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On the Integration of CO_2 Capture Technologies for an Oil Refinery

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Abstract: This study determines and presents the capital and operating costs imposed by the use of CO_2 capture technologies in the refining and petrochemical sectors. Depending on the refining process and the CO_2 capture method, CO_2 emissions costs of EUR 30 to 40 per ton of CO_2 can be avoided. Advanced low-temperature CO_2 capture technologies for upgrading oxyfuel reformers may not provide any significant long-term and short-term benefits compared to conventional technologies. For this reason, an analysis was performed to estimate the CO_2 reduction potential for the oil and gas industries using short- and long-term ST/MT technologies, was arriving at a reduction potential of about 0.5–1 Gt/yr. The low cost of CO_2 reduction is a result of the good integration of CO_2 capture into the oil production process. The results show that advanced gasoline fraction recovery with integrated CO_2 capture can reduce the cost of producing petroleum products and reduce CO_2 emissions, while partial CO_2 capture has comparative advantages in some cases.

Keywords: CO_2 capture; oil refinery; Residual Oil Zones (ROZ); CCUS

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1. Introduction

While the oil and gas industries have assumed the major responsibilities with respect to the transition towards achieving a low carbon footprint by 2050 through the development and implementation of CO_2 capture technologies, at the signing of the Paris Agreement, Russia committed itself to regulating the reduction of greenhouse gas emissions by industry. According to BP, the global emissions of CO_2 (the main greenhouse gas) in 2019 amounted to almost 33.9 billion tons. For this reason, China (9.4 billion tons), the USA (5.1 billion tons), India (about 2.5 billion tons), Russia (about 1.6 billion tons) and Japan (more than 1.1 billion tons), along with large companies in Russia (companies supported by the Russian Federation), are studying CO_2 capture technologies, as well as carbon capture and sequestration (CCS) technologies, with respect to their performance in the specific areas of production, extraction, and storage for economic and technical feasibility. Roadmaps are also being developed to reduce the carbon footprint in the production and processing of heavy oil, the conversion of coal into oil, the production of biofuels, and the conversion of liquefied gas into oil products. Currently, a step-by-step assessment process is underway aimed at reducing carbon emissions using unconventional resources. The goal of these projects is to enable the use of traditional resources in the oil and gas industries to limit carbon emissions without increasing the cost of producing the final products. This methodology was evaluating using the example of the impact of carbon emissions reduction at Russian refineries. The baseline levels of carbon dioxide emissions from refining oil were established, and the cost of reducing these emissions using proven post-combustion carbon capture technology was calculated. Alternatively, a study on the Carbon Capture Project (CCP) study was performed in which the technical and economic possibilities of CO_2 capture technologies were compared and found that this technology reduced the cost of avoiding CO_2 emissions by 35 percent compared to carrying out capture after the reforming process in the refinery scenario [1–3].

Oil refineries are one of the largest sources of anthropogenic CO_2 emissions, with the metallurgical industry being roughly on par with this. In 2020, the oil and gas industries accounted for over 11 gigatons of CO_2, accounting for almost 32 percent of total global CO_2 emissions [4,5]. The industry's overarching goal is to achieve energy efficiency in production using the best available technologies (BAT) using renewable energy sources such as CO_2 capture and storage (CCS) [6,7]. The oil and gas industries consider this BAT option to be one of the options that could result in energy efficiency being achieved by reducing CO_2 emissions. The use of CCS technologies in refineries is being considered due to the large number of processes that generate large amounts of CO_2 emissions such as VOCs and flue gases. At the same time, the introduction of CO_2 capture BAT using the proposed technologies could reduce the economic burden assumed by plants arising from the production of pure CO_2 [8,9]. By 2050, with reference to authoritative reports from international governmental and non-governmental organizations in the field of oil and gas processing, the release of CO_2 emissions into the atmosphere should be reduced by more than 10 Gt per year [10,11]. Today, Russia is operating within the framework of the UN Framework Convention on Climate Change, in which measures for reducing the carbon dioxide content in the atmosphere from 2020 are regulated. Therefore, following the example of the United Nations Industrial Development Organization, Russia intends to implement a roadmap project for the industrial capture and storage of CO_2 [12,13].

For example, at the XII Eurasian Economic Forum in Verona (Italy) in 2019, Rosneft signed an agreement with DeGolyer & MacNaughton Corp. to assess the resources available for underground CO_2 storage at areas licensed by the company in Russia. In December 2021, it became known from open sources that GazpromNeft was going to invest about RUB 30 billion (about USD 383 million) in the first CCS projects in the Orenburg region. In Russia, there are no permanent CCS systems, and large refineries are not technologically equipped for the capture of CO_2 [14,15]. The first stage consists of the implementation of a project in which 1 million tons of CO_2 will be injected into underground layers annually. The Orenburg region was not chosen at random; the deposits in this region enable the pumping of up to 50 million tons of CO_2 per year.

GazpromNeft, in collaboration with NIS, is currently implementing a project in Serbia facilitating the collection and treatment of natural gas with a high carbon dioxide content, with an injection volume of about 100,000 tons of CO_2 per year. The resulting CO_2 is then pumped into the developed deposits, located at a depth of more than 2500 m. A project is also being considered that would allow Sakhalin Island to achieve carbon neutrality by 2025.

