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An Analysis of the Value Chains of the Petrochemical Industry With a Focus on the New Approach of Petro-Refinery

Abdolhosein Bayat[a*], Farhad Rahbar[b], Ali Vatani[c], and Seyyed Abdollah Razavi[d]

[a] *Ph.D Candidate, Department of Economics, Alborz Compus University of Tehran, Tehran, Iran., Email: bayat.abdolhosein@ut.ac.ir*

[b] *Professor, Department of Economics, Faculty of Economics, University of Tehran, Tehran, Iran, Email: frahbar@ut.ac.ir, avatani@ut.ac.ir*

[c] *Professor, Professor, Faculty of Chemical Engineering, University of Tehran, Tehran, Iran*

[d] *Professor, Associate Professor, Energy Economics and Management Department, Petroleum Faculty of Tehran, Petroleum University of Technology, Tehran, Iran*

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ABSTRACT

As one of the mother industries, the petrochemical industry is one of the essential pillars of development and the driving engine of various sectors of the country's economy. This industry will achieve several important goals, such as increasing export income, expanding downstream sectors, creating jobs, and increasing GDP. This importance has been emphasized in the country's upstream documents, such as the general policies of the resistance economy, focusing on developing petroleum refineries to prevent the vulnerability of oil and gas revenues by extending the value chain and increasing the export of these products. The current work aims to investigate the value chain of the petrochemical industry with the new approach of petrochemical refineries, as well as the pathology and evaluation of the current state of the chains mentioned above in the country with the descriptive research method and the library method using policy research. The research results show that the chain of petrochemical products with the approach of creating petrochemical refineries has relatively high advantages compared to focusing on chains with the traditional method.

1. Introduction

Iran has about 160 billion barrels of extractable crude oil and 34 trillion normal cubic meters of extractable natural gas from the country's known oil and gas fields. The country's crude oil and gas production capacity in

* Corresponding Author

2018 was equal to 4.07 million barrels per day and 1079 million cubic meters per day, respectively, of which the average export of crude oil and gas in non-sanctioned conditions is equal to 2.5 million barrels per day and 48 million cubic meters per day. The easiest way to earn money in a country rich in oil and gas is to sell these valuable materials. Nevertheless, “uncertainty about the security of fuel supply and demand”, “possible sanctions in the field of crude oil sales”, “fluctuations in global crude oil prices”, “necessity of diversity in sales methods with the help of product production”, and “creating more added value in the macroeconomy” point out the need to develop the downstream value chain of the oil and gas industry. Therefore, according to the approach of sustainable development based on using finite resources, with an emphasis on securing the benefits of the next generation, avoiding raw materials and converting natural hydrocarbons into products with high added value have always been one of the primary and emphasized strategies in the country because raw materials such as oil, gas, and gas condensates in the chain of the downstream part of the oil industry can create added value and more national wealth compared to their crude exports. The value chain includes activities that have added value for the economic enterprise and can facilitate the process of production and supply of the product and make the final product competitive in terms of price. The value chain is a set of activities that cause the actual value of a product to be scientifically analyzed in the process of supply, production, and distribution. It helps add value to the stakeholders, especially the customers, and ensures the survival of the economic enterprise in a competitive environment.

According to their conditions and requirements, different countries have followed various competitive models to develop the value chain of the oil and gas industry, thereby creating more added value. Based on the experience of other countries, in line with the implementation of the value-added chain development strategy, Iran faces four models of “integration of different levels of the oil and gas industry”, “relying on advanced technologies and license design”, “encouraging and creating competition in the industries related to oil and gas”, and “combined look at refining and petrochemical industries and creating more added value”. In this regard, in 2018, in the downstream part and the value chain of the Iranian petrochemical industry, there was 25 million tons of production capacity for essential products, of which 36% was related to methanol production, 29% was related to ethylene production, 20% was associated with the production of ammonia, and 9% was related to the production of aromatics, including benzene, toluene, and xylene. In this context, about 63% of the feed of basic (semi-crude) products is gas, including natural gas (methane), ethane, and rich gas, and about 38% of the feed of these products is related to liquid petroleum and gas products. Increasing the added value through completing the value chain of the oil and gas industry, developing and producing products with optimal efficiency, and increasing the export of petrochemical products and artifacts to prevent crude sales (oil and natural gas) and semi-crude sales (petrochemical base products) are emphasized in the upstream documents, such as the general policies of the resistance economy, especially paragraph (15). This importance can be realized through the development of the value chain of the petrochemical industry.

From the importance of developing the value chain of the petrochemical industry, we can mention the role and place of this new approach in risk reduction. Since crude oil export can be traced worldwide according to its technical characteristics and the specific and limited number of oil refineries suitable for the type of Iranian crude oil, the United States of America may sanction the company buying Iranian oil. Therefore, the country’s risk of selling raw materials is very high, and with natural materials being placed in the value chain of the petrochemical industry, it can manage the mentioned risks to a large extent. In this context, it is essential to explain the new approach of the industry to the development of the value chain. This research tries to answer the question of the country's value chains of the petrochemical industry. The first part is the background of the study, and the second part presents the theoretical foundations. The research method is given in the third part, and the fourth part examines the findings and an overview of petrochemical chains. The final part presents the conclusions and policy recommendations.

2. Background research

In an article titled “Refinery Change Perspective from Conventional to Integrated: An Opportunity for Sustainable Investment in the Petrochemical Industry”, Al-Samahan et al. (2022) critically examined current changes in oil prices, heavy oil production, and technical challenges for converting heavy crude oil into chemicals. (c-t-c) or petrochemical (c-t-p) were discussed, and the remarkable flexibility as a comprehensive approach to dealing with unconventional feedstocks (using thermal and catalytic methods) to produce sustainable feedstocks for chemicals and petrochemicals was emphasized.

In an article titled "Sustainable Development Management Model of Petrochemical Industry Enterprises", Ponikarova et al. (2022) examined the set of management measures in the public management system in the process of introducing innovations in conditions of uncertainty and risk. At the same time, the state of the level of sustainable, innovative development of the petrochemical complex is investigated. The relationship between the components of the company's sustainable development and the role of the internal state of the economic system in this process is determined to achieve these goals, and the limitations that inhibit the transition to new innovative quality are determined. Finally, based on the results of the study, a model for the evaluation of sustainable development management of a company is proposed considering its innovative nature.

In an article entitled "Evaluation of the Financial Situation and Optimization of the Performance of the Petrochemical Industry Organization in the Context of Increasing Financial Risks", Oksana et al. (2021) analyzed the financial situation, evaluated the development prospects, and optimized the activity of one of the largest systemically important organizations of the petrochemical industry in Russia, PJSC. SIBUR Holding has paid in the conditions of macroeconomic instability. To carry out the research, the authors have collected financial data from the company's financial results report and balance sheet. They have chosen the key indicators of performance and solvency, especially liquidity, business activity, profitability, solvency, and investment attractiveness. Further, financial risk factors affecting business expansion opportunities have received particular attention. Econometric modeling methods were used to determine the company's development prospects, which depend on the internal policy of cash flow management, accounts receivable, debt, and the external impact of inflation risk. The research results indicate that continuous cash flow, that is, the formation of a policy for managing accounts payable in crisis conditions, significantly impacts the company's further development.

In an article entitled "A Dynamic Model for Formulating Effective Policies to Increase Capacity in Iran's Petrochemical Industry to Complete the Value Chain", Haji Ebrahimi et al. (2021) investigated the determination of factors affecting the development of the petrochemical industry and modeling the mechanism of creating capacity increase using a dynamic approach. This research needed a tool to analyze the complexities, model the industry structure to an acceptable level of detail, and include nonlinear and feedback relationships between variables. The tool should also use the built model to provide practical solutions to various stakeholders and policymakers. For this purpose, the system dynamics (SD) approach was used. The obtained results pointed out the policy solution of program improvement and budget allocation as the most effective solution to achieving the development of the petrochemical industry.

In an article entitled "Dynamic Model for Effective Capacity Development in the Petrochemical Industry to Complete the Value Chain", Haji Ebrahimi Farashah et al. (2018) modeled the dynamics of capacity development budget formation using the system dynamics approach. In this regard, the budget allocation structures between petrochemical production complexes with the ability to produce different products were modeled, and other vital matters such as the amount of production capacity, the amount of production, the income from domestic sales, and the export of petrochemical products were modeled. The results show that the modeling in the primary state, the petrochemical industry, in 2025, has a production capacity of over 104 million tons, including 10.2 million tons of methanol, 20.6 million tons of ammonia and urea, and 11 million tons of ethylene. Moreover, there will be 2.2 million tons of polypropylene and 59.6 million tons of other products, which will be significantly less than the target in the vision document for 2025 countries. Further, the income from the domestic sale and export of petrochemical products will reach about 30 billion dollars in 2025, based on the dollar price in 2010. According to the third policy, which is the most effective policy proposed by this research, on the one hand, increasing the share of petrochemicals from the development budgets of the oil and gas industry and the National Development Fund should be on the agenda. On the other hand, the allocation of the desired capital to produce a portfolio of more value-added products should be done so that, finally, with the development and progress of the petrochemical industry, the country will be freed from selling semi-crude products forever.

