal proportion of the companies' energy consumption.

This section concerns the establishment of inter-company energy sources (power plants, boiler houses, energy centers, etc.) to provide oil and gas enterprises with electric and heat energy with reduced carbon footprints (compared to their alternatives, namely, purchasing energy from external providers).

In the case of thermal power plants and boiler houses, this is achieved due to cogeneration (combined production of heat and electric energy at a power plant). Russian oil and gas companies have been working for a long time at creating such energy centers in oil and gas extraction or processing. Among the most prominent plants in operation are the LUKOIL-Permnefteorgsintez energy center and the Rosneft Priobskaya gas turbine power plant.

The development of renewables in oil and gas production facilities may serve the same purpose. Thus, Gazprom Neft commissioned a small solar power plant at Omsky oil refinery (area: 2.5 hectaresl; capacity: 1 MW). [309] This company has also launched Yurta, a 47.5 kW solar-wind power plant at a remote deposit in the Yamalo-Nenetsky Autonomous District. Renewables can be utilized as a single-point method of cutting costs of supplying energy to remote facilities (upstream, midstream). The impact of such projects on reducing the GHG emissions of the companies is still insignificant.

Companies are also testing switching to less carbon-intensive types of fuel for transporting their hydrocarbons, in particular, using LNG for tankers. It should be noted that the Plan for Development of the Infrastructure of the Northern Sea Route (NSR) for the Period Lasting until 2035, approved by the Russian government, envisages development of the infrastructure for using LNG, as well as methanol, in the territorial waters of the NSR and coastal territories. In 2019, the NSR became the world first route, where the proportion of alternative fuels was substantia (over 43% of cargo was transported over the NSR using LNG as bunker fuel).

[308] https://www.kommersant.ru/doc/4503448
[309] https://www.gazprom-neft.ru/technologies/energy-efficiency/

At the Zvezda shipbuilding plant, Rosneft ordered the construction of 10 Aframax tankers operating on LNG. In 2018, Zvezda shipyard produced the first oil Aframax tanker, the Vladimir Monomakh. This vessel can use two types of fuel: oil-based and LNG. The Zvezda portfolio already comprises 12 orders for vessels of this type.[310] The total number of LNG vessels to be built by Zvezda for Rosneft, i.e., gas carriers and tankers, will exceed 20% of the total amount of the shipyard's orders (118 vessels).[311] Gazprom Neft ordered a pilot LNG bunkering tanker for work in Russian Baltic Sea ports in 2021. Its cargo capacity is 5,800 m^3 of LNG.[312]

NOVATEK utilizes renewables based on PV (installed capacity up to 2 kW) and wind turbines (installed capacity 1 or 3 kW). Renewables supply power to telemechanic system points to control block valve stations of mainline pipelines and cluster sites of gas condensate fields.[313] For example, to supply energy to the condensate line of the Yurkharovsky field - Purovsky CPP, NOVATEK used solar PV and wind turbines, which resulted in CapEx savings, since the company did not have to build a power transmission line.[314]

Transneft, based on the 2019 results, achieved 507,000 kWh of electricity generated by renewables. The energy is generated by three solar PV stations (Transneft – Sibir (Tymen), Transneft – Ural (Tchelyabinsk), and Transneft – Privolga (Samara). Additionally, at Chernomortransneft facilities, a solar water-heating station has been mounted to meet the needs of heating and hot water supply using mirror heat boosters.[315]

Corporate decarbonization methods

Optimization and diversification of the asset portfolio and carbon offsetting

Russian companies are not yet as active in using corporate decarbonization methods as their international peers. In the absence of a national system for accounting for GHG emissions and mechanisms allowing for their monetization, companies are unable to take advantage of carbon offsets.

For the same reasons, optimizing the asset portfolio is given much less attention by Russian companies than by leading foreign oil and gas companies. Development of gas assets, as a rule, is caused by the strive for diversification of the core business, rather than by the aspiration for its decarbonization. No divestments have been observed yet, whereas diversification