To achieve these goals in Russia, there are several unresolved issues:

1. There is no regulatory or legal framework regulating the achievement of carbon neutrality and control over CO_2 emissions by industry.
2. There is no regulatory framework for regulating industrial safety on the issue of CO_2 in subsoil use.
3. For projects related to the capture, transport, and storage of CO_2 to be effective, it is necessary to develop an economic model for state support of and compensation for costs to the owners of enterprises involved in the implementation of capture, transport, and storage technologies.

GazpromNeft owns four major refineries: the Moscow Refinery, the Omsk Refinery, the Slavneft–YANOS plant in Yaroslavl (jointly with Rosneft), and an oil and gas processing complex in Serbia (Pancevo). The total refining volume of the company at these refineries in 2021 amounted to 43.3 million tons of oil. Another problem for the Russian oil refining industry is the lack of ownership of underground natural reservoirs suitable for storing CO_2. For this reason, some companies are considering ways of utilizing CO_2, including its reuse in construction and in the food industry.

According to the annual review by the audit company Ernst & Young for 2021, CCS technology in Russia is in the initial stage of development and is not economically beneficial for companies due to the high cost of the technology; 1 ton of sequestered CO_2 costs USD 160–170. For example, in the USA, the state pays enterprises that have implemented CCS technologies a subsidy of USD 35–50 per ton of CO_2 for the purpose of using CO_2. In the countries of the European Union, companies that have implemented CCS technologies pay for them at a cost of 60 to 65 EUR/tCO_2.

It is worth mentioning that Russia is a country with many opportunities for the introduction of new technologies, and there are many projects that need state support, without which the introduction of CCS technologies will be impossible.

Research on CO_2 capture rates in carbon-intensive industrial processes began in the late 20th century and became widespread in the 2000s, as described in works such as [16–18]. Research has been focused on the application of chemical absorption to capture CO_2 in petrochemical plants [19–22]. Scholars have concluded that, compared to CO_2 capture in the operation of thermal power plants [23–26], the cost indicators are comparable to those in the oil and gas industries [27–32]. For example, the IEA Greenhouse Gas Research and Development Program (IEAGHG) compiled reports that include refinery performance and technical and economic carbon neutrality performance [33–35]. An IEA report demonstrated the effectiveness of carbon dioxide capture technologies [36–38], and for refinery technologies, the economics of flue gas amine-based capture and oxy-fuel combustion capture are comparable to those in metallurgy.

The IEA reports contain overviews of the use of CCS technology in the oil and gas industries [39–41]. It is also worth noting the report of the Intergovernmental Panel on Climate Change on CO_2 [42]. These reports present an analysis of the literature on industries such as oil and gas processing, metallurgy, and the construction industry. We conducted a comparative literature review analyzing CO_2 capture rates for a wide range of industrial processes (Table 1).

Table 1. Review of major publications analyzing CO_2 capture performance.

Reference	Plant Economic Lifetime	CO_2 Avoidance Costs	
		Petroleum Refineries	Other Industries
[42–44]	20–30	∼45 EUR/t captured (2035year)	25–40 EUR/t (2030)
[45]	30	∼40 EUR/t captured (2050 year)	45–60 EUR/t (2050)
[46–48]	25	∼43 EUR/t captured (2050 year)	45–60 EUR/t (2050)
[49–53]	25	∼45 EUR/t captured (2050 year)	45–60 EUR/t (2050)
Varied (original figures from reviewed studies)	30	Catalytic crackers ∼45 EUR/t captured (oxyfuel combustion)	30–50 EUR/t (2030)
Varied (original figures from reviewed studies)	Not stated	Not stated	Not stated

Table 1. *Cont.*

Reference	Plant Economic Lifetime	CO_2 Avoidance Costs	
		Petroleum Refineries	**Other Industries**
[54]	Not stated.	Not stated	Not stated
[55–57]	20–30	∼40 EUR/t captured (2050 year)	Not stated
Varied (original figures from reviewed studies)	Not stated	∼25 EUR/t captured (gas recycling)	Not stated
[58–60]	Not stated.	∼30 EUR/t captured (gas recycling)	35–50 EUR/t (2030)

The information provided in Table 1 provides an overview of the technologies for CCS of CO_2, as well as research and development efforts in the CO_2 capture industry. The purpose of this review is to comprehensively cover all aspects of CCS, including fuel price, capital cost, interest rate, and life, which can have a big impact on the results of CO_2 technology research. In previous studies, the authors did not provide a specific CO_2 capture technology and did not consider describing the storage costs. Thus, the purpose of this study is to consistently evaluate and compare the technical and economic performance of CO_2 capture technologies for the oil and gas industries.

Based on our analysis of the literature, several CO_2 capture technologies can be identified, which can be grouped into the production of fuel, gasoline, and other raw materials for petroleum products, making chemicals, polymers, and biofuels.