3. Theoretical framework

There are two general approaches to the development of the petrochemical industry.

The first approach is the same as the traditional approach (the existing state of the industry) to the current development conditions, which is based on the value chain of its stages after exploration and extraction and on the separation of refining and petrochemical industries.

- Refining crude oil and gas in oil and gas refineries and converting them into main consumer products (gasoline, oil, and gas), petrochemical industry feed (light and heavy naphtha, LPG, propylene, and kerosene), gas products (methane and gas condensate), petrochemical industry feed (methane, ethane, LPG, and gas condensate), and export gas. These stages are structurally separate and independent, and with the production of products, they have a different status economically; oil and gas refineries are built separately from themselves and petrochemical units.
- Complexes for the production of essential petrochemical products (ethylene, methanol, ammonia, aromatics, and propylene), which are mainly built in a separate and isolated form in terms of structure and economy and unbalanced (such as the Kavian, Sadaf, and Gachsaran olefin units, the Zagros methanol unit, and the Aromatic Nouri unit) or sometimes together with production units of intermediate petrochemical products (polyethylenes, polypropylenes, polyvinyl chloride, mono ethylene glycol, ethylene oxide, and vinyl acetate).
- Production complexes of intermediate petrochemical products mainly built in a separate form in terms of structure and economy, such as Mehr, Isfahan, Golpayegan, Lorestan, Mahabad, Kurdistan, and Urmia petrochemical companies.
- Few production units of downstream (complementary) petrochemical industries, which are very small and scattered and can only convert about 30% of the products produced in the middle and essential sectors of petrochemicals into final consumer goods with higher added value.

The second approach (the new value chain development approach) focuses on creating more added value and higher profitability and even reducing additional costs such as value-added tax, performance tax, repeated installation of equipment and goods, and repetition of parallel organizational, administrative, financial, and technical structures. It has been institutionalized in many countries, such as China, Japan, South Korea, Turkey, Germany, India, and Russia, and has been favored as an efficient economic approach. The steps of this approach are based on an integrated and continuous look at the value chain of oil and gas and its products and a wide range of fuel and chemicals. It provides the means to create more added value by combining the current traditional separate steps, in the first approach, by reducing additional costs, developing the product chain, and producing more diverse products.

4. Basic concepts

The petrochemical industry refers to sectors in which hydrocarbons in crude oil, gas condensates, gas liquids, ethane gas, natural gas, light and heavy naphtha, and refined products are transformed into petrochemical products after being processed in a series of chemical processes (Bayat, 2016).

Value chain: Porter (1985) believes that the value chain is a systematic way to consider the series of activities that the organization performs to provide products for customers. Organizations must define their value chain to recognize competitive advantages to enter competitive markets.

The value-added chain of the petrochemical industry includes primary industries (upstream), intermediate industries (intermediate), and complementary industries (downstream), which consist of an extensive range of essential products and primary feeds to intermediate and final products. It includes the meaning of the petrochemical industry in this research: all the state-owned petrochemical companies transferred (privatized) or remained in government ownership (Bayat, 2016).

The value chain of the oil industry: Iran's oil industry includes six layers of exploration, production, refining, petrochemical, international transactions, and distribution, as shown in Figure 1 (Bayat, 2016).

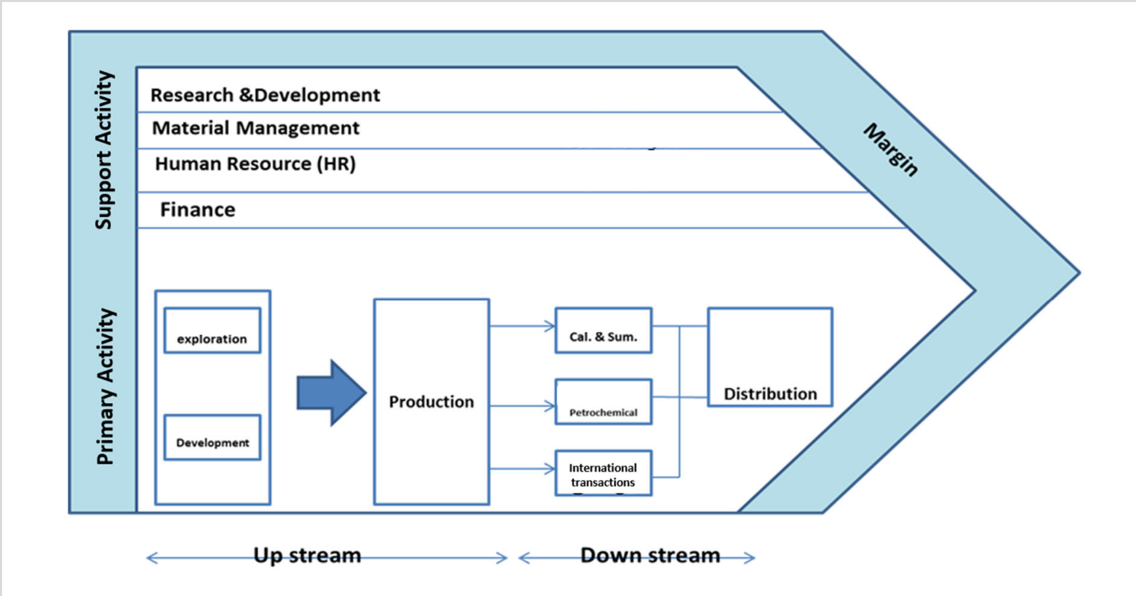

Figure 1: The oil industry value chain Bayat (2016)

4.1. An overview of the state of Iran's petrochemical industry

Currently, 67 active petrochemical units (26 communities in the Mahshahr economic zone, 17 communities in the Asaluyeh region, and 20 communities in other areas) with a production capacity of 90 million tons per year are engaged in production. Petrochemical industries consume a part of these products as inter-complex feed, and the rest is sold. Currently, there are 55 development projects (with a total capacity of 70.2 million tons) in the petrochemical industry. Among them are three projects of Kaveh Methanol, Bushehr Petrochemical, and polybutadiene in Takht Jamshid, with a total production capacity of 6.5 million tons in 2013. As a result of the activity of these complexes, this industry currently has a share of 2.9% of gross domestic production, 18.2% of industrial value-added, and 48.2% of industrial exports (Business Studies and Research Institute, 2019).

According to Figure 2, Iran's petrochemical industry ranks first among Iran's manufacturing industries in terms of foreign exchange income generation and value-added creation.

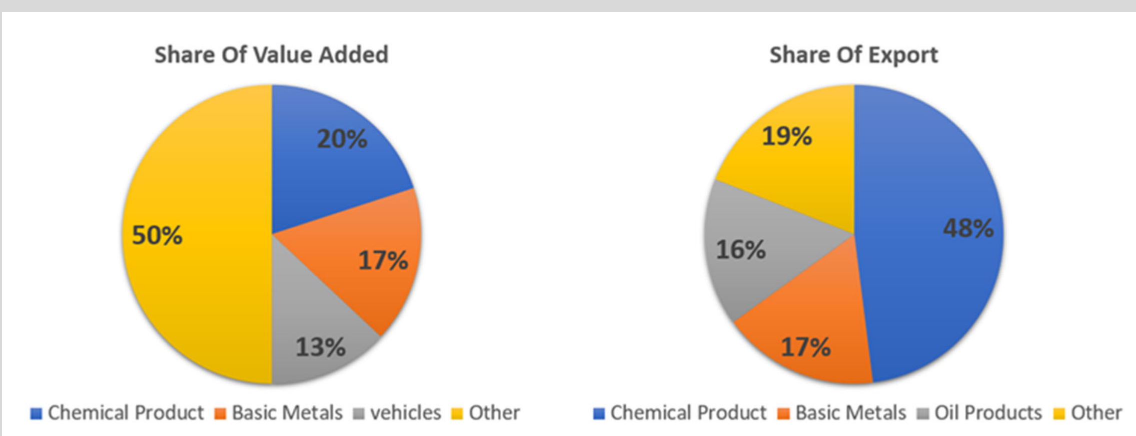

Figure 1: The share of petrochemical industries in generating foreign exchange income and creating added value (Business Studies and Research Institute, 2019)

4.2. The production capacity of Iran's petrochemical industry

Basic products

The horizontal and vertical development of the value chain of the Iranian petrochemical industry requires the production and use of essential products. Methanol, ammonia, olefins (ethylene, propylene, and butadiene), and aromatics (benzene, toluene, para-xylene, ortho-xylene, ethylbenzene, and styrene) are considered the main base products. In 1999, with 30 million tons of production capacity for primary products, Iran ranked second in the region after Saudi Arabia and had a share of 3.5% of the world. The production capacity of basic products in 2020 in China, America, and Saudi Arabia was 260, 104, and 44 million tons, respectively (Petrochemical Industry Year Book, 2019).