[310] https://www.rosneft.ru/press/news/item/200653/
[311] https://www.kommersant.ru/doc/3675554?fbclid=IwAR3QZfbgkBEfeFwtV1sPAAIngWWQlrWOr3OgF6G1_63APo-jfDT0pPbQNWw
[312] "Implementation of alternative fuels for bunkering. From the Baltic to the Arctic region" – Discussion materials for international conference NEVA-2019, A.Yu. Klimantiev, A.Yu. Knizhnikov, September 2019, Saint-Petersburg.
[313] Sustainability report 2019, PJSC "NOVATECH"
[314] https://www.finam.ru/analysis/newsitem4EECB/
[315] Sustainability report 2019, PJSC Tatneft

due to investments in green assets is gradually becoming popular, especially for assets outside of Russia (due to the more substantial role of decarbonization in the foreign markets where these companies operate). For example, there are renewables projects from LUKOIL in Romania and Bulgaria and from Gazprom Neft in Serbia, where the NIS company, together with its Swiss partner, MET Renewables AG, is building a 102-MW wind park with plans for being commissioned in 2021.[316] For NIS, this project is first and foremost a way to forge a material niche in the Serbian electric power market, taking into consideration the country's plans for renewables development in the power sector.

Russian companies are not yet as active in using corporate decarbonization methods as their international peers. In the absence of a national system for accounting for GHG emissions and mechanisms allowing for their monetization, companies are unable to take advantage of carbon offsets.

Larger-scale diversification into green energy is practically non-existent. The only exception is the electric power business being developed by LUKOIL Group since 2008, represented initially by gas-fired thermal power plants, which, by now, have become a source of best practices for renewables development for LUKOIL Group. Now the company assets now comprise four hydroelectric power plants with a total capacity of nearly 300 MW, as well as solar and wind.[317] Further plans for renewables development for LUKOIL Group, as follows from the company report, involve the modernization of these assets, implementation of commercial renewables projects (particularly due to using mechanisms of state support), reduction in and prevention of GHG emissions, and creation of a synergy effect through the construction of renewables facilities at existing oil and gas extraction and processing enterprises.

Reforestation

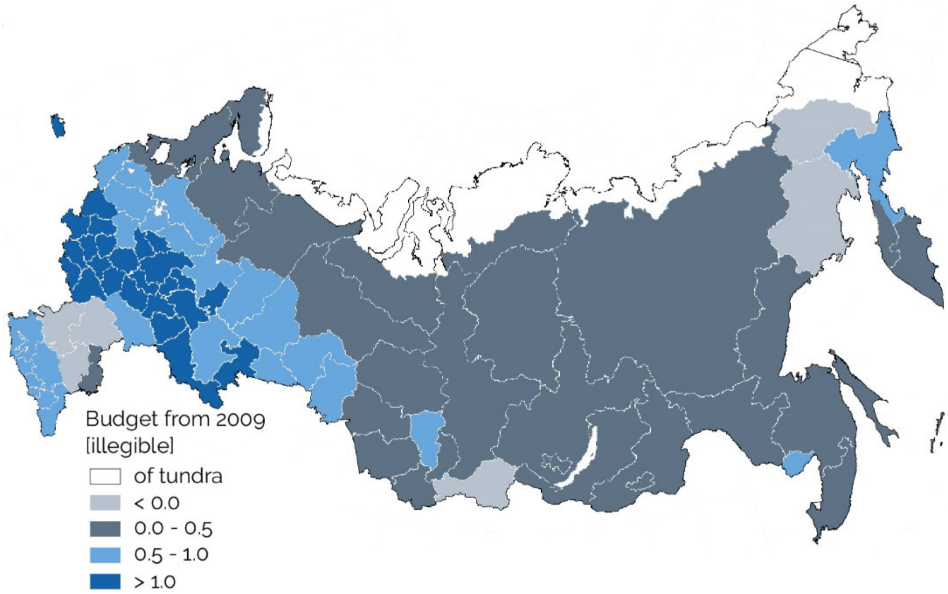
Russia does not have a national system for carbon offsets accounting; tools based on international standards are extremely limited; there are currently no legislative tools for mobilizing resources from the oil and gas industry for reforestation and forest conservation.

The role of LULUCF in Russia is more important than in a number of other major GHG-emitting countries: the managed lands in Russia support the sustainable upward trend towards net GHG absorption (up to 577 Mt, 27% of the emission amount in all other sectors).

In Russia, the largest volumes of accumulated carbon are stored in the southern boreal forests and broad-leaved forests of European Russia (areas with mild climate, the largest amount of middle-aged forests that actively accumulate carbon and are successfully protected against fires). Siberian forests have a low carbon reserve; they are less productive because of the harsh continental climate and a large number of forest fires. Some regions are even carbon sources due to frequent, vast forest fires (Fig. 50).