Technical solutions for CO_2 storage in geological formations are another hotly debated CO_2 capture technology, considering the economic and environmental attractiveness of such projects, which include the following technologies for the capture and utilization of CO_2 (Table 2).

Table 2. CO_2 utilization technologies.

Technology	Description
Pre-combustion	Based on the gasification process through which the fuel passes, pre-combustion produces syngas, which is primarily composed of hydrogen and carbon monoxide. Subsequently, hydrogen and carbon monoxide are converted to carbon dioxide, which then goes through a gas separation process.
Combustion	The capture of gases that occurs during combustion is called "oxygen combustion", and its principle is to burn fuel in an oxygen-enriched environment.
Post-combustion	Capture takes place in the final phase of the release of combustion products. This process is ideal for capturing CO_2 from energy-generating sources such as thermal power plants and other plants that use waste to generate energy. After the exit of the flue gases, they go through a process whereby CO_2 is separated from other gases using an appropriate technology.

In the current study, special attention is paid to oil and gas processing and petrochemistry. The petrochemical industry accounts for almost a quarter of industrial CO_2 emissions [61], or approximately 1 $GtCO_2$/year. As the main sources of CO_2 emissions are similar across industries, industrial processes, and feasibility studies on CO_2 capture technologies, such as metered gas cleaning, ammonia production, and coal or oil gasification, are currently being conducted in an industry-wide manner. According to expert forecasts, CCS technologies will play a significant role, at a level of more than 50 percent, in the production of synthetic fuel, synthesis gas, and hydrogen by 2050 [62]. This study considers technologies for capturing CO_2 at the pilot project, pilot implementation, and commercialization stages [63,64].

2. Methodology

2.1. Process Description of CO_2 Capture Plant

This section describes a research methodology for estimating and reducing CO_2 emissions based on a typical plant using technology consisting of syngas production—the so-called Fischer–Tropsch process.

Flue gas utilization is envisaged in the design of the heat exchanger at temperatures between 160 and 400 °C. Due to the large sources of CO_2 emissions in existing refineries, two separate lines should probably be installed, one for flue gas cooling and the other for CO_2 recovery. The cooled flue gases are combined and sent to the line for CO_2 absorption, heat recovery, and drying, followed by preparation for transportation to the CO_2 pipeline system at the required predetermined pressure. The low-pressure gas stream comes into contact with the amine recycling solution. Instead of a traditional stripper, a saturated amine heat exchanger is used as a flash evaporator to regenerate the amine and remove the top layer of CO_2. The heat exchanger overhead is condensed in a remote mixing condenser, refluxed with circulating cold diesel distillate, and sent to a drying and CO_2 compression line to meet product specifications (Figure 1).

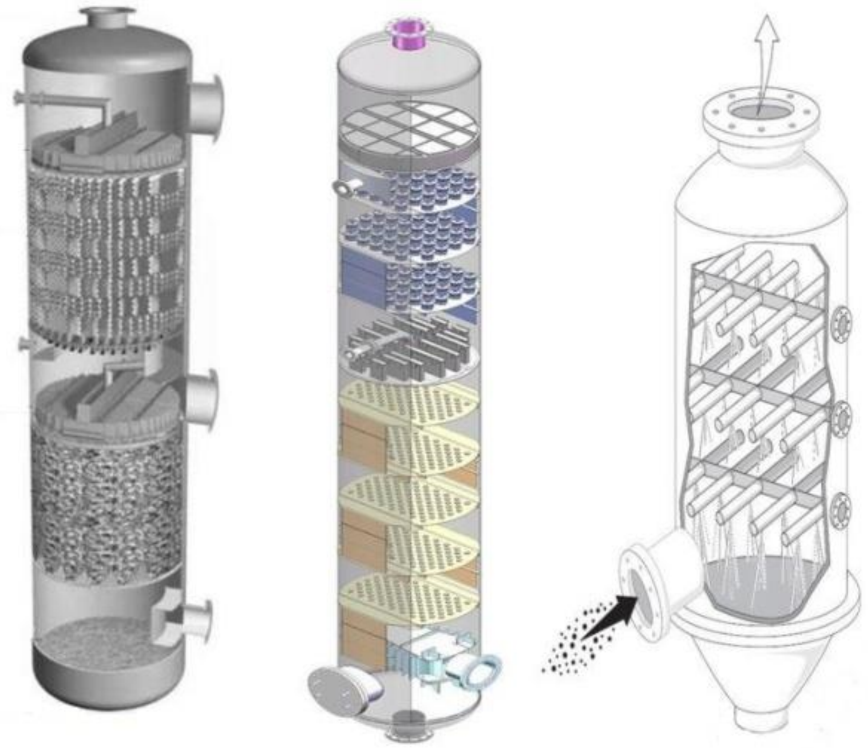

Figure 1. General view of a heat and mass transfer apparatus for the separation of volatile impurities from liquid mixtures.

The key utility requirements for a post-combustion capture plant include power, steam, and cooling. Accessories support the installation of traps [65,66]. Figure 2 shows a diagram of the CO_2 capture process after oil refining. Technological solutions include the capture process and the possibility of further transportation to the process pipeline system.