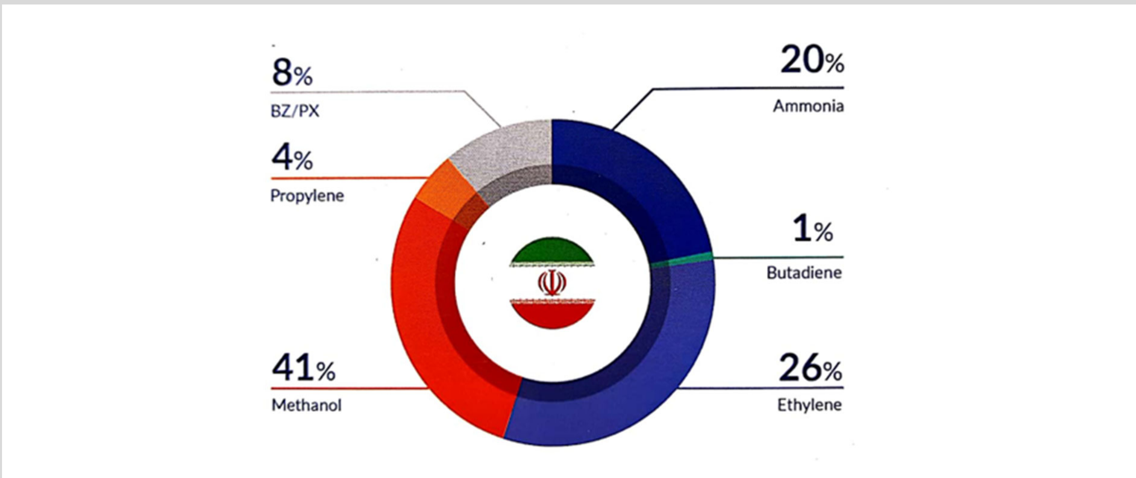

Figure 3: The production capacity of the basic products of Iran's petrochemical industry (Petrochemical Industry Yearbook, 2019)

According to Figure 4, the largest production capacity of the base product of Iran's petrochemical industry is related to methanol (41%), ethylene (26%), and ammonia (20%).

Oman	Turkey	Qatar	Kuwait	UAE	Saudi	Iran	
1815	859	3800	0	1089	5427	5855	Ammonia
2350	0	1070	0	0	7480	12304	Methanol
663	588	2520	1770	3620	17685	7778	Ethylene
506	265	0	243	2502	7990	1348	propylene
0	0	0	0	0	130	236	butadiene
199	211	356	393	0	3004	950	Benzene
818	139	0	822	0	2436	1374	Paraxylene
6351	**2062**	**7746**	**3228**	**7211**	**44152**	**29845**	**Sum**

Figure 4: The production capacity of the basic products of Iran and the countries of the region (2020) (unit: million tons) (Petrochemical Industry Yearbook, 2019)

5. Methodology

The research method in this study is to investigate the development of the value chain in the petrochemical industry in the new model and the completion of the value chain in comparison with the traditional approach, using the descriptive analytical method, and the proposed policies will be presented using the policy research method.

Policy analysis is the process of conducting research with analysis about a fundamental problem of society, which provides policymakers with realistic and practical suggestions to reduce the issues. In other words, policy analysis begins with a social problem such as malnutrition, poverty, or inflation. It is completed through an analytical process, through which alternative policy measures are presented to reduce the pain and provide them for the policymakers (Majchrzak, 1948).

6. Research findings

6.1. Iran's petrochemical industry value chains: methanol value chain

Methanol is one of the essential basic products of chemical industries in the world, which has a high consumption in chemical industries, and many materials and goods are derived from it; its price fluctuation often affects many manufacturing industries. It is an alcohol fuel made from natural gas, wood, coal, and other natural resources. Since the production of methanol from natural and renewable sources is economically more expensive than gas, most of it has been obtained from natural gas in recent years, so it can be said that after ammonia, the product is the second substance that has the most production from natural gas. Therefore, the competitive advantage in methanol production is from regions rich in these resources, especially natural gas (methane). The Middle East region, China, and recently North America (due to the development of shale gases) are the leading players in the global methanol production market in this regard. In 2018, out of 680 million tons of petrochemical products produced by petrochemical industries worldwide, 78 million tons, equivalent to 12% of these products, belonged to methanol production. According to the IEA forecast, methanol production capacity will grow by 50% by 2030 and by 100% by 2050. Two-thirds of this growth will be in the Asian continent (led by China) (Mirnizami, 2019).

The cost curve of methanol production in different regions of the world shows that it is economical except in the Middle East and Africa due to cheap food. The only change in this diagram in recent years is the movement of North America to the left side of the representation and the increase in the efficiency of methanol production in this region (IHS, 2018).

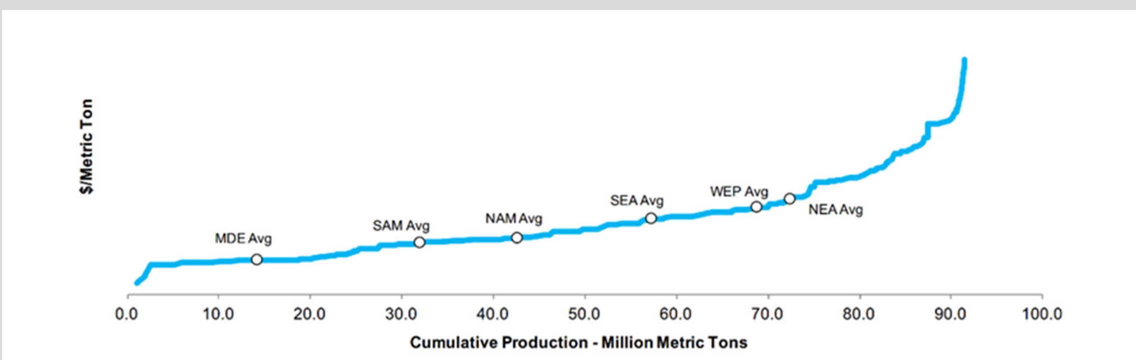

Figure 5: Methanol production cost curve in different regions of the world (HIS, 2018)

Since methanol is vital in the feed basket of petrochemical units, the production of methanol is high-ranking. The Middle East region, with a production capacity of about one-fifth of the methanol production in the world, uses 100% of the natural gas feed. In contrast, the Northeast Asia region (China, Japan, South Korea, and Taiwan), with a production capacity of about 50%, produces more than 90% of the world's methanol. They produce 90% of methanol from coal and only about 10% from natural gas. Like the Middle East, North America obtains 96% of its methanol from natural gas. The trend of changes in the share of different feedstocks for methanol production shows that due to the presence of China in the methanol production market, the portion of coal feedstock increased from 15% in 2005 to 35% in 2015. The share of natural gas has experienced a 30% decrease, but again due to the increase in investment in the production of methanol based on natural gas, as well as the reduction in gas price, the share of natural gas is expected to increase (IHS, 2018).

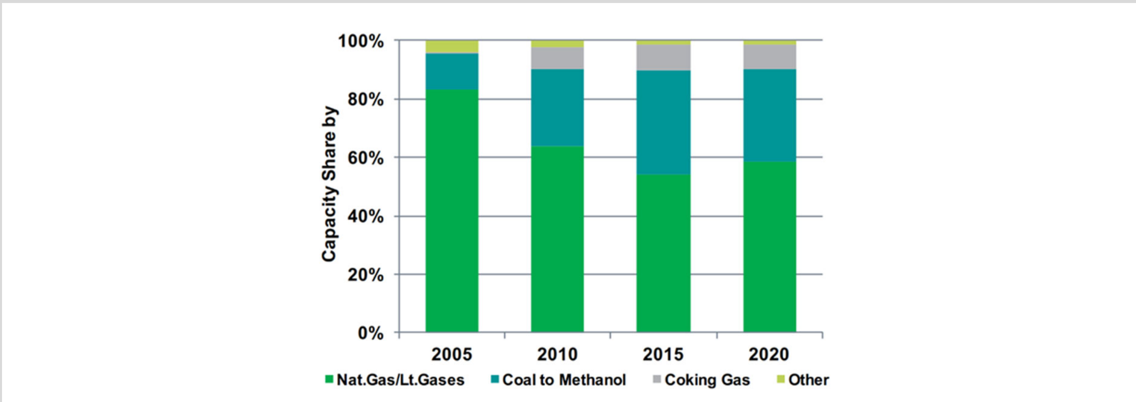

Figure 6: The trend of changes in the share of different feedstocks for world methanol production (HIS, 2018)

Methanol as a primary product is divided into three general categories: the first category is the traditional methanol derivatives: the chief demand for methanol was formed based on their development in the past few decades. The second and third categories are derivatives that have faced an increase in production in recent years; in fact, one of the main drivers of the demand for this product in the future includes fuels and MTO/P. The chief methanol derivative division and its production percentage in 2018 are given in Figure 7 (Mirnizami, 2019).

