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Report

The Petrochemical Industry at a Crossroads toward 2050 Carbon Neutrality

Navigating GHG Emissions Reduction Pathways, Costs, and Policy Implications through NCC Electrification

The Petrochemical Industry at a Crossroads toward 2050 Carbon Neutrality:

Navigating GHG Emissions Reduction Pathways, Costs, and Policy Implications through NCC Electrification

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Author	**Ayoung Kim** | Petrochemical Team, SFOC | ayoung.kim@forourclimate.org

Acknowledgements	**Seokhwan Jeong** | Petrochemical Team, SFOC **Yujung Shin** | Legal Team, SFOC
Data Analysis and Modeling	**PLANiT**
Design	**sometype**

Solutions for Our Climate (SFOC) is an independent nonprofit organization that works to accelerate global greenhouse gas emissions reduction and energy transition. SFOC leverages research, litigation, community organizing, and strategic communications to deliver practical climate solutions and build movements for change.

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Executive Summary

Decarbonization of the Petrochemical Industry and Feasibility of Achieving Net Zero

> Achieving carbon neutrality in the petrochemical industry is no longer optional but imperative in a response to the climate crisis. It is also a critical strategy not only for achieving the Nationally Determined Contribution (NDC), but also for enhancing long-term industrial competitiveness.

- According to related studies (including the Bank of Korea's economic outlook), while the transition to decarbonization may entail upfront transition costs, it is expected to exert positive effects across the entire industries over the medium to long term.

> This study analyzes the feasibility of achieving the 2035 industrial-sector NDC target and 2050 carbon neutrality in Korea's petrochemical industry by **comparing, combining, and applying** key transition technologies. The major technologies assessed in this study include:

① **Electrification of Naphtha Cracking Centers (NCCs) and Replacement of Conventional NCC Fuels with Hydrogen (hereinafter referred to as "NCC Hydrogen");**

② **Heat pumps; and**

③ **Low-carbon technologies for high-temperature BTX (Benzene, Toluene, Xylene) processes**

- **The analysis confirms that both the 2035 industrial-sector NDC target (a 24.3% reduction) and 2050 carbon neutrality can be achieved in the petrochemical industry.**
- **In this study, only fuel switching (electrification or hydrogen) is considered among the available carbon emissions reduction measures.**

Key cost-effective strategies to achieve carbon neutrality in the petrochemical industry – NCC electrification using renewable electricity and production reduction through industrial restructuring

- Naphtha Cracking Centers (NCCs) are the largest source of Greenhouse Gas (GHG) emissions within the petrochemical production process, accounting for approximately 70% of total emissions from the petrochemical industry in the national GHG inventory. In this respect, NCCs constitute a critical transition target in pursuit of carbon neutrality.

- The results show that **NCC electrification using renewable electricity is the core transition technology to achieve a cost-effective carbon neutrality in the petrochemical industry.**
    - **While using green hydrogen for NCC furnaces is considered, the analysis finds NCC electrification to be more cost-effective and advantageous across key metrics.**

- Furthermore, the analysis demonstrates that reducing current production levels (NCC capacity) by 25% through industrial restructuring will lower the overall costs for achieving carbon neutrality (cumulative costs from 2025 to 2050) through NCC electrification by 19%. It suggests that industrial restructuring would play a critical role not only in securing industrial competitiveness, but also in the effective achievement of carbon neutrality. It suggests that industrial restructuring would play a critical role not only in securing industrial competitiveness, but also in the effective achievement of carbon neutrality.

Policy tasks to achieve carbon neutrality in the petrochemical industry – supporting NCC electrification demonstration and renewable energy infrastructure through government funds

- At present, domestic NCC electrification technologies remain at the experimental stage (TRL 3–4) and require advancement to the demonstration (pilot) stage (TRL 5–6). On the other hand, internationally, leading companies such as BASF, SABIC, and Linde have already joined hands to complete the construction of an electric cracking furnace demonstration plant in 2024, highlighting a clear gap in technology maturity and readiness between domestic situation and overseas leading examples.

> To accelerate NCC electrification demonstration and commercialization, preemptive investment of the industry is necessary. At the same time, policy support at the government level is also indispensable, given the considerable costs for achieving carbon neutrality.

- In particular, the budget for '2027 Climate Response Fund' should significantly expand support for the demonstration of NCC electric cracking processes using renewable electricity.
- Furthermore, NCC electrification should be explicitly included within the scope of both "core strategic petrochemical technologies" and "high value-added transition" to be specified under the Enforcement Decree of the Special Act on Enhancing and Supporting the Competitiveness of the Petrochemical Industry. Also, beyond regulatory measures, substantive support measures should be in place for prompt demonstration and commercialization of the NCC electrification.
- Finally, the successful decarbonization of the petrochemical industry through NCC electrification will require the expansion of renewable energy infrastructure tailored to the specific conditions of regional petrochemical complexes.