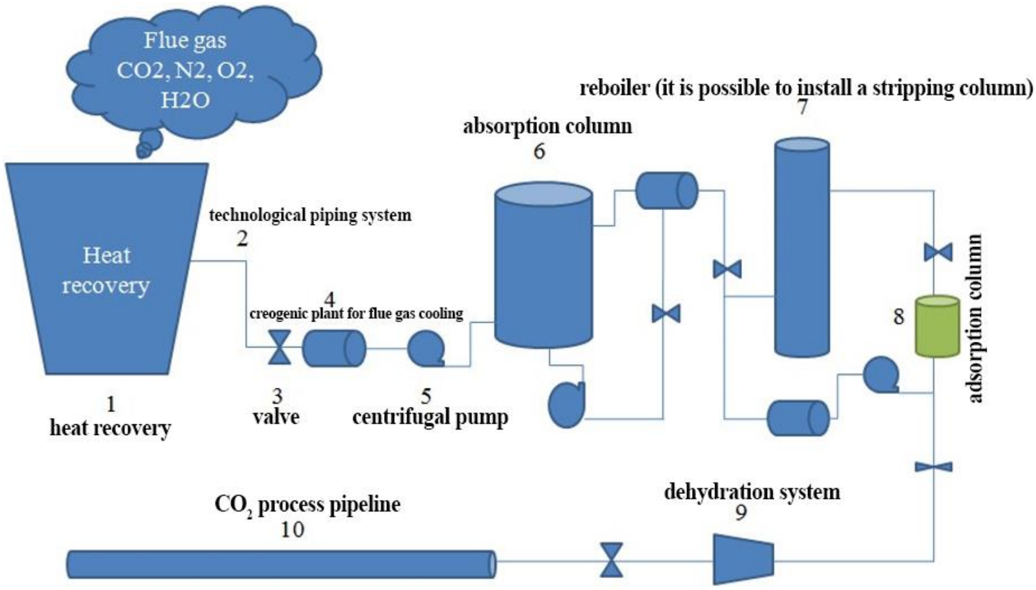

Figure 2. Diagram of a CO_2 capture plant.

To this end, flue gases are cleaned of CO_2 to 90 percent, with further transportation through the process pipeline system located on the territory of the refinery at a pressure of up to 100 bar and a temperature of 35 °C.

Constituents such as amines and the CO_2 steam that forms in the reboiler are passed to the bottom of the reboiler stripper. In the next step, a condenser is installed, which is necessary to receive the steam flow, which exits the upper part of the stripping column after being decomposed into water and absorbent.

2.2. Technical Indicators

Specific avoided CO_2 emissions from an industrial product are used as the main technical measure of CO_2 capture efficiency. When calculating the possible cost of CO_2 as a fuel gas used in the processing of process steam, Equation (1) can be used to determine the volume of CO_2 lost during operation of the refinery [67].

$$\Delta M_{CO2,sp,avoided} = \frac{M_{CO2,cap} - \left[\Delta M_{CO2,site} + \left\{\left(\Delta P_{Ind} + \Delta H_{Ind} \cdot f_{st,Ind}\right) + \left(p_{Cap} + H_{Cap} \cdot f_{st,Cap}\right) - \Delta F_{gas} \cdot f_{PP}\right\} \cdot Em_{sp,Elec}\right]}{M_{Ind}} \quad (1)$$

where $\Delta MCO_{2,\mathrm{Cap}}$ is the CO_2 capture rate (tonne/s); f_{PP} is the fired plant gas-power efficiency; $Em_{Sp,Elec}$ is the CO_2 emission factor of grid electricity (tCO_2/MJe); f_{St} is the power equivalent factor for steam (dimensionless); ΔF_{gas} is the change in the net process gas export from the industrial process to power plants due to the CO_2 capture (MW); H_{Cap} is the steam import for CO_2 capture and compression (MW); ΔH_{Ind} is the change in the steam import for the industrial process due to the CO_2 capture (MW); $\Delta MCO_{2,site}$ is the change in total carbon input to the industrial process due to CO_2 capture (tCO_2-equivalent/s); M_{Ind} is the production rate of the industrial product (tons/s); P_{Cap} is the electricity import for CO_2 capture and compression (MW); and ΔP_{Ind} is the change in the electricity import for the industrial process due to CO_2 capture (MW).

For all sites, the final pressure after capture is set at 110 bar; deviations in the literature values are corrected using Equation (2) [67]:

$$E_{Sp,comp} = \frac{ZRT_1}{M\eta_{is}\eta_m} \cdot \frac{N_\gamma}{\gamma - 1}\left\{\left(\frac{p_1}{p_1}\right)^{(\gamma-1)/N_\gamma} - 1\right\} \quad (2)$$

where Z is the CO_2 compressibility factor at 1.0 bar, 20 °C (0.9); R is the universal gas constant (8.3145 J/(mol K)); T_1 is the suction temperature (313 K); $E_{Sp,comp}$ is the specific electricity requirement (kJ/kg CO_2); N is the number of compressor stages; p_1 is the suction pressure (101 kPa); p_2 is the discharge pressure (11,000 kPa); M is the molar mass (44 g/mol for CO_2); η_m is the mechanical efficiency (90 percent); η_{is} is the isentropic efficiency (80 percent); γ is the specific heat ratio (cp/cv) (about 1,2).