[316] https://group.met.com/press-releases/swiss-met-group-and-gazprom-neft-owned-nis-to-build-102-mw-wind-park-in-serbia/98
[317] https://ekoenergo.lukoil.ru/ru/About/GeneratingFacilities

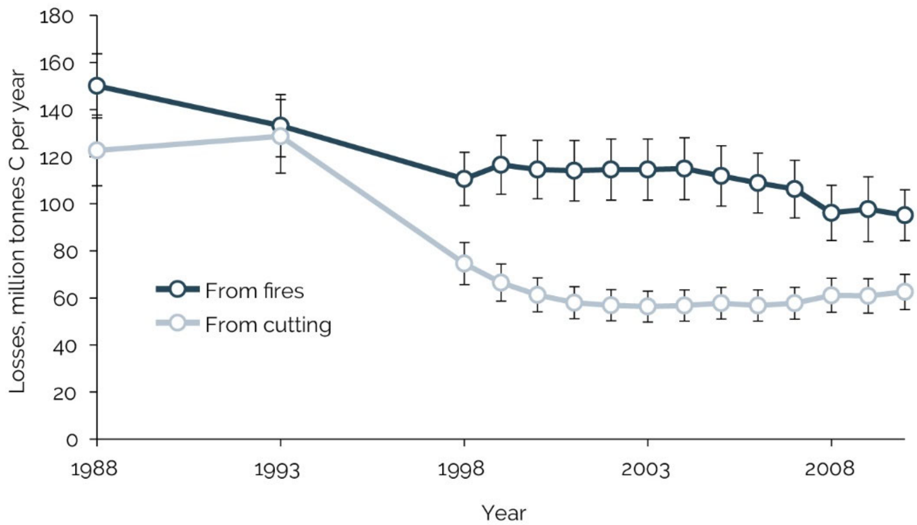
Fig. 50 - Geographic distribution of average values of the Russian forest carbon balance



Source: http://cepl.rssi.ru/wp-content/uploads/2016/05/BNK2014-prezentation_Zamolodchikov.pdf

The forest cover is not permanent. Lumber cutting and outbreaks of harmful organisms reduce carbon consumption, and the decomposing of dead wood becomes a source of carbon emissions. In Russia, fires are traditionally the main source of carbon losses in forests, although, in the future, the situation may change. Pre-1990s, when Russia harvested an amount of timber 3x greater than today (up to 95% of the calculated felling rate), losses from cutting and fires were more or less comparable (Fig. 51).

Fig. 51 - Dynamics of carbon losses in Russia due to cutting and fires



Source: http://cepl.rssi.ru/wp-content/uploads/2016/05/BNK2014-prezentation_Zamolodchikov.pdf

Worldwide reforestation mostly occurs naturally. From 2015 to 2020, reforested areas accounted for 5 million hectares, while deforested areas accounted for 10 million. Plantation forestry makes up no more than 3%, and 4% are accounted for by forest planting. In this situation, the amount of natural reforestation is diminishing, and the amount of planted forests is not growing. In Russia, in spite of large volumes of planted forests, more than half (and according to unofficial statistics, up to 90%) of young plants fail to take root. Actually, most reforesting is occurring naturally, if at all. As a rule, opened areas are colonized by economically low-value species, which incentivizes lumber harvesting in undisturbed forests and protected forests. The main reasons for low effectiveness in reforesting are poor-quality planting material, irregularities in planting procedure, and lack of care after planting.[318]

In Russia there are currently no legislative tools for mobilizing financial resources from the oil and gas industry for reforestation and forest conservation in order to reduce carbon footprints.

According to estimates by U.A. Izrael Institute of Global Climate and Ecology,[319] the most essential directions for GHG reduction in Russia through reforestation are as follows:

- escalating fire safety measures in forests, including measures for preventing, monitoring, quickly discovering, and extinguishing fires, which will all help to reduce GHG emissions on average by 240-420 MtCO2e per year,
- sparing wood harvesting in forests, providing for minimum soil damage by equipment, (which may ensure an annual reduction in emissions of 37 MtCO2e), minimizing refuse wood losses in the process of wood harvesting, (which in Russia reaches 40-50% of wood biomass and would result in an emissions cut of 61-76 MtCO2e per year), and increasing paper recycling to 100% and the added-value converting of the released amount of wood into long-life products, (which may entail an annual accumulation of about 51-79 MtCO2),
- replacing pure crop softwood reforestation with mixed cultures, which will help to form more tolerant ecosystems and raise the absorption by 50-70 MtCO2e per year, and
- replacing extensive types of tillable land use for intensive ones, (which will reduce soil carbon losses due to optimum organic manuring, reduction of erosion, and deflation losses and potentially reducing the annual emissions from tillable land by approximately 100-160 MtCO2, from forage lands up to 13-19 MtCO2), and