Major Analysis Results: Analysis on Carbon Abatement Costs (Cumulative from 2025 to 2050) to Achieve 2050 Carbon Neutrality through NCC Electrification[1]

Category	Carbon Neutrality costs by 2050 ($B, cumulative costs from 2025 to 2050)	Maximum Annual Electricity Demand (TWh)	Total GHG abatement cost by regions ($B, cumulative costs from 2025 to 2050)		
			Yeosu	Ulsan	Daesan
Maintaining Current Production Outlook (Including the Shaheen Project)	75.6 (KRW 112 trillion)	164.2	29.1 (KRW 43 trillion)	18.6 (KRW 27 trillion)	27.9 (KRW 41 trillion)
25% production reduction compared to current level	61.2 (KRW 91 trillion)	91.4	24.5 (KRW 36 trillion)	15.4 (KRW 23 trillion)	21.2 (KRW 31 trillion)
40% production reduction compared to current level	55.5 (KRW 82 trillion)	79.3	22.5 (KRW 33 trillion)	12.6 (KRW 19 trillion)	20.4 (KRW 30 trillion)

1 All calculations in this study are based on an exchange rate of 1 USD = 1,470 KRW (December 2025).

1. Introduction

The petrochemical industry is one of Korea's major high-emissions sectors, alongside the steel industry. As of 2024, it accounts for approximately 18.8% of total industrial greenhouse gas (GHG) emissions, equivalent to about 53.6 million tonnes[2]. Given such large-scale emissions, the decarbonization of the petrochemical industry constitutes a critical component of Korea's pathway toward achieving its Nationally Determined Contribution (NDC).

Concurrently, the intensification of carbon-neutral policies at both domestic and international levels has heightened the need for a rapid transition of the petrochemical industry toward a low-carbon industrial structure. Such demand extends beyond a simple matter of environmental regulation and is expanding into a broader issue directly linked to industrial competitiveness. In particular, amid ongoing discussion on the potential inclusion of petrochemical products under the EU's Carbon Border Adjustment Mechanism (CBAM), the petrochemical industry —accounting for 7.2% of Korea's total exports in 2023— might have greater significance because the carbon intensity of petrochemical products at the production stage is expected to exert a direct influence on future export competitiveness[3]. Accordingly, the transition toward decarbonization in Korea's petrochemical industry is recognized as a pressing task rather than a discretionary option.

Greenhouse gas emissions from the petrochemical industry primarily originate from naphtha cracking centers (hereinafter referred to as 'NCCs'), accounting for approximately 70% of total emissions. NCCs are facilities that thermally crack naphtha at high temperatures to produce basic petrochemical building blocks such as ethylene, propylene, and butadiene. NCC furnaces primarily use byproduct gases generated during the cracking process, as well as methane and liquefied natural gas (LNG), as fuels. Among these, methane combustion (including LNG) accounts for the largest share of carbon emissions[4]. The naphtha cracking process exhibits one of the highest levels of carbon intensity among industrial processes worldwide. In this sense, fuel substitution in NCC operations is regarded as the most urgent priority for accelerating decarbonization in Korea's petrochemical industry.

2 Greenhouse Gas Inventory and Research Center of Korea (GIR): *2035 National Greenhouse Gas Reduction Target (NDC) Public Consultation and Discussion Forum (Industrial Sector) – Presentation Materials.*

3 Korea Chemical Industry Association (KCIA) (2024). Petrochemical Mini Book, p.6

4 LG Chem (2022). https://www.lg.co.kr/media/release/24968

At the same time, the domestic petrochemical industry is experiencing a deterioration in profitability due to global oversupply and a production portfolio concentrated on general-purpose products. In response, industry-wide restructuring is currently underway including consolidation of facilities and production reduction. Facing current challenges where decarbonization and industrial restructuring are required at the same time, the transition toward low-carbon NCC processes has emerged as a key task having significant implications for the industry's sustainability and future competitiveness.

This report presents the electrification of NCC operations using renewable electricity as one of the key transition technologies to achieve decarbonization of Korea's petrochemical industry, and particularly the carbon neutrality by 2050. In addition, the report conducts a comparative analysis of NCC hydrogen-based technologies, another alternative under discussion together with NCC electrification, through a Marginal Abatement Cost (MAC) analysis. This approach aims to evaluate which technological options may represent more cost-effective and practically feasible pathways for decarbonization in the domestic petrochemical sector.