For the investment costs of the compressor, the following equation from the literature was used, using the Kölbel–Schulze Index (Formula (3)) [68]:

$$CAPEX_{compressor}(Euro/USD) = 88 \times 10^3 \cdot (P[MW] \cdot 1000)^{0.55} \quad (3)$$

This equation considers intermediate cooling and drying as well as installation costs (factor 2.5). The value of operating costs for CO_2 pumping stations corresponds to 5 percent of the investment costs. The CO_2 avoidance costs are calculated using Equation (4) [67]:

$$C_{CO2} = \frac{\alpha \cdot \Delta I + \Delta C_{energy} + \Delta C_{O\&M} + \Delta M_{Mat}}{\Delta M_{CO2,sp,avoided} \cdot M_{Ind,annual}} \quad (4)$$

According to sources in the literature, the pressure must be at least 100 bar during the compression of CO_2 in the pipelines using this technology. If the CO_2 concentration is below 95 percent, additional purification processes will be necessary, since the CO_2 capture rate is controlled by the multiplication factor ηRec, and since part of the CO_2 is released along with the impurities removed during the purification process ηRec, in most cases, the pipelines through which CO_2 is transported operate at concentrations of 95 percent [69,70]. The specific energy consumption is estimated using Equation (5), adapted from Damenet al. [71]:

$$E_{Sp,comp} = \frac{ZRT_1}{M\eta_{is}\eta_m} \cdot \frac{N_\gamma}{\gamma - 1} \left\{ \left(\frac{p_2}{p_1} \right)^{\gamma - 1/N_\gamma} - 1 \right\} \quad (5)$$

Capital costs depend on the productivity of the enterprise. To correctly compare different technologies for capturing CO_2, it is necessary to present the indicators of the enterprise. Base scales for the refinery were determined based on a review of the literature and open sources. A scaling factor is used to rescale the investment costs in consideration of the effects of different plant sizes according to Equation (6):

$$\frac{CostA}{CostB} = \left(\frac{ScaleA}{ScaleB} \right)^{SF} \quad (6)$$

By analyzing the literature, a method for estimating the cost of CO_2 capture was developed (Table 3), making it possible to obtain the following data:

Table 3. Cost model inputs.

Cost model inputs	Units
Capital costs	Euro/kWh
Fuel Cost	Euro/MMBtu
Thermal output based on the lower heating value in determined	Btu/kWh

3. Case Study

3.1. Development Scenarios

Targets in the development of the Russian oil and gas sector and the technical equipment required for low-carbon projects change depending on the external conditions implemented in each scenario. Therefore, when implementing a scenario representing the new era of hydrocarbons, the task of the sector is the maximization of hydrocarbon production, and technologies facilitating enhanced oil recovery and involving hard-to-recover unconventional reserves will become priorities of technological development.

In other scenarios, value creation will become a priority for industry, in which case integrated design technologies and cost engineering tools (for the manufacturing of high-value-added products) will be the focus of development. The global CO_2 emissions produced by refineries are close to 1 Gt/year, or about 10 percent of total global emissions [72]. Oil and gas refineries are the main sources of CO_2 emissions, with the main contributors being the catalytic crackers used in the production of electricity and heat, as well as hydrogen processes [67]. Additionally, data from refineries around the world show that a large volume of CO_2 emissions come from catalytic crackers, which generate heat to produce electricity [73]. For this reason, for the period 2020–2030, WIPs were included among the large-scale projects with the Net Zero Scenario for industrial CO_2 capture (Figure 3).

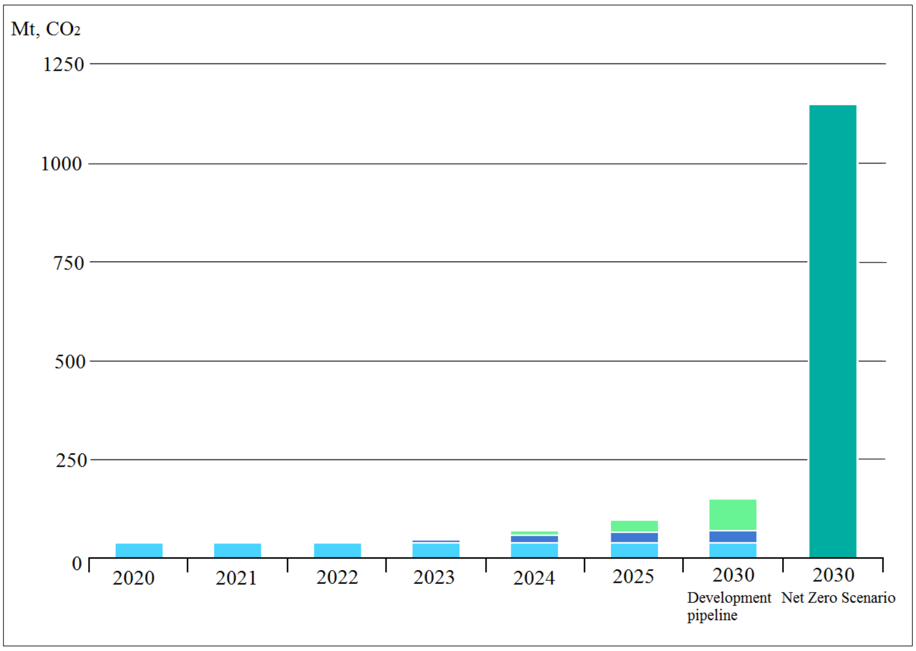

Figure 3. Comparison of the Net Zero Scenario 2020–2030 with actual industrial CO_2 capture projects.