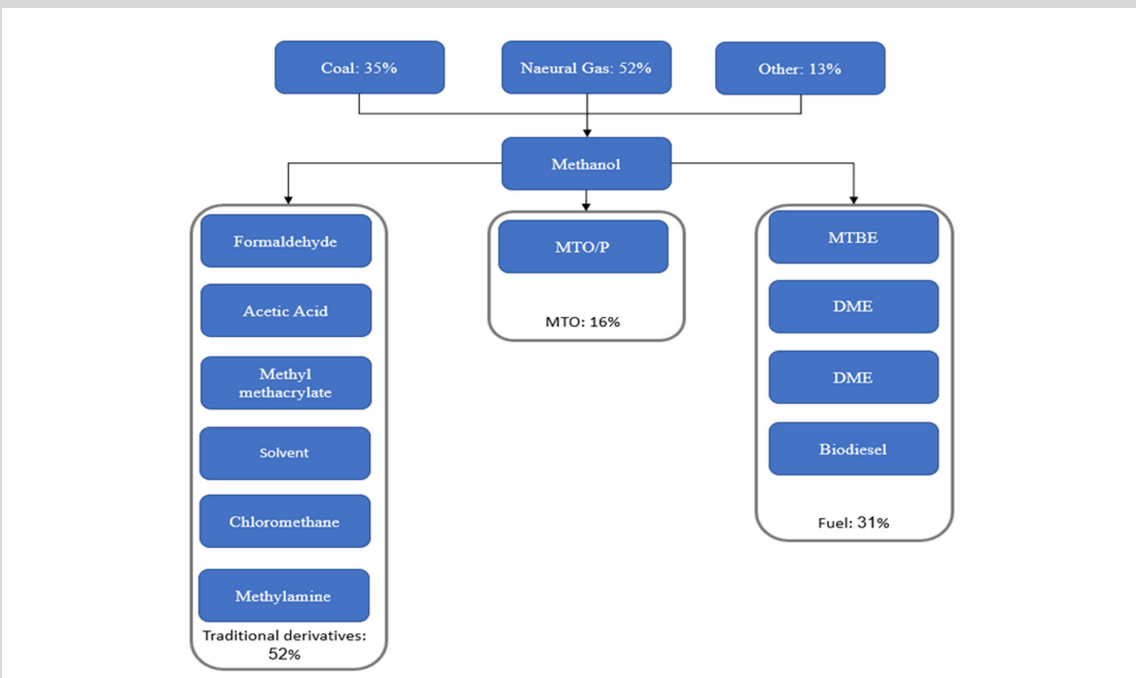

Figure 7: The general diagram of methanol production and its leading derivatives in 2018 (Mirnizami, 2019)

The methanol industrial applications are very diverse: industrial adhesives, solvents, antifreezing agents, plastics, plywood, paint, explosives, laminates, varnishes, kitchen utensils and equipment, resins, cameras, formaldehyde (formalin) for household use, preparation of methylated butyl ether (MTBE) to increase gasoline octane, dimethyl ether (DME) for use in atomizers, production of hydrogen used in fuel cells, production of acetic acid and especially its replacement as a clean fuel instead of fossil fuel (Kohzadi, 2015) Further, in some countries such as South America, methanol is used to produce biodiesel which is implemented in cars, trucks, buses, and even electricity generation turbines. Most methanol is used to prepare fuel, a combination of 85% methanol and 15% unleaded super gasoline, and is produced in many countries, including the United States. The largest share of methanol consumption is formaldehyde, and about 27% of methanol is converted into this substance (Study and Review of Methanol Market, 2019).

Iran, due to the lack of development of the methanol value chain, the current approach to this semi-raw product is to export it. It can be considered one of the most effective products to provide the currency needed by the country, especially during sanctions, with the development of future investments to build new similar units and complete and develop the chain. Its value and the role of this strategic and essential product in the country's economy will become more serious and effective. Moreover, the lack of complexity of the methanol production process compared to the production of products such as ethylene and ammonia and the low influence of the producing units on other products of the petrochemical industry have made the production of this product more sustainable. According to the information from the exchange, about 276 thousand tons of methanol products were registered in the internal transactions of the country's energy exchange in 2018, which is about 3% of the total capacity of 9 million tons of methanol produced by the petrochemical industry in that year (Baghban and Narimannejad, 2019).

In the following, we will describe the application of some methanol derivatives (Study and Review of Methanol Market, 2019).

- *Formaldehyde* is produced from the catalytic oxidation of methanol. Formaldehyde is used as a disinfectant solution because it kills most bacteria and is used to store biological samples. The primary use of formaldehyde is in producing polymers and other chemical compounds.
- *Acetic acid* (ethanoic acid, $COOH_3CH$, $C_2O_2H_4$) or vinegar essence is used to prepare materials such as acetanilide, ethyl acetate, isopropyl acetate, butyl acetate, acetyl chloride, monochloroacetic acid, and ketone.
- Products from the downstream industries of methanol, including MTBE, ethylene, propylene, methyl acetate, methyl amine, dimethyl ether (DME), methyl bromide (methyl bromide), dimethyl sulfide, dimethyl sulfate, dimethyl carbonate, nitro anisole, methyl acrylate, dimethyl aniline, methyl formate, dimethyl terephthalate, methyl chloride, and antifreeze. It should be noted that each of these derivatives is an agent for producing other materials and derivatives.
- Due to the predictable lack of energy sources over time, the direct consumption of methanol as a clean fuel or the primary hydrogen used in fuel cells is vitally important.

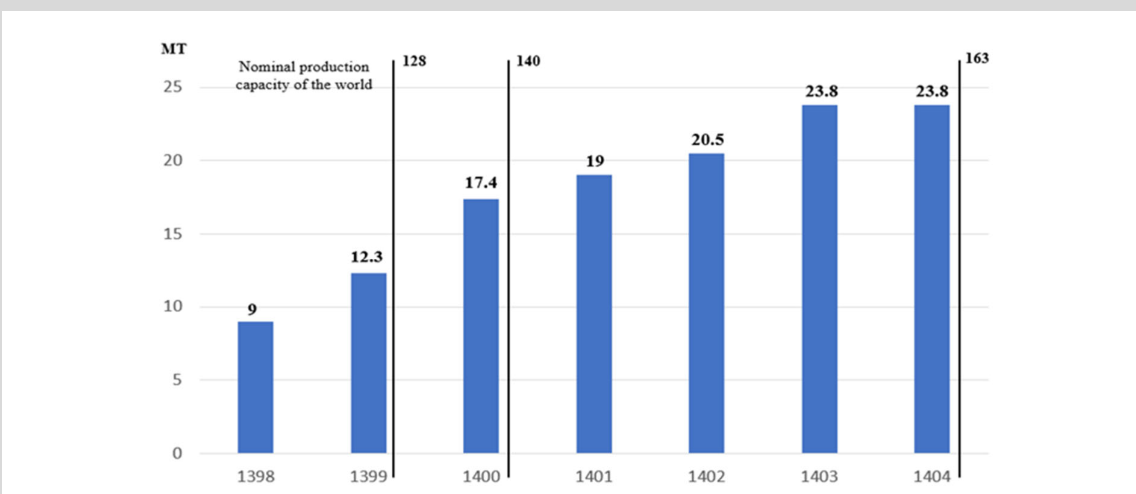

Figure 8: The process of increasing the nominal capacity of methanol production until 2025 (Petrochemical Industry Year Book, 2019)

Methanol has a special place in the portfolio of the Iranian petrochemical industry. Of the nominal production capacity of 83.5 million tons of petrochemical products, 10% is dedicated to methanol, and capacity development programs show an increase in the share of methanol in Iran's production portfolio. Until the end of 1999, nine petrochemical complexes with a total capacity of 12.3 million tons were active in Iran. With the plans for increasing the methanol production capacity, the overall nominal capacity of this product in 2025 with nine complexes will be about 23.8 million tons (Petrochemical Industry Year Book, 2019). According to Figure 9, it is expected that the nominal capacity of methanol production in the world will reach 163 million tons by 2025, of which 23.8 million tons will be Iran's production share (Petrochemical Industry Year Book, 2019).

Figure 9 shows Iran's progress in the methanol value chain: green means total production, yellow means production less than the domestic requirement, and red means no production.