Furthermore, to analyze the necessity of production reduction through industrial restructuring from the perspective of climate response costs, the report develops various production scenarios: (1) a production increase scenario reflecting the Shaheen project, scheduled for commercialization in 2026; (2) a 25% production reduction scenario achieved through reductions in NCC capacity (according to the government's petrochemical industry restructuring plan); and (3) a 40% production reduction scenario. For each scenario, the report conducts an integrated analysis on GHG abatement costs and the associated renewable electricity demand required to support the transition.

Finally, the report examines the feasibility and costs of achieving carbon neutrality by 2050 when NCCs are electrified based on renewable electricity, with a particular focus on major petrochemical clusters in Yeosu (Jeonnam Province), Daesan (Chungnam Province), and Ulsan. It also discusses the economic and institutional support measures required at the national level to accelerate the transition toward decarbonization of Korea's petrochemical industry.

2. Current Status of Korea's Petrochemical Industry

a. Overview of the Petrochemical Industry

Domestically, Korea's petrochemical industry accounts for approximately 5.6% of total manufacturing output[5] and internationally, the industry ranked fourth in ethylene production capacity in 2024 (an annual ethylene capacity of 12.29 million tons in 2024), following China, the United States, and Saudi Arabia. As such, the industry holds great significance not only in Korea's export, but also in the global petrochemical market[6]. In particular, large-scale petrochemical industrial complexes have been established in Yeosu, Ulsan, and Daesan, where basic petrochemicals, intermediates, synthetic resins, synthetic feedstock, and synthetic rubbers are produced **[Table 1]**.

[Table 1] Overview of Korea's Major Petrochemical Complexes

Category	Yeosu (Est. 1979)	Daesan (Est. 1991)	Ulsan (Est. 1972)
No. of tenant companies	135 (incl. LG Chem, LOTTE Chemical, Kumho Petrochemical, GS Caltex, Kolon Industries, Hanwha Solutions, etc.)	11 (incl. HD Hyundai Chemical, LG Chem, Lotte Chemical, Hanwha TotalEnergies, etc.)	314 (incl. KPIC, S-Oil, SK Energy, SK Geo Centric, Hyosung Chemical, etc.) [AK1.1][AK1.2]
Site area (10,000 pyeong)	947	473	2,295
Production output (KRW)	83 trillion	47 trillion	111 trillion
Ethylene production capacity (KTA, as of June 2024)	6,265	4,775	1760
Export value (USD 100 mil.)	384	N/A	371
No. of employees (thousand persons)	21.7	4.2	21.0

Source: Korea Industrial Complex Corporation (KICOX), Statistics Korea, Korea Chemical Industry Association (KCIA)

5 NEXT Group (2024). Net-Zero Roadmap for South Korea's Petrochemical Industry
6 Korea Chemical Industry Association (KCIA), Industry status

b. Key Trends in the Petrochemical Industry

Korea's petrochemical industry has continued to experience the sluggish market due to production and export structure centered on general-purpose products as well as intensified global oversupply. Against this backdrop, the government has been leading the discussion within the industry on industrial restructuring. In November, LOTTE Chemical and HD Hyundai Chemical submitted applications to the Ministry of Trade, Industry and Energy for approval of their restructuring plans, the first applications since government-led restructuring discussions began in August. The plans propose the integration of the naphtha cracking centers (NCCs) operated respectively by the two companies within the Daesan petrochemical complex. Similar restructuring initiatives are reportedly being prepared by LG Chem and GS Caltex in the Yeosu complex[7]. Given that the government presented a target to reduce NCC capacity by up to 3.7 million tons (equivalent to approximately 25% of current capacity) for reshaping the petrochemical industry, restructuring plans for other petrochemical clusters should be developed.

However, S-Oil is pushing ahead with the Shaheen Project, the massive petrochemical complex development in Korea, located within the Onsan National Industrial Complex in Ulsan. Upon mechanical completion in the first half of next year, followed by test operation and full-scale operation, the project is expected to additionally supply up to 1.8 million tons of ethylene every year[8]. Compared with the scale of existing supply capacities in the same region such as SK Geo Centric (0.66 million tons) and the Korea Petrochemical Ind. Co., Ltd. (KPIC) (0.9 million tons), this additional capacity may lay a significant burden on industry-wide restructuring efforts[9].