Oil refineries are owned by international oil cartels, multinational companies, and small state-owned companies. At refineries, the concentration of flue gases ranges from 6 percent at thermal power plants to 12 percent at facilities that burn heavy oil products [72].

According to a study by Brown et al. addressing the problem of oil refining, the 25 largest oil refineries owned by large oil companies use more than 50 percent of their production capacity to capture CO_2 and VOCs [74]. Furthermore, 55 percent of the capacity of the entire global oil refining sector belongs to transnational oil companies and international cartels such as Gazprom Neft, Rosneft, Lukoil, ExxonMobil, Shell, BP, ConocoPhillips, and Total. Figure 4 shows these companies along with companies from China, Venezuela, and Saudi Arabia. The main difference with the latter group is that they operate exclusively within their regions.

The oil and gas industries are the largest consumers of energy, together accounting for CO_2 emissions of about 1.3 Gt. The main sources of CO_2 emissions from the oil and gas industries are reformers and steam boilers [75]. In the production of ethylene by steam cracking, compounds such as naphtha, liquefied petroleum gas, and ethane cause an increase in CO_2 emissions [73]. In Russia, crude oil accounts for three-quarters of all steam cracker production, while LNG units predominate in the US, Canada, and Norway [76].

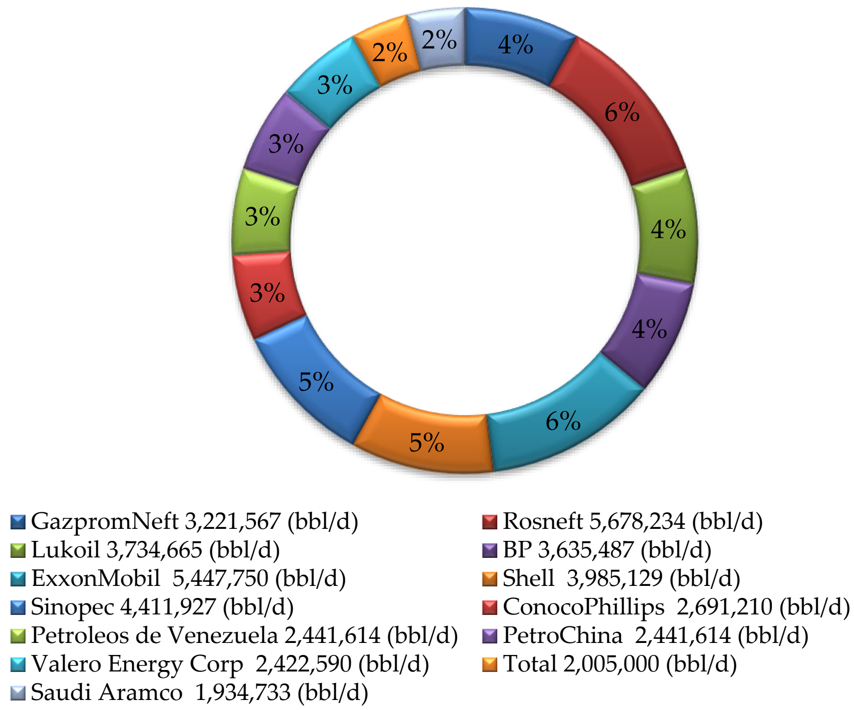

Figure 4. Top 12 refining companies by capacity in bbl/d.

In Russia, the depth of oil refining has been at 70–72 percent for a long time; the yield of light oil products is 56–58 percent, and the industry average value of the Nelson complexity index (which estimates the ratio of secondary and primary processing capacities) has not exceeded 6 points, while at the leading foreign refineries in the USA, Canada, and Norway, the refining depth reaches 95 percent and the Nelson index is 14 [77]. A significant proportion of operating secondary processing plants in Russia were built before 1995 and are physically and ethically outdated. In recent years, to overcome the technological backwardness of the industry, there have been significant efforts both on the part of the state and on the processing enterprises. With the emerging modernization of refineries, it has become possible to increase the average depth of oil refining to 73.5 percent and create conditions under which the use of motor fuels belonging to low environmental classes in the domestic market can be avoided (in 2015, the share of motor gasoline belonging to environmental classes 4 and 5 was 93.6 percent, and diesel fuel accounted for 82.4 percent of total production). At the same time, an increase in processing depth has occurred, mainly due to the involvement of vacuum gas oil in the catalytic cracking and hydrocracking processes, and the large volumes of tar remaining following processing, while insufficient attention has been paid to the development and production of non-fuel oil products. In addition, large volumes of straight-run gasoline, which is not involved in processing, remain at Russian refineries, and constitute a valuable raw material in the petrochemical industry. Obviously, the production, economic, and scientific and technological development of the industry in the medium term will have to take place under rather unfavorable natural, climatic, geological, financial, macroeconomic, and foreign policy conditions.