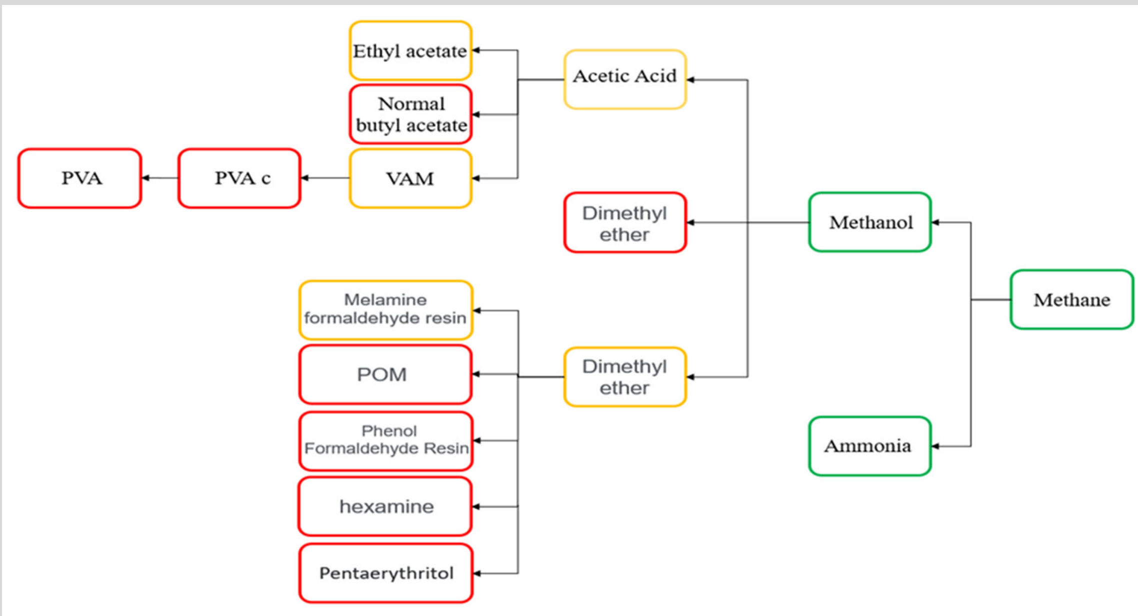

Figure 9: Iran's progress in the methanol value chain (Business Studies and Research Institute, 2019)

Iran produces acetic acid, ethyl acetate, vinyl acetate monomer, formalin, and melamine resin, but the production volume is less than the domestic demand. In other products of the methanol value chain, it meets its needs through imports (Business Studies and Research Institute, 2019).

6.2. Ethylene value chain

Ethylene is the simplest unsaturated hydrocarbon and the first member of the group of alkenes. C_2H_4 has a double bond between its two carbon atoms, which causes the ethylene isomer to be unstructured, even rotating around the double bond. The structure of ethylene is flat. The angle between carbon and hydrogen is 117 degrees, which is suitable for hybridization closer to the 120-degree sp2 angle. Ethylene is a colorless and flammable gas found in the combination of oil and natural gas. Ethylene is one of the most important basic materials in petrochemical industries and has countless applications comprising the polymerization industry, synthetic fibers, softening solvents, antifreeze, and alcohol (Kianfar, 2015).

Steam cracking produces ethylene in the petrochemical industry and is a vital raw material for creating many organic compounds. Ethylene polymerizes to produce polyethylene, an essential plastic; repetition makes the polyvinyl chloride (PVC) precursor. The ethylene combination with benzene creates ethylbenzene, the main ingredient of polyesters (Baghban and Narimannejad, 2019).

Due to the large size of the ethylene market and its extensive applications in other industries, this product is mainly used as a benchmark to measure the performance of petrochemical industries worldwide. A study conducted in 2019 by the IHS on the perspective of chemical raw materials shows that ethylene has experienced the highest production capacity growth rate among raw materials during 10 years (2009–2018) in the course span, with the highest utilization rate of 8%. It has been considered one of the basic chemistry units (IHS Markit Chemical and Energy, 2019).

The primary process of ethylene production is steam cracking units. The unit feed is ethane, naphtha, and liquid gas, respectively. According to statistics, about 99% of global ethane production is used in steam cracker complexes to produce ethylene. Of course, it is worth mentioning that there are different methods for producing ethylene or olefins in general, and the production of propylene and ethylene from coal has a long history in the petrochemical industry (especially in China). Figure 10 summarizes olefin production routes from primary sources (Mirnizami, 2019).

6.3. Ethylene derivatives

Despite the relatively wide range of ethylene products and derivatives, more than 60% of the ethylene produced worldwide is the input for polyethylene units (including high-density polyethylene, low-density polyethylene, and linear low-density polyethylene); therefore, the global market of ethylene and polyethylene are highly correlated. This correlation with ethylene is lower in downstream products of the ethylene value chain than in polyethylene (Mirnizami, 2019).

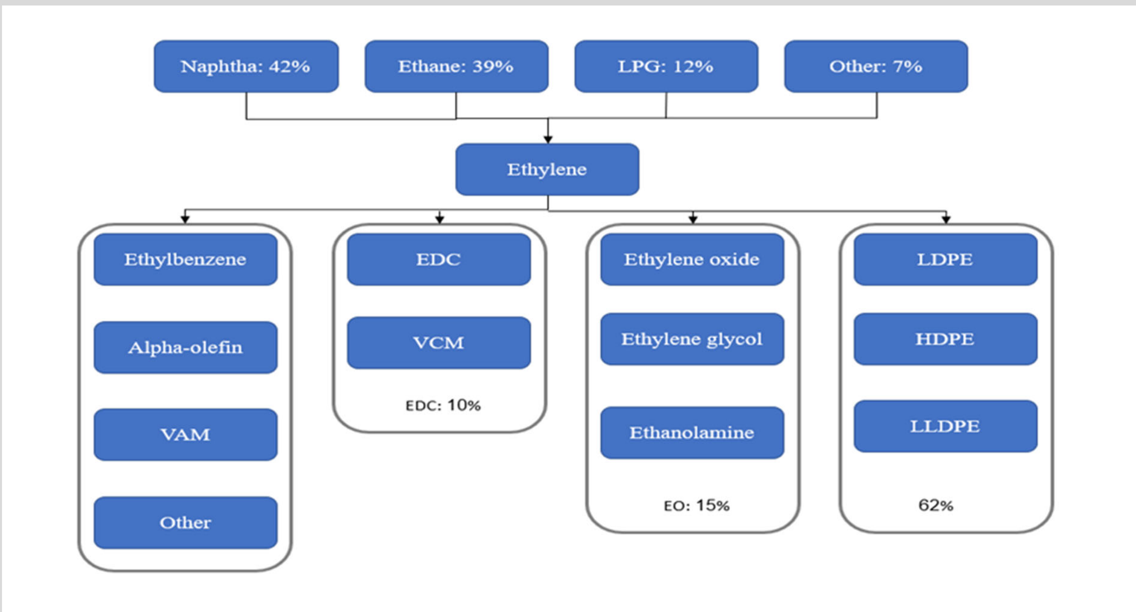

Figure 10: The general picture of ethylene production and its leading derivatives in 2018 (Mirnizami, 2019)

6.4. Ethylene in the petrochemical industry of Iran

Ethylene and its derivatives have a special place in the portfolio of products of the petrochemical industry of Iran. More than 10% of about 67 million tons of the nominal capacity for producing petrochemical products is dedicated to ethylene. Taking into account the production of ethylene derivatives, such as different grades of polyethylene (which are often produced in one complex), the contribution of the ethylene chain in the petrochemical industry will be more substantial. The development of different phases of South Pars and access to cheap ethane feed, along with the proximity of established complexes to this region, have caused the spurt capacity of the country's ethylene production in the past 15 years. Until the end of 1997, a total of 9 petrochemical plants with a capacity of 340.7 million tons were active in Iran. According to the fifth plan for developing the petrochemical industry, if programs are accomplished entirely, Iran's ethylene production capacity will reach 12.9 million tons annually.

Furthermore, it will be in third place among the main petrochemical products of Iran. The main reason for the development of ethylene units has been the access to cheap ethane feed in the South Pars region during the last decade. Figure 11 shows the contribution of different petrochemicals to the country's ethylene production capacity (Petrochemical Industry Year Book, 2019). According to Figure 11, Iran has produced ethylene glycols and types of polyethylene products more than the domestic demand. It does not produce glycol ether, ethylene, propylene, and other products such as ethylene oxide, ethylene dichloride, or acetaldehyde. The amount of production has been less than the domestic demand.