[318] Zamolodchikov, expert interviews, WWF. http://forest.akadem.ru/News/20141104_01/Forest_management_2014_proceedings.pdf
[319] U.A. Izrael Institute of Global Climate and Ecology. http://www.igce.ru/2020/03/%D0%BC%D0%BD%D0%B5%D0%BD%D0%B8%D0%B5-%D0%B4%D0%B8%D1%80%D0%B5%D0%BA%D1%82%D0%BE%D1%80%D0%B0-%D0%B8%D0%B3%D0%BA%D1%8D-%D1%80%D0%BE%D0%BC%D0%B0%D0%BD%D0%BE%D0%B2%D1%81%D0%BA%D0%BE%D0%B9-%D0%B0-%D0%B0/

measures aimed at reducing the washing-out of nitrogen for applied mineral and organic fertilizers, (which may result in a decrease of the country's annual GHG emissions by an additional 4-8 MtCO2e and has the ancillary benefits of national food security and an increase in the adaptation potential of agricultural lands).

Regulators traditionally focus on reforestation when discussing climate policies in Russia, and oil and gas companies regularly report on the relevant measures (mostly concerning forest transplanting within the scope of recovering land polluted by oil in the regions of the companies' presence). Below are some examples from company reports from 2019.

- LUKOIL recovered of 56.6 hectares of land in 2019.
- Tatneft, has been implementing the Program for Greenery Planting, with more than 10 million trees and bushes having been planted since 2000. And, in 2020, the company announced plans to plant more than 3 million plants.
- Rosneft planted 1 million trees within the scope of forest preservation activities.
- Gazprom, in 2019, allocated RUB 2.18 million for forest protection and harmonious forest exploitation as part of investments in environment protection and sustainable utilization of natural resources.
- Gazprom Neft is implementing the Green Seismic project, which has already saved the felling of 3.5 million trees.

The efficiency of this type of activity for decarbonization goals is constrained by the lack of a regulatory framework, namely, a national carbon offsetting system and tools based on international standards. This restricts possibilities for mobilizing resources from the oil and gas industry for reforestation and forest conservation to reduce carbon footprints. And, most regenerative land use projects are often implemented at a low-quality level, with an unprovable long-term carbon accumulation effect.

For oil and gas companies, the most promising directions of carbon footprint reduction through forest projects in Russia are as follows:

- reducing impact on forest ecosystems in the process of operational activity (for example, through minimally invasive seismic testing, etc.),
- investing in fire prevention projects to limit the negative effect of fires,
- increasing the quality of reforestation projects to preserve the long-term effect of carbon accumulation, and

- investing in reforestation and agricultural projects outside the regions of their presence, in forests with maximum carbon accumulation potential.

Thus, Russia is facing the necessity of creating a national carbon offsetting system and a methodology of measurement and certification for various projects, in particular, in the forestry and agricultural sector. This certification has to meet the requirements of international standards, so that Russian carbon offsets could be recognized in the global markets and could be acquired by, *inter alia*, international organizations.

It is necessary to support (by way of establishing special-purpose funds or programs, and accelerators) the formation of a sector of qualified contractors working on quality projects on regenerative land use (including wetland restoration) with provable long-term carbon accumulation effect.

It also seems expedient to introduce a complex of education and awareness programs aimed at having oil and gas managers and employees better understand the principles and methods of regenerative land use.

Decarbonization of the petrochemical sector

Russian oil and gas companies are developing petrochemical strategies, which allow for monetizing oil and gas resources, responding to challenges, and leveraging the new decarbonization and global environmental agenda opportunities.

In Russia, oil and gas companies are also developing a petrochemical wing to their strategies. This wing allows for monetizing oil and gas resources, responding to challenges, and leveraging the new decarbonization and global environmental agenda opportunities.