At the same time, the National Assembly passed a bill in December 2025 known as the *Special Act on Enhancing and Supporting the Competitiveness of the Petrochemical Industry*[10] to facilitate restructuring of petrochemical companies and ensure their industrial competitiveness. To this end, the Act establishes a legal basis for tax, fiscal, and employment-related support measures and provides support for research and development in transition toward high value-added products and GHG mitigation technologies. The legislation aims to enhance the medium- to long-term competitiveness of the petrochemical industry through a transition toward low-carbon processes and a production portfolio increasingly focused on higher value-added products.

7 Han Yena & Choi Eunkyung (2025), CHOSUN Daily.

8 S-Oil (2025). Shaheen Project reaches 85% completion, leading a new leap forward in the petrochemical sector

9 Hwang Gyuwon. (2025). Company Report, Korea Petrochemical Ind. Co., Ltd.

10 Ministry of Government Legislation: Legislative progress, the Special Act on Enhancing and Supporting the Competitiveness of the Petrochemical Industry

3. Key Vehicles for Achieving Carbon Neutrality in the Petrochemical Industry

a. Need for Decarbonizing the Petrochemical Industry

As of 2024, the petrochemical industry represented one of Korea's major GHG emitting sectors, accounting for 18.8% of total industrial emissions (53.6 million tons). In particular, NCCs are key facilities while they constitute the largest source of emissions in the petrochemical production processes, with approximately 70% of the petrochemical industry's emissions reported in the national GHG statistics attributable to NCC-related processes[11]. This indicates that in decarbonizing the petrochemical industry, it is a critical task to drive energy transition from fossil-based fuels currently used for thermal cracking processes in NCC to low-carbon energy sources such as renewable energy-based electricity or green hydrogen.

According to the government's Nationally Determined Contribution (NDC) for 2035, released in November 2025, the industrial sector is required to reduce GHG emissions at least 24.3% compared to 2018 levels. Given the considerable share of the petrochemical industry among the industrial emissions and the concentration of emissions within NCC operations, the low-carbon transformation of NCC processes is a pivotal task in achieving NDC as well as the industry's own carbon neutrality.

b. Technological Transition Measures

i. Electrification of Naphtha Cracking Centers (NCCs)

As NCC processes are highly carbon-intensive in their nature, active research and development (R&D) efforts for NCC electrification are underway both domestically and internationally to replace fuels used for thermal cracking with renewable electricity[12]. NCCs constitute a core process in petrochemical production, cracking naphtha and producing basic petrochemical building blocks such as ethylene and propylene.

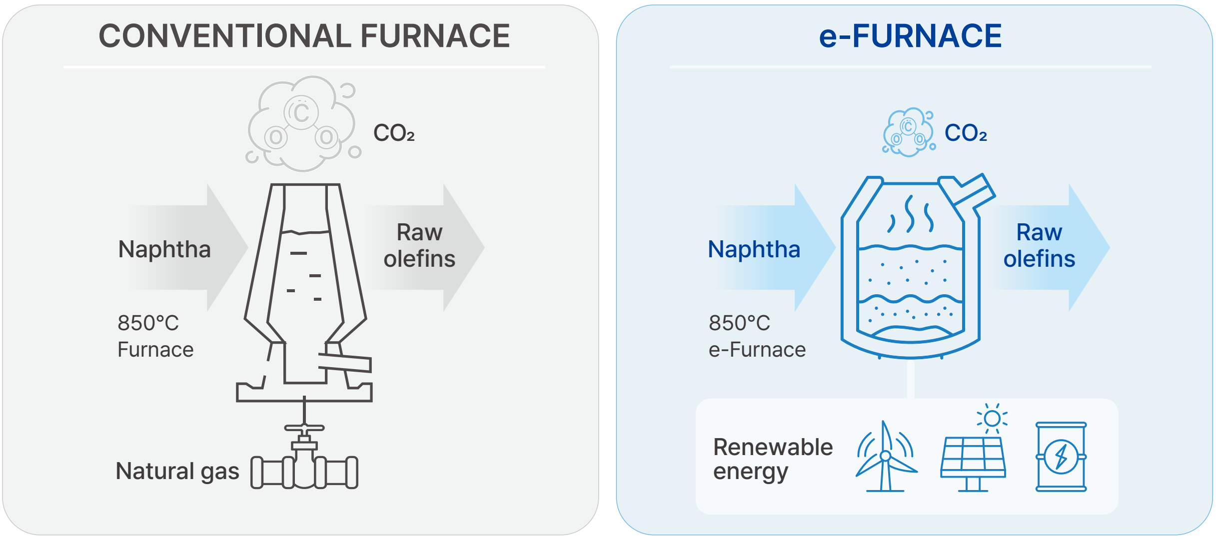
11 Greenhouse Gas Inventory and Research Center of Korea (2025). Presentation materials for public discussion forum (industrial sector) on the NDC by 2035

12 Korea Institute of Energy Research (KIER) (2022). Industrial Electrification Status and Outlook: Focus on Steel and Petrochemical Industries

Major international chemical companies have advanced the electrification technology to the demonstration stages that transform fuels for NCC thermal cracking processes to renewable energy-based electricity. In 2024, BASF (Germany), SABIC (Saudi Arabia), and Linde (United Kingdom) completed and launched the demonstration plant for large-scale electrically heated steam cracking furnace. In addition, Dow (United States) and Shell (Netherlands/United Kingdom) started up an experimental unit to electrically heat steam cracker furnaces in 2022 [Figure 1].