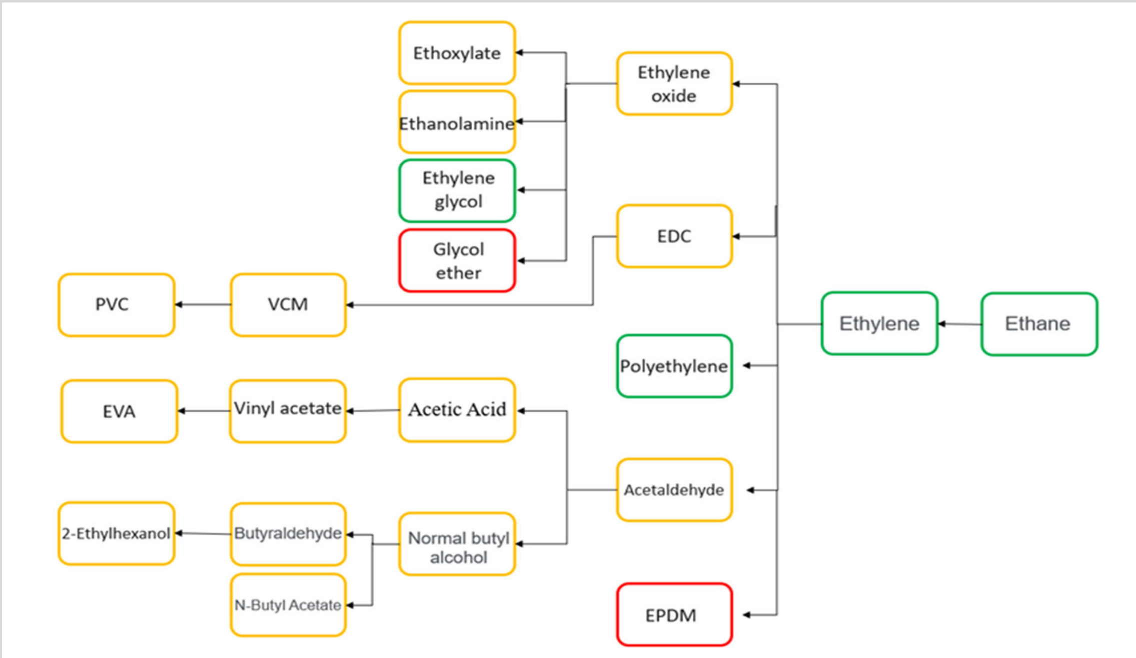

Figure 11: Iran's progress in the ethylene value chain (Business Studies and Research Institute, 2019)

6.5. Propylene value chain

Propylene (or methyl ethylene) is one of the critical petrochemical products conventionally obtained from steam cracking (production of propylene as a by-product of ethylene production) and recycling of refinery FCC streams (which contain little propylene). It is used as a feedstock for the production of various polymers. The most important derivatives of propylene are polypropylene, acrylonitrile, propylene oxide, phenol, oxo alcohol, acrylic acid, isopropyl alcohol, oligomers, and other intermediate materials, which are used in the form of materials needed in electronics, automotive, construction, packaging, and similar industries. The global demand for propylene is still growing due to the need for its derivatives, especially polypropylene; the price of propylene has the potential to increase further. Figure 12 shows the value chain of this valuable material. Currently, the propylene production industry in the Middle East is small due to the low-efficiency technologies. Luckily, due to access to cheap natural gas sources and suitable geographical features, it has a high potential to expand the production of this valuable and necessary petrochemical material. Most propylene in the Middle East is made through the steam cracking process, which produces excess ethylene. The natural gas advantage as a petrochemical feed has led to the use of ethane in cracking units, which has turned these areas into massive production areas of ethylene and its derivatives. On the other hand, these regions are less effective in terms of propylene and its derivatives production (Mahdavipour, 2016).

6.6. Propylene derivatives

Propylene demand for chemical derivatives is heavily dominated by polypropylene production, which accounted for about 67% of the total market in 2021. Other significant uses are propylene oxide, acrylonitrile, cumene, and acrylic acid. After conversion, propylene is mainly found in durable goods (cars and furniture), packaging, and infrastructure (buildings and houses). Thus, its demand is broadly linked to the general economy. Propylene consumption has become increasingly associated with emerging regions (especially mainland China), where improving living standards and growing urbanization are increasing the use of a wide range of polymers and chemicals. Over the past five years, propylene demand growth has averaged 3.4% per year, with Northeast Asia accounting for nearly 70% of new demand (IHS Markit petrochemical Industry Overview, 2021).

Iran has devoted about 830 thousand tons of its production to producing propylene, which is only to meet the domestic demand, and the amount of export and import is zero (Business Studies and Research Institute, 2019).

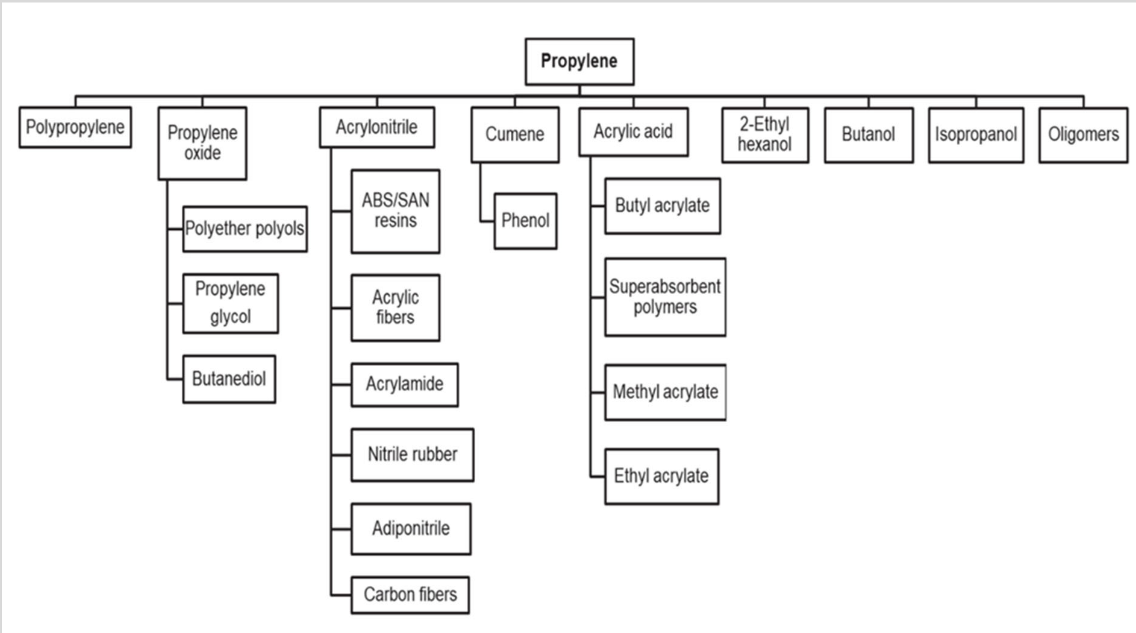

Figure 12: Propylene derivatives in the petrochemical industry of Iran

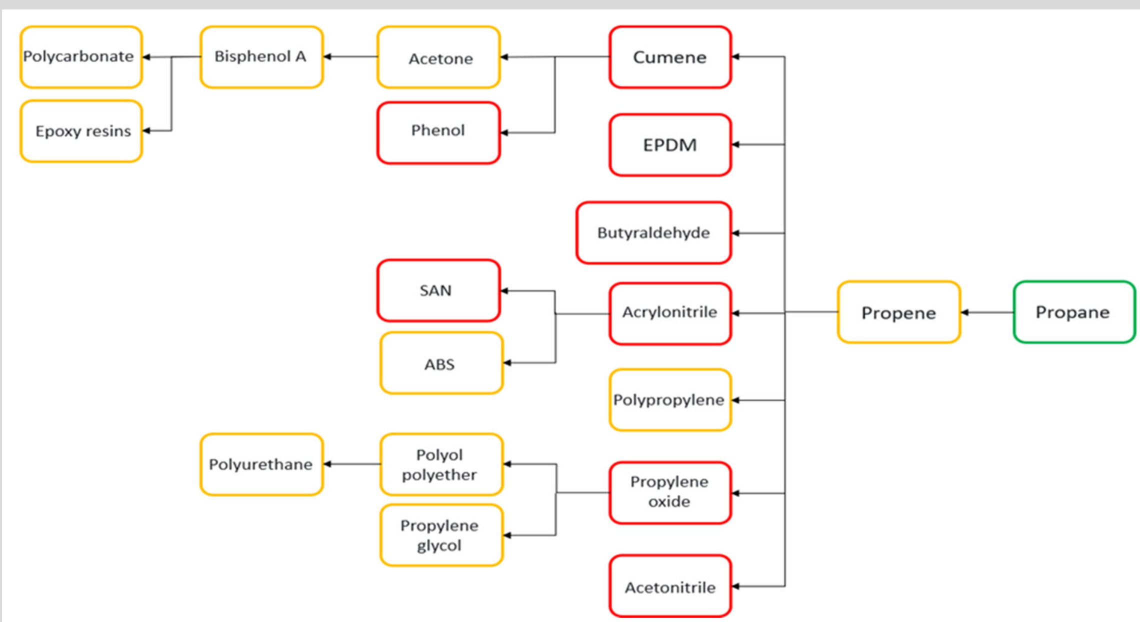

Figure 13: Iran's progress in the propylene chain (Business Studies and Research Institute, 2019)

According to Figure 13, no products in Iran's propylene chain could fully meet domestic demand. Regarding the number of products whose production is less than the country's need or is zero, it is necessary to identify the priority areas for investment in the petrochemical industries of the country. This issue will necessarily improve the value chain balance of the petrochemical industry and the development of downstream (complementary) petrochemical industries.