Gazprom already comprises one of Russia's leading petrochemical facilities, Gazprom Neftekhim Salavat, LLC, which is engaged in manufacturing a wide range of refined products, petrochemicals, and mineral fertilizers. Gazprom is building the Amur gas processing plant, which has annual capacity of 42 BCM of natural gas, where valuable components for gas chemicals and others (ethane, propane, butane, pentane-hexane fraction, and helium) will be extracted from gas, for efficient resource use of the Yakutsk and Irkutsk gas production centers. The derived ethane will be used at Sibur's Amur gas chemical plant.[320]

LUKOIL has two plants in Russia (Stavrolen LLC and Saratovorgsintez LLC) that manufacture petrochemical products, the output of which reached 0.8 Mt in 2019. In the near future, the company intends to implement a 0.5 Mt polypropylene production project at the Nizhny Novgorod refinery, by using its own raw materials from the existing catalytic cracking units.[321] For processing gas produced at North Caspian fields, the company is going to set up a major gas chemical

[320] https://www.gazprom.ru/projects/amur-gpp/
[321] LUKOIL PJSC Annual Report for 2019.

facility in Budennovsk.[322] The plant will manufacture carbamide, ammonia, polyethylene, and polypropylene.

Rosneft comprises several petrochemical assets (Novokuybyshev Petrochemical Company JSC, Angarsk Polymer Plant JSC, Ufaorgsintez), where the aggregate processing of raw hydrocarbons amounted to 2.4 Mt in 2019.[323] Construction of a petrochemical facility in Nakhodka (EPCC) may become the company's promising project under certain conditions. However, this project is now suspended. In 2019, Rosneft deemed it unprofitable in the then existing market and regulatory conditions.[324]

At its refineries, Gazprom Neft produces a broad range of basic petrochemical products, including aromatics (benzene, paraxylene, orthoxylene, toluene, and aromatic hydrocarbon fraction) and propylene containing liquefied hydrocarbon gas. Gazprom Neft is a successful example of integrating the oil refining and petrochemical sectors in Russia. In 2019, the company's petrochemical output was as high as 1.55 Mt. In addition, Polyom and Neftekhimiya ORP, the joint ventures of Gazprom Neft and Sibur Holding, produce polypropylene. Gazprom Neft regards oil and gas chemicals as a promising and growing business sector. In the near future, the company intends to upgrade its catalytic cracking unit at the Omsk refinery for petrochemical manufacturing and build a pyrolysis plant with a 1 Mt capacity. The company plans to bring the proportion of petrochemicals in its downstream operating profit (EBITDA) up to 15% (from the current 3-4%) by 2030.[325]

APG utilization via development of petrochemicals is also applied by several Russian companies. Irkutsk Oil Company has used associated petroleum gas at the Yarakta and Markov oil and gas condensate fields since 2012 since 2018, respectively, by processing it in complex natural and associated gas treatment units to derive a propane and butane mixture, stable gas condensate and dry gasoline-free gas (methane with up to 10% ethane content) that is still disposed by its flooding in the field. In 2023, the company plans to commission an LDPE (Low Density Polyethylene) and HDPE (High Density Polyethylene) plant with a 650 000 t annual capacity, using raw materials from the Yarakta and Markov fields.

Tatneft comprises a whole range of petrochemical enterprises managed by Tatneft Neftekhim management company and Tatneftegazpererabotka, which specialize in processing APG and wide light-hydrocarbon fractions. Thanks to the latter, the company has managed to efficiently utilize APG.

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[322] In 2020, Lukoil may make the final investment decision on its gas chemical facility in the Stavropol Region, TASS Information Agency //URL: https://tass.ru/ekonomika/6803456
[323] Rosneft PJSC website: // https://www.rosneft.ru/business/Downstream/petrochemicals/
[324] Rosneft Gives Up EPCC – The Kommersant // https://www.kommersant.ru/doc/3967501
[325] Gazprom Neft PJSC website // https://www.gazprom-neft.ru/company/retail/petrochemistry/

Other measures

So far, other decarbonization activities popular with international companies are either not used in Russia or are in the early stages of R&D.

CONCLUSIONS AND RECOMMENDATIONS

Recommendations for the Russian government

The analysis of changes in the global environment and the experience of decarbonization of leading international oil and gas companies shows that in order to ensure continuous competitiveness of the Russian oil and gas sector in the international market, it would be advisable to implement the following measures:

- national GHG (including methane) emissions monitoring system, as well as reporting requirements for GHG emissions, recognized by the relevant international monitoring systems.
- transparent and internationally recognized rules for the implementation and verification of GHG reduction projects and GHG utilization and carbon sequestration.
- scientifically based and internationally recognized methodologies for determining the effects of projects to reduce GHG emissions, GHG utilization and carbon sequestration (especially in relation to forestry projects).
- a system of carbon credits trading with a transparent pricing mechanism between domestic and international companies.
- a system of "green certificates" in the domestic market in order to provide oil and gas companies with the opportunity to purchase certified green electricity and reduce emissions of the scope 2.
- to revise the requirements regarding the companies' responsibility for failing to achieve the level of APG utilization. Setting a more ambitious target for APG utilization - at least 98%: the utilization rate by 2027.
- national GHG pricing mechanisms in the form of carbon taxation or carbon credits and carbon credits trade.
- comprehensive methane strategy in addition to national GHG focused systems.
- updated technical operational standards that take into account best practices for methane and other GHG reduction.
- for oil and gas companies with state participation to establish a commitment to achieve a certain position in the international rating. For example, by 2026, in the Climate Change category, achieve a CDP rating of C and above.