By contrast, in Korea, the government launched a project in 2023 with the goal of conducting a pilot experiment on electrifying NCC thermal cracking fuels, but no projects for actual field demonstration have been initiated. As a result, a gap remains between domestic and leading international firms in the development of innovative low-carbon production processes.

[Figure 1] NCC e-FURNACE Model for Joint Project between BASF, SABIC, and Linde



Source: Reconstructed image from the SABIC 13

NCC electrification technologies are primarily based on the deployment of electric cracking furnaces (E-Crackers) that can be applied to conventional processes. As such electrification technologies cover the heat demand for processes using renewable electricity, they are assessed to have approximately 90% emissions abatement potential compared to conventional NCC thermal cracking processes.

13 SABIC (2021). SABIC forms collaboration to realize the world's first electrically heated steam cracker furnace.

ii. Fuel Replacement with Hydrogen for NCC Operations

Hydrogen can be utilized in NCC operations in two distinct ways: as a fuel and as a feedstock. When it comes to using hydrogen as a fuel, it refers to hydrogen substitutes for fossil-based combustion fuels currently used in naphtha cracking processes. Under this approach, the fundamental structure and reaction mechanisms themselves of thermal cracking processes remain the same. In other words, this measure does not entail a shift in the chemical reaction routes of the cracking process to a hydrogen-based process, but rather reduces GHG emissions by replacing fossil fuels at the combustion stage with green hydrogen.

The two technological options compared and analyzed in this study—NCC electrification and green hydrogen–based fuel transition—exhibit distinct characteristics in terms of required infrastructure and energy demand. A comparative overview of these characteristics is provided in **[Table 2]**.

[Table 2] Comparison between NCC Electrification and NCC Hydrogen

Category	NCC Electrification	NCC Hydrogen
Energy Vector	Renewable electricity	Green hydrogen
Energy Consumption ∗based on the energy consumed per ton of ethylene produced	5.0 MWh/t	0.2t H_2/t (~11.3 MWh/t)
Required Infrastructure	Reinforced grid to expand renewable energy	H_2 pipeline + storage

iii. Heat Pumps

In petrochemical production, not only high-temperature processes but also heat demand in low-temperature processes below approximately 165°C can be satisfied by using electricity, thus contributing to decarbonization of the petrochemical industry. Heat pumps operate by absorbing ambient heat (waste heat), utilizing electricity to increase the temperature, and converting it into the heat required for processes. In particular, heat pumps display high energy efficiency due to their high Coefficient of Performance (COP), and therefore, are considered as an effective option for significantly reducing energy consumption in low-temperature processes. That is, heat pumps substantially lower primary energy consumption required to meet the same level of heat demand, and thereby contributing to reducing carbon emissions. Furthermore, from a Technology Readiness Level (TRL) perspective, heat pump technologies have already reached TRL 9 which indicates full commercial deployment and stable operation. As such, heat pumps are expected to firmly contribute to the decarbonization of low-temperature processes within petrochemical processes.

iv. Low-Carbon Technologies for High-Temperature BTX Processes

Certain high-temperature processes for producing Benzene, Toluene, Xylenes (BTX) (aromatics)—such as catalytic reforming—require heat sources exceeding 400°C. However, industrial heat pumps are generally applicable up to approximately 165°C, making them difficult to directly replace technologies for such high-temperature processes. As a result, since such high-temperature furnace processes are beyond the scope of heat pumps, alternative low-carbon heat supply technologies are needed, and active researches are underway on these technologies for decarbonization of high-temperature processes. Electrically powered heaters are being explored as one potential solution. For example, Coolbrook's RotoDynamic Heater (RDH) is an electricity-based technology capable of supplying high-temperature heat, exhibiting high thermal efficiency.

c. Carbon Emissions Abatement Potential through Production Reduction

Recent studies indicate that if global plastic production is on a continuous upward curve, it could rapidly deplete the remaining global carbon budget, thereby posing a significant risk to achieving the global goal outlined under the Paris Agreement to limit global warming to 1.5°C[14]. Against this backdrop, discussions within the context of the Global Plastics Treaty have invited views that the petrochemical industry should reduce production volumes of fossil fuel–based primary chemicals for effective responses to climate crisis.