6.7. Petro-refinery

The lack of a single policy approach to completing and developing the country's refining and petrochemical industries has caused the development of these industries to be unbalanced. Due to various reasons, the refining industry has low profitability because of inadequate technology levels. The current small profit is also due to the allocation of cheap feed and the granting of subsidies. On the other hand, the plans for the petrochemical industry are often developed based on gas feed, and the goal is to produce and export basic petrochemical. Meanwhile, combining, completing, and improving the refining and petrochemical industries will enjoy a better economy (Hosseini, 2019). Nowadays, one of the most important new approaches to the world's oil industry is integrating petrochemical and refining units (Nemati, 2015).

Petro-refineries consume raw oil feed with gas condensates; their final products are fuel and chemicals (Saidi, 2021). Petro-refineries are responsible for the production and conversion of methane, ethane, liquefied gas (propane and butane), naphtha, and heating oil feedstocks into ammonia, methanol, olefins (ethylene, propylene, butadiene, and butylene), and aromatics (benzene, toluene, and xylenes). Thus, in the future, polymer and chemical complexes will be able to produce dozens of different products by receiving such feeds (Mahdavipour and Mirjalili, 2017).

7. Review of petroleum refinery models

In normal refineries, the focus is on fuel products such as gasoline, diesel, jet fuel, and fuel oil for the consumption of the transportation sector. According to Figure 14, the higher we move, the higher refinery and petrochemical correlate, the higher the share of chemical production in the product portfolio increases, the higher the percentage of fuel decreases, and the higher the complexity factor increases (Saidi, 2021).

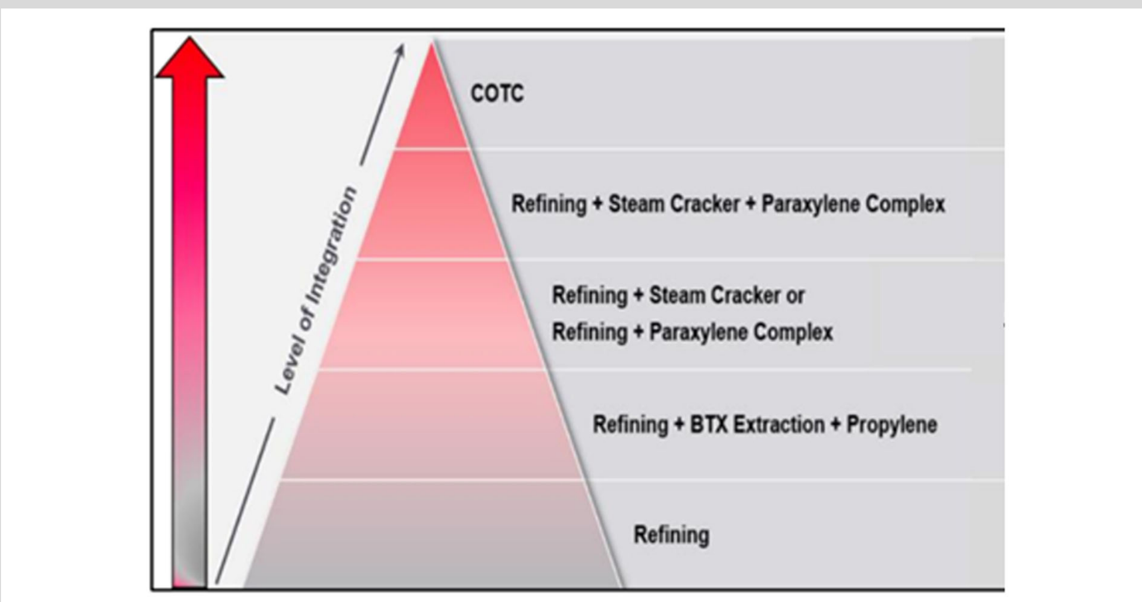

Figure 14: The degree of the integration of the refinery and petrochemicals

According to the above figure, we classify the degree of integration of the refinery and petrochemicals based on five levels. COTC can be considered the final integration of the refinery and petrochemical operations to produce maximum chemicals (more than 70%) compared to level one, which is the typical nonintegrated refinery (less production from 10% of chemicals) (IHS, 2019).

1. A refinery
2. A refinery with aromatic products separation unit and FCC unit for propylene production
3. A refinery in addition to a steam cracker petrochemical unit or refinery plus aromatic production petrochemical unit
4. A refinery plus steam cracker petrochemical unit plus aromatic production petrochemical unit

5. A unit for converting crude oil into COTC chemicals

7.1. Refinery

In normal refineries, crude oil or gas condensations entering to distillation tower unit cause different fractions. These different parts are divided from each other, producing various products such as ethane, liquid gas, light naphtha, heavy naphtha, gasoline, kerosene, diesel, and atmospheric residues. Light naphtha is consumed in the isomerization unit, and heavy naphtha is consumed in the reforming catalytic conversion unit. It is poured into the gasoline pool to improve the quality of gasoline. Currently, the general structure of refineries in Tehran, Bandar Abbas, Lawan, Shiraz, and Kermanshah is shown in Figure 15. The main output products are fuel, and no specific chemical products are produced in these units (Saidi, 2021).

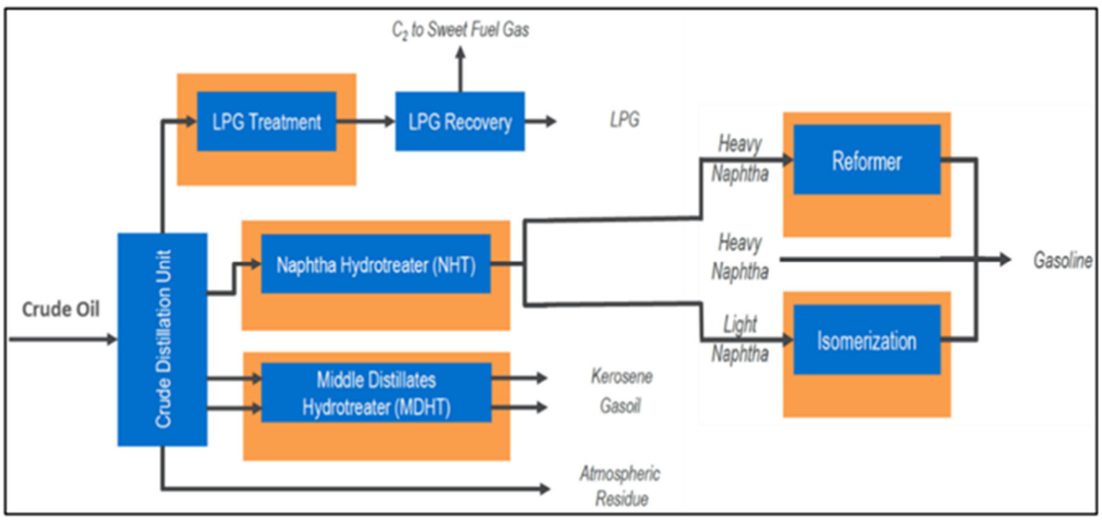

Figure 15: The refinery procedural structure (Saidi, 2021)

Source:

7.2. Refinery with aromatics separation unit and FCC unit

In these refinery units, a part of the aromatic products produced in the reforming catalytic conversion unit is separated for petrochemical use. Furthermore, atmospheric residual materials enter the vacuum distillation tower and the FCC unit, producing olefinic chemical products such as propylene and ethylene. Currently, Shazand Arak and Abadan refineries in the country have FCC units. Units are designed and launched to produce gasoline fuel, and less than 3% of the output mass is converted into olefins (Saidi, 2021).

7.3. Petro-refinery (refinery plus steam cracker petrochemical or aromatic petrochemical)

The naphtha produced in the refinery can be used as the main feed of the steam cracker unit to produce olefins or aromatics in the aromatic petrochemical unit. In these units, 40% of the products will be chemicals and petrochemicals.

The primary olefins produced in steam cracker units form the value chain of ethylene and propylene, which includes a wide range of chemicals and polymeric materials, including polyethylene, mono ethylene glycol, polyvinyl chloride, ethylene oxide, polypropylene, acrylonitrile, acrylic acid, cumene, and propylene oxide. Moreover, suppose aromatic petrochemicals are built downstream of the refinery. In that case, it is possible to produce a benzene value chain, including styrene, nitrobenzene, cyclohexane, maleic acid, and materials such as polyethylene terephthalate and phthalic anhydride in the xylenes value chain. Currently, there is a production exchange between refineries and petrochemicals in the country, and these units are independent. An example is the light and heavy naphtha feed of Shazand Olefin Petrochemical Unit (former Arak Petrochemical) from Imam Khomeini Arak Refinery and Isfahan Refinery (Saidi, 2021).