Russia should increase state support of the research, piloting, and venture financing of decarbonization projects and technologies. Some examples of possible priority areas are:

- high-resolution hydrocarbon reservoir modelling for improving reservoir pressure management (and water cut reduction), gas flaring reduction, and assessment of reservoirs for CCUS use in the future,
- methane monitoring and leaks prevention technologies including digital/AI predictive tools,
- emerging detection mechanisms, including aerial detection detects (air surveys, drones), and satellites.
- innovative hydrogen production and transportation/storage technologies.
- high-efficiency gas and LNG turbine and compression technology.
- biofuels and bioplastics.

Russia's natural advantages in decarbonization should be further analyzed in an internationally-recognized technical and commercial framework and promoted within the country and on the global markets. These advantages include:

- abundant opportunities for renewable and hydro power investments.
- low-carbon gas production and transportation, otential for the development of CCUS, as well as the production of carbon-neutral hydrocarbons.
- opportunities to leverage existing gas infrastructure for hydrogen supplies to Europe and Asia.
- opportunities to leverage existing strengths in low-carbon footprint nuclear power for power generation and export, including marine applications and as a source of energy for oil, gas, and hydrogen production.

Though all of the above in well-known in the Russian professional community, fact-based evidence needs to be provided to the international stakeholders. It is important to promote and encourage international and cross-industrial cooperation with European and Asian companies on decarbonization projects. For example,

- support educational programs and cross-industrial and international dialogues and exchanges of opinions.
- have the Russian government and Russian businesses representatives play a more proactive role in international climate policy-making discussions.
- facilitate technical regulations and permits for importing the equipment and technologies necessary for decarbonization projects.
- support the localization of equipment manufacturing once demand for such products stabilizes.

- support and promote international cooperation on decarbonization projects where coal and oil is substituted by gas or "blue" hydrogen (hydrogen from CH4 combined with CCUS project).

The potential of natural carbon sinks (forests, swamps, Artic zone, etc.) and biofuels should be analyzed in internationally recognized technical and commercial frameworks, and mechanisms for carbon credits linked to natural sources should be implemented.

Recommendations for Russian oil and gas companies

Decarbonization is a long journey with many unknowns and therefore the success of decarbonization efforts requires four things:

- a solid understanding of GHG emission sources and their future dynamics,
- incentives both at strategic and operational levels within oil and gas companies and with their suppliers,
- a balanced portfolio of long-term and short-term initiatives, and
- international and cross-industrial cooperation on R&D, piloting of technologies, and scaling solutions.

For oil and gas companies climate and decarbonization strategy must be an increasingly integral part of overall strategy discussion, involving all business and functional lines, not just HSE or IR department tasks. Effective decarbonization is a major strategic shift and requires a complete review of corporate governance and available technologies, as well as a mindset shift. In this context, it would be important for the companies to be much more involved in the development of decarbonization goals and objectives at the state level.

- The comprehensive review and reporting of GHG emission sources and the development of decarbonization strategy are important first steps. Each company has unique opportunities and challenges in decarbonization and these need to be reflected in its strategy. Methane mitigation is specifically important, given the relative contribution of methane in scope 1 and 2.
- Even in the absence of domestic GHG emissions pricing, an internal CO_2 price should be incorporated into investment and strategy decisions.
- Decarbonization strategy should be supported by clear governance and an incentive system.

Create ecosystems of partners that can support decarbonization through existing and future technologies, as well as corporate governance, such as:

- educational and research institutes,
- international peers to share R&D and venture investments, and
- local upstream (suppliers) and downstream (customers) actors that face similar challenges.

Clearly articulate the company's unique, competitive advantage for the decarbonization strategy to the external stakeholders and pro-actively share achievements on a global stage.

Climate transformation is already becoming inevitable, at least for the companies in the oil and gas sector. It will be a long process, and not a one-step action, so it is important to approach it systematically, realizing that this is a task for several decades.