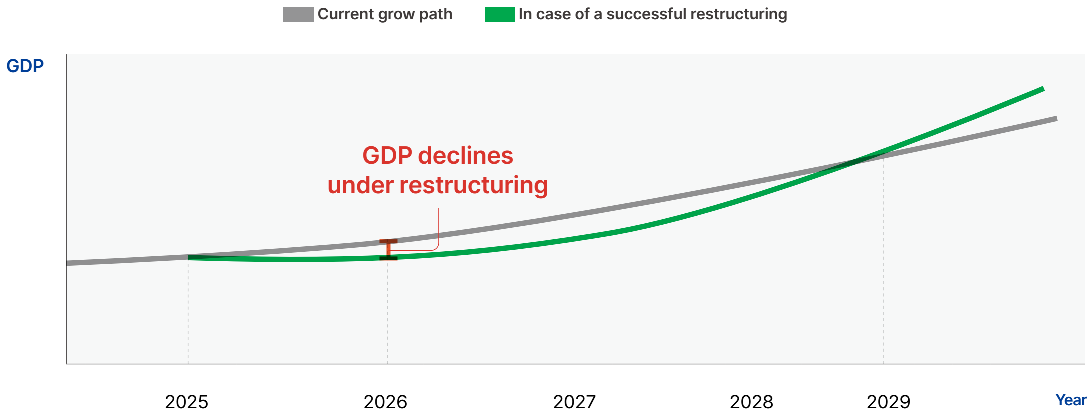
Meanwhile, in the domestic context, production reduction is being considered not only as a means of reducing the climate impact, but also as a strategic option for enhancing industrial competitiveness of the petrochemical industry. According to the *Economic Outlook* published by the Bank of Korea, production reduction and a transition toward higher value-added products are identified as key strategies for maintaining global competitiveness over the long term. While production reduction may entail short-term economic burden, the report also notes that it could contribute to a recovery in industrial growth momentum over the medium to long term[15]. This assessment is based on the premise that facility capacity reduction through industrial restructuring would lower fixed operating costs, thereby giving companies more financial rooms to increase their investments in R&D, upgrading of production facilities, and enhancing competitiveness of higher value-added products. The report assumes that the

14 Karali, N., Khanna, N., & Shah, N. (2024, April). Climate impacts of plastics production. Lawrence Berkeley National Laboratory; The Pew Charitable Trusts. (2025, December). Breaking the plastic wave 2025: An assessment of the global system and strategies for transformative change. The Pew Charitable Trusts, etc.

15 Bank of Korea (2025). Economic Outlook, November 2025

companies will actively pursue R&D and expand investment by approximately 3.5% over a three-year period **[Figure 2]**. In this context, this report also examines how much the overall cost of achieving carbon neutrality in the petrochemical industry is reduced lowered as a result of industrial restructuring.

[Figure 2] Projected Growth Path under Petrochemical Industry Restructuring, Economic Outlook, Bank of Korea



Source: Reconstructed image from the Bank of Korea

▶ Restructuring may place burden on economic growth in the short term, but contribute to economic rebound in medirum to long term

d. Scope and Further Research Tasks

A comprehensive decarbonization strategy that accounts for Scope 3 emissions in the petrochemical industry would require not only fuel transition, as examined in this report, but also measures to replace fossil fuel-based feedstock. However, as a means of achieving NDC and carbon neutrality, this study primarily examines options to reduce emissions in the petrochemical industry reflected in the national GHG statistics. Accordingly, the study identifies fuel transition in NCC thermal cracking processes as the core task for decarbonization. In this sense, exploring options to reduce Scope 3 emissions of the petrochemical industry as well as measures to replace fossil fuel-based feedstock are left for future study.

In addition, this study does not incorporate Carbon Capture, Utilization, and Storage (CCU/CCUS) technologies into the transition model. While CCU/CCUS technologies are frequently mentioned as an important option for achieving carbon neutrality in hard-to-abate sectors such as the petrochemical industry, questions are also being raised about the timing of large-scale commercial deployment, costs, and feasibility in the domestic context. In this respect, this study places priority on examining transition technologies such as NCC electrification, NCC hydrogen, heat pumps, and low-carbon technologies for BTX high-temperature processes (see Section 3-b. Technological Transition Measures). The study indicates that there exist feasible pathways where the Korean petrochemical industry could achieve carbon neutrality by 2050 through combinations of these transition technologies.

4. Transition Cost Analysis for Achieving Carbon Neutrality in Korea's Petrochemical Industry

a. Overview of Transition Cost Analysis Results

This report aims to attain a 24.3% reduction in GHG emissions by 2035 compared to 2018 levels according to the industrial reduction target under the NDC, as well as carbon neutrality of the Korean petrochemical industry by 2050. To this end, it calculates Marginal Abatement Costs (MACs) for each transition technology, identifies the most cost-effective technology, and estimates total abatement costs and required electricity demand for each production volume scenario.

The analysis identifies NCC electrification as a key transition technology for decarbonizing the petrochemical industry from a cost-effectiveness perspective.

Assuming current production levels are maintained due to unsuccessful voluntary restructuring in the petrochemical industry and additional capacity from the Ulsan Shaheen Project (fully operational in 2026) is reflected, the cumulative abatement cost of achieving carbon neutrality through NCC electrification is estimated at USD 75.6 billion (KRW 112 trillion) over the period from 2025 to 2050.

By contrast, if the government's petrochemical industry restructuring plan succeeds in achieving its maximum reduction target to cut NCC capacity by 25% compared to current levels, the total abatement cost is projected to decrease to approximately USD 61.2 billion (KRW 91 trillion) by 2050.

Furthermore, under a more ambitious production reduction scenario where production level is reduced by 40% compared to current levels, the total abatement cost (transition cost) is expected to decrease further to approximately USD 55.5 billion (KRW 82 trillion) by 2050 **[Table 3]**.

[Table 3] Key Results by Technology and Scenario, 2025–2050

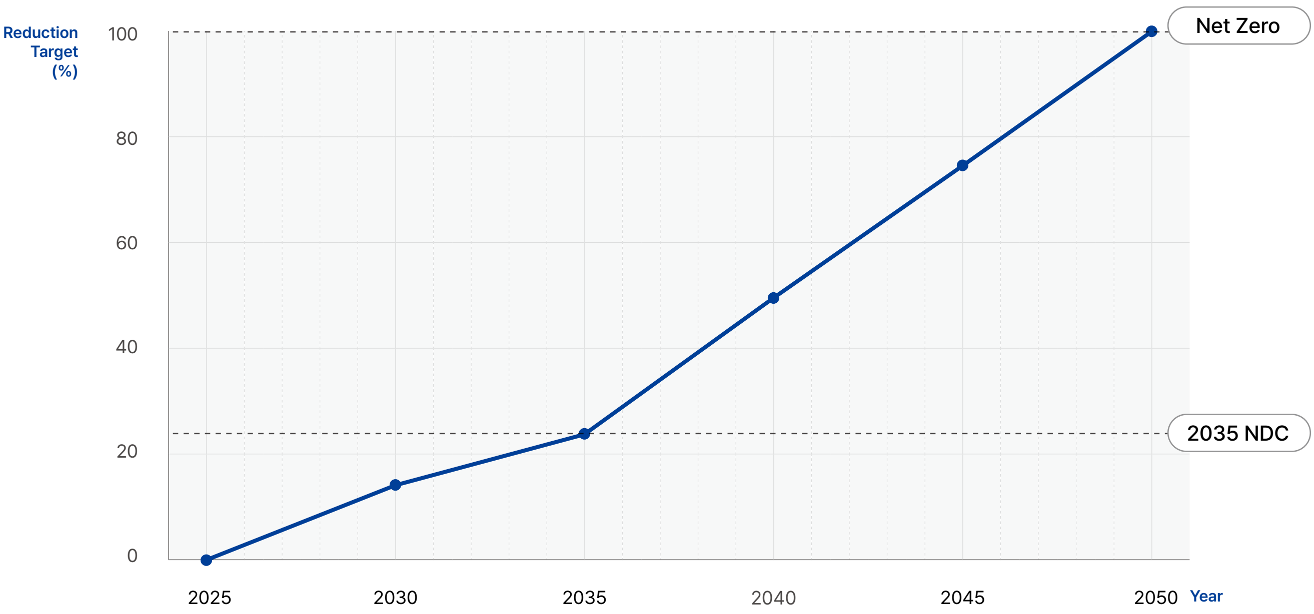
Transition technology	Production Scenario	Total Abatement Cost ($B)	Maximum Annual Electricity Demand (TWh)	Total GHG abatement cost by regions ($B)		
				Yeosu	Ulsan	Daesan
NCC electrification	Maintaining Current Production Outlook (Including the Shaheen Project)	75.6 (KRW 112 trillion)	164.2	29.1 (KRW 43 trillion)	18.6 (KRW 27 trillion)	27.9 (KRW 41 trillion)
	25% production reduction compared to current level	61.2 (KRW 91 trillion)	91.4	24.5 (KRW 36 trillion)	15.4 (KRW 23 trillion)	21.2 (KRW 31 trillion)
	40% production reduction compared to current level	55.5 (KRW 82 trillion)	79.3	22.5 (KRW 33 trillion)	12.6 (KRW 19 trillion)	20.4 (KRW 30 trillion)
Transition technology	**Production Scenario**	**Total Abatement Cost ($B)**	**Peak hydrogen demand (Mt)**	**Total GHG abatement cost by regions ($B)**		
				Yeosu	**Ulsan**	**Daesan**
NCC Hydrogen	Maintaining Current Production Outlook (Including the Shaheen Project)	148.8 (KRW 219 trillion)	4.3	61.7 (KRW 91 trillion)	38.4 (KRW 56 trillion)	48.2 (KRW 71 trillion)
	25% production reduction compared to current level	123.9 (KRW 183 trillion)	2.3	52.0 (KRW 76 trillion)	32.2 (KRW 47 trillion)	39.4 (KRW 58 trillion)
	40% production reduction compared to current level	110.1 (KRW 163 trillion)	2.0	48.1 (KRW 71 trillion)	26.2 (KRW 39 trillion)	35.5 (KRW 52 trillion)

b. Model Framework and Production Scenarios

i. GHG Reduction Targets and Analytical Objective

This model aims to identify cost-effective carbon abatement pathways and associated costs for the Korean petrochemical industry, targeting decarbonization pathways that would reduce GHG emissions by 24.5% by 2035 compared to 2018 levels (reflecting NDC for 2035) and achieve net-zero emissions by 2050 [Figure 3]. The carbon reduction targets of this model are defined using 2018 GHG emissions from the domestic petrochemical industry (approximately 47 $MtCO_2e$) as the baseline. The model is structured to achieve a 24.5% reduction by 2035 and carbon neutrality by 2050 relative to this baseline.

[Figure 3] Korean Petrochemical Industry's Emission Reduction Targets and Pathways Applied in This Study



Under these targets, the study is designed to identify the transition technology that considers both cost-effectiveness and technical feasibility. In particular, this study focuses on fuel transition in NCC operations and presents cost-effective decarbonization strategies applicable to the Korean petrochemical industry through quantitative comparison and analysis of renewable energy-based electrification and green hydrogen-based fuel transition.

ii. Scenario Overview

With focuses on fuel transition in NCC operations, this study applies NCC electrification and NCC hydrogen technologies across three production level scenarios to quantitatively estimate GHG emissions reductions, marginal and total abatement costs, electricity or hydrogen demands required for GHG reductions for each scenario. The deployment of heat pumps and low-carbon technologies for high-temperature BTX processes is assumed across all scenarios.

Production level of each scenario is differentiated according to the reduction level of production (NCC capacity). It is assumed that when production reductions occur, the facilities with higher levels of aging are closed first.

Based on these premises, a total of **six scenarios** are defined as below (detailed common assumptions and transition technology-specific assumptions are provided in **Appendix 1**):

- Maintaining current production levels + additional production (facility capacity) from the Shaheen Project + NCC electrification
- Maintaining current production levels + additional production (facility capacity) from the Shaheen Project + NCC hydrogen
- 25% reduction in production level (NCC capacity) + NCC electrification
- 25% reduction in production level (NCC capacity) + NCC hydrogen
- 40% reduction in production level (NCC capacity) + NCC electrification
- 40% reduction in production level (NCC capacity) + NCC hydrogen

iii. Scope of Analysis

This study selects a total of 237 facilities within the Korean petrochemical industry where transition technologies such as NCC electrification, NCC hydrogen, heat pumps, and low-carbon BTX high-temperature process technologies can be applied. The scope includes not only NCCs, but also polymer and aromatics production facilities. It is also defined that if the S-Oil Shaheen Project is fully operated, an additional six facilities are included.

c. Analysis Results

i. The Cost-Effective Technology for Achieving Carbon Neutrality: NCC Electrification

Based on the premises as mentioned above, the analysis indicates that under all scenarios, the Korean petrochemical industry is able to achieve carbon neutrality by 2050. A comparison of total abatement costs by technology shows that replacing NCC fuels with renewable electricity (NCC electrification) is more cost-effective than fuel substitution with green hydrogen (NCC hydrogen).

If failed voluntary restructuring within the petrochemical industry maintains current production levels and additional capacity from the Ulsan Shaheen Project (scheduled to fully operate in 