In the broadest sense, three major directions of scientific and technological development in the industry can be distinguished, based on three approaches to production development, being beneficial in the case of high demand and oil price, as well as under alternative conditions:

1. Technologies that contribute to the maintenance (or even restoration) of profitable production at existing conventional fields, often already largely depleted (increasing CCS).
2. Technologies for the extraction of oil from unconventional fields and the development of unconventional oils (heavy, high-viscosity, and super-viscous oil; oil sands and

bitumen; oil of low-permeability rocks, including shale; oil of the Bazhenov formation; and other hard-to-recover reserves).
3. Technologies for oil production in offshore fields.

In recent decades, the oil refining industry has been particularly affected by the discovery of new supplies of unconventional liquid fuels and the introduction of legislative requirements aimed at combatting climate change. The impact of fuels such as tar sands, liquefied natural gas, shale oil, synthetic oil, natural gas, and coal is likely to impact the oil refining industry in the future. Biofuels are less impacted by the chemical processing process and have the potential to have a positive impact on the refining industry, while synthetic oils extracted from shale oil and tar sands still require deeper processing. Figure 5 shows the volume of crude oil refined at Russian refineries during the year 2021, indicating the impact of traditional raw materials, such as crude oil, on the industry.

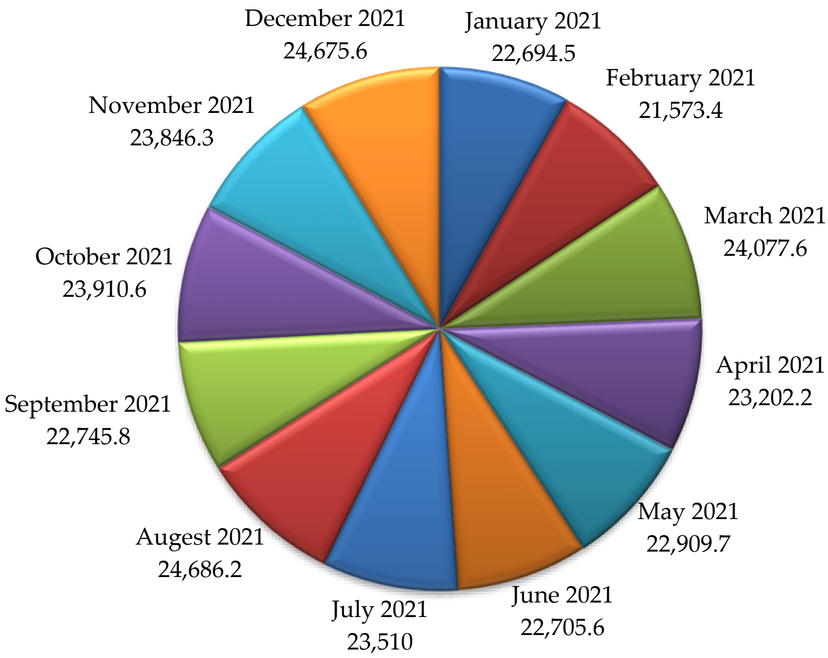

Figure 5. Primary oil refining at Russian refineries from January 2021 until December 2021, (thousands of tons) [78].

3.2. Cost Estimation for CO_2 Capture Plants

This section is devoted to comparing the costs of technologies for the capture and cleaning of CO_2. The technical characteristics of the plant are based on the production of pure CO_2, which is prepared for transportation and storage through process pipelines that may contain inert gases such as Ar, O_2, and N_2. In other plants, the content of CO_2 is lower than 3 percent, with pipeline pressures of up to 100 bar and temperatures of 35 °C. Additionally, the operation of the CO_2 capture unit is assumed to be offline. The power and cryogenic cooling systems are not integrated with the existing plant.

In this study, when calculating the operating costs, it is assumed that the site of the CO_2 capture plant is at a remote, closed location, and that the location allows inexpensive transport of CO_2 through the pipeline. Moreover, the refinery's CO_2 capture plant is expected to use Monoethanolamine for flue gas cleaning. Based on the simulated flue gas data, a process flow diagram is proposed, equipment dimensions are calculated, and a cost estimate model is determined.

The design of the plant is based on the extraction of 90 percent of CO_2 from the feedstock at the refinery. According to open sources, the percentage of gas emitted into the atmosphere during raw material processing at Russian refineries is 10 percent [79–82]. For CO_2 capture technology employing an oxygen system, a furnace design is assumed that can convert CO_2 into pure oxygen combustion after the implementation of emission control regulations. The capture plant corresponds to a modified design consisting of two absorber tanks, an absorber, an oxygen plant, a flue gas drying system, a flue gas cleaning system, a cryogenic air separation system, a generator, pumps, and the engineering of the necessary technological pipelines.

4. Results and Conclusion

Russian CO_2 Capture Projects in the Oil and Gas Industries

For the end consumers of petroleum products, which include end products such as gasoline, fuel oil, aviation kerosene, diesel fuel, lubricants, oils, bitumen, petrochemical raw materials, coke, etc., the quality of the refined oil is important. Therefore, the value of oil products is entirely dependent on the quality of the refining of crude oil. This highly energy-intensive process results in significant CO_2 emissions. The CO_2 emissions resulting from the refining of oil in the years 2017–2021 amounted to about 1174 million tons of CO_2-equivalent per year [83–88].

CO_2 emissions from oil and gas processing and marketing make up 1526 million tons of CO_2-equivalent per year. Up to 72 percent of emissions are accounted for by oil refining; the remaining 28 percent are caused by gas processing.

Of the total CO_2 emissions coming from refineries, 50 percent come from liquid and steam ejectors, atmospheric vacuum tubes, and oil blocks, 25 percent come from plant production services, and the remaining 25 percent come from hydrogen production [66,83,89]. About two-thirds of CO_2 emissions from refineries come from secondary processes and hydrotreatment. In this way, the number of secondary processes in a refinery is an important factor in determining CO_2 emissions. Small refineries involved only in primary crude oil distillation and a small volume of hydrotreatment processes emit relatively low levels of CO_2. However, the large refineries belonging to companies such as Gazprom Neft, Rosneft, and Lukoil process about 34,300 barrels of oil per day, while emitting about 1.5 million tons of CO_2 per year, thus having much higher emissions (see Figure 4). Details of the CO_2 emissions generated by oil refining are shown in Figure 6.

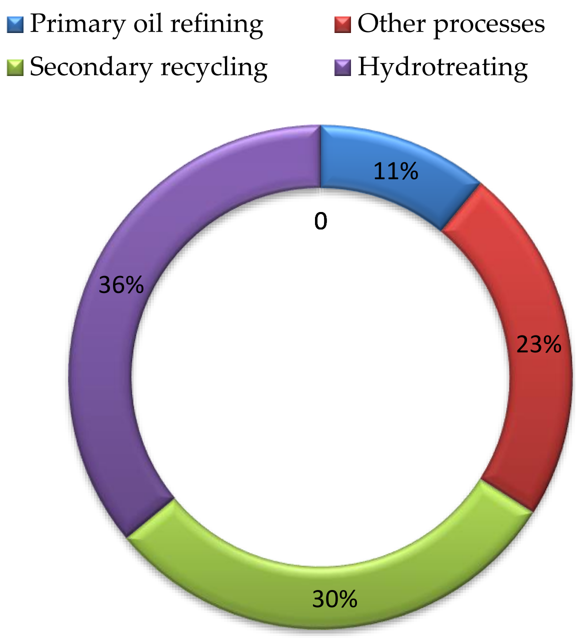

Figure 6. Percentage of CO_2 emissions from different sources in oil refining.

The purpose of this study was to provide a technical proposal and a short economic analysis regarding CO_2 capture technology in the oil refining industry. We referred to open sources that addressed the main parameters affecting the calculation of costs as well as direct emissions from the production process of refineries around the world [90–104]. The CO_2 capture technologies found in the literature [105–156] were divided into short-term and long-term technologies. The following conclusions can be drawn from this analysis of the general context:

With respect to refinery technology, the cost of the oxygen capture of CO_2 is about 65 Euros per ton of CO_2, while post-combustion capture is over 65 Euros per ton CO_2 for catalytic crackers with a capacity of 1 million tons of CO_2 per year. It should be noted that it is necessary to modernize the design of heat exchangers to achieve oxygen fuel capture of CO_2, which in the long term could become an economical energy carrier for refineries.

Due to the lack of state support for low-carbon technologies, the prediction of costs in Russia is complex, but in the future, the price may drop from 160 US dollars per ton of CO_2 to 70 US dollars or lower. The overall technology for and economics of CCS in the oil and gas industries will be highly dependent on market conditions.

The transition of the oil and gas industries towards economic efficiency is a complex and gradual process. No companies in the industry have yet developed detailed competencies in this area. Therefore, to achieve the stated emission reductions, each company is looking for ways to reduce emissions. At the same time, it is important to emphasize that, with respect to decarbonization, it is hardly possible to find a universal approach that will be optimal for all companies in all sectors, either in terms of emission reduction or regarding the economic efficiency [157].

The economics of CO_2 capture technologies will depend to a large extent on individual technologies and operating conditions, industrial applications, etc. It should be noted that some of the studies surveyed in this article showed that the introduction of new technologies for CO_2 capture is impossible without upgrading the industrial production process at the refinery plant. Therefore, it is highly recommended that in future studies, the industrial production process should be investigated both with and without the upgrades having taken place.

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Abbreviations

MW	Megawatt
PSA	Pressure Swing Adsorption
VPSA	Vacuum Pressure Swing Adsorption
ASU	Air Separation Unit
BAT	Best Available Technique
CCP	CO_2 Capture Project
CCS	Carbon Capture and Storage
FCC	Fluid Catalytic Cracker

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