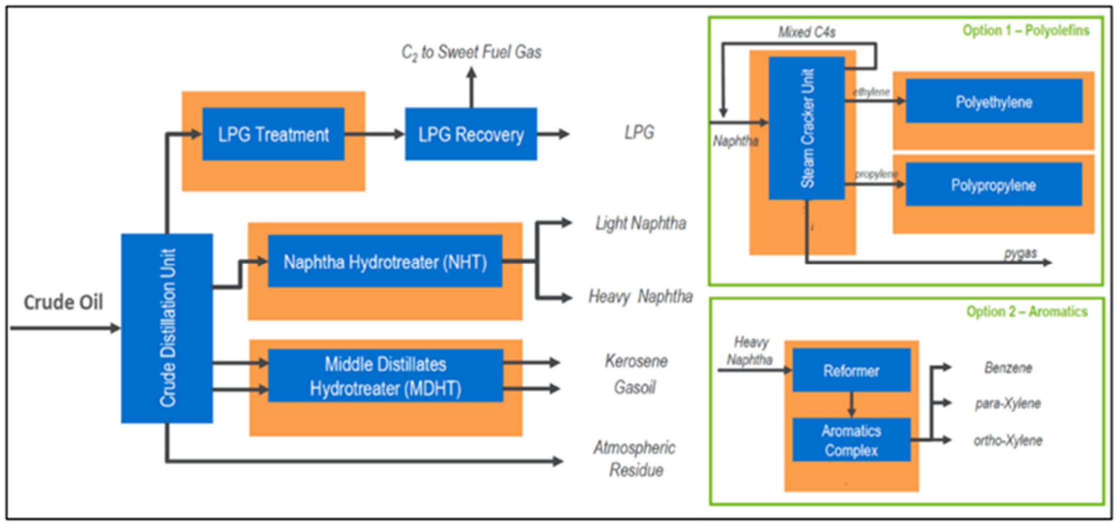

Figure 15: Petrorefinery (refinery plus steam cracker petrochemical or aromatic petrochemical) (Saidi, 2021)

7.4. Petrorefinery (refinery plus steam cracker petrochemical plus aromatic petrochemical)

In this structure, the steam cracker and aromatic units are built simultaneously after the refinery unit, and the products are exchanged between these trial sets. The advantage of these units is the simultaneous production of olefins and aromatics because some polymeric and chemical materials, such as polyethylene terephthalate, ABS polymer, and SAN polymer, require the supply of both aromatic and olefinic chains. Currently, there are steam and aromatic cracker units in Imam Khomeini Port Petrochemical, which produce olefins and aromatics simultaneously. In this petrochemical, the naphtha feed of the aromatic module is provided by the Abadan refinery, and the feed of the steam cracker unit is served by gas liquids produced in oil fields (Saidi, 2021).

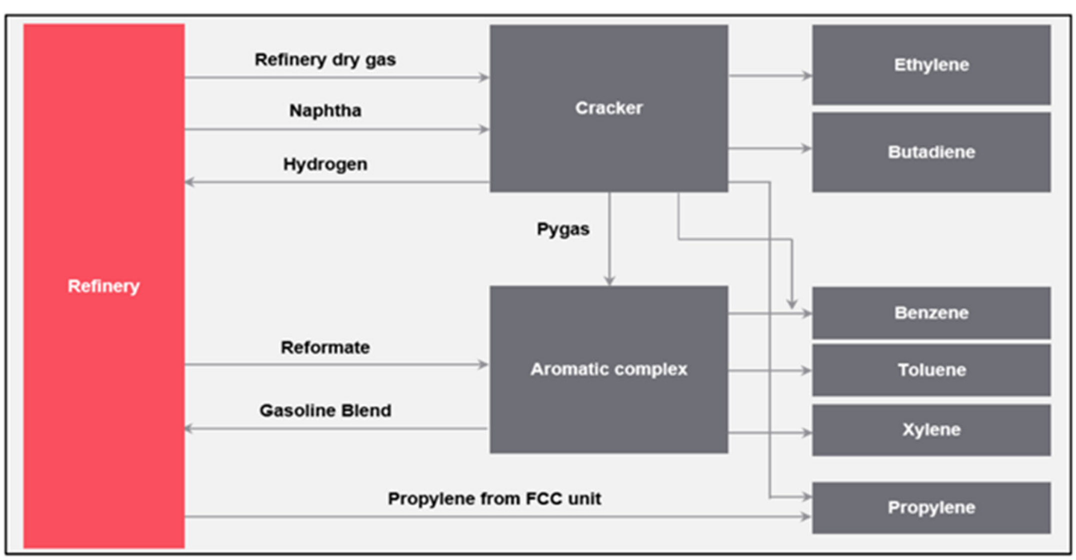

Figure 16: Petro refinery (refinery plus steam cracker petrochemical plus aromatic petrochemical) (Saidi, 2021)

7.5. Petro refinery (unit for converting crude oil into chemicals, COTC).

This set of petrol refineries is a new approach to the correlation and integration of petrochemical units and refineries, including a new generation of technology in the refinery and petrochemical industry. These units are configured to produce the most chemical and polymer products (more than 40%) to create more added value instead of fuel. Due to the large scale of these units (between 10 and 20 million tons per year of input feed) and the high-scale production of products in the output of the unit, the cost price of products in COTC units is significantly reduced. It can change the future of conventional petrochemical units in the world. Four main ways of converting crude oil into COTC chemicals are mentioned below (Saidi, 2021):

- Process of using refinery and petrochemical steam cracker with crude oil feed (usual process);
- ExxonMobil company's technology in using light crude oil in steam cracker units;
- Petrorefineries based on the production of para-xylene products using crude oil in China;
- The technology of Aramco company in converting crude oil into olefinic materials

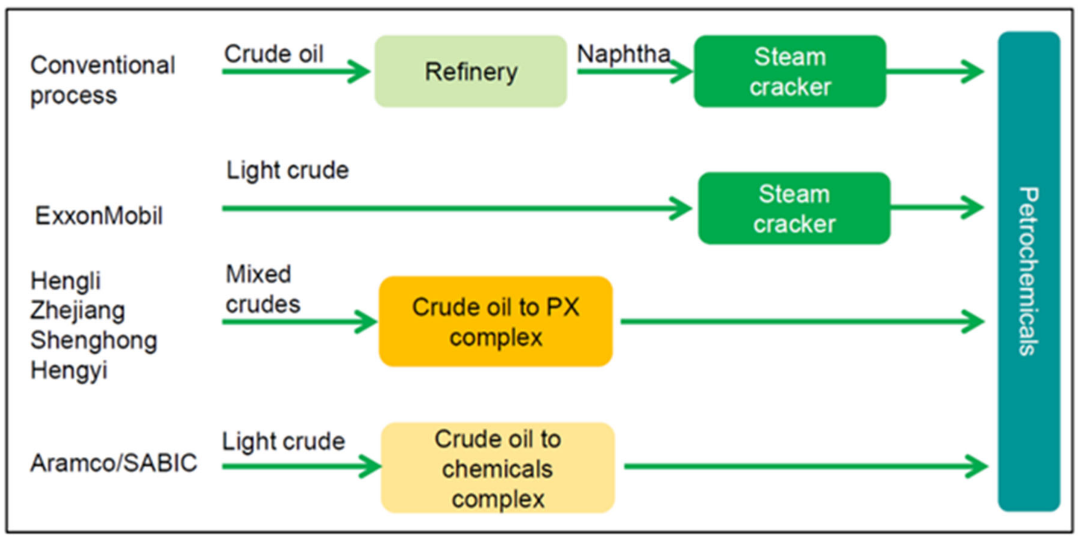

Figure 17: Petrorefinery (unit for converting crude oil into chemicals (COTC) (Saidi, 2021)

8. Conclusions

By processing the production chains and creating higher added value, the country's petrochemical industry can invent a high potential to accelerate the growth of the country's economy and various economic sectors and play a vital role in Iran's non-oil economy, preventing the impact of oil and gas revenues. The existence of a policy approach to completing and developing the country's refining and petrochemical industries has caused the development of these industries to be unbalanced.

Therefore, the refining industry has low profitability for various reasons. On the other hand, the plans for the petrochemical industry are often based on gas feed, and the goal is to produce rudimentary petrochemical products and export them. Meanwhile, with the integration of the refining and petrochemical industry and the completion and development of the value chain, both industries will enjoy a better economy, while today's world is developing the oil and gas industry from upstream to downstream industries and maximizing the benefits of the products. Hydrocarbons have taken a big step in building and completing their value chain. One of the most important strategies adopted has been integrating refining and petrochemical units for optimization.

An optimal state can be achieved in a petroleum refinery by sharing human resources, reducing feed supply costs, using integrated management and coordination between units, and reducing environmental pollution, thereby increasing profit margins, optimizing energy costs, and improving the economy. It will be a petrochemical refinery and change the fuel-oriented approach to the petrochemical products-oriented approach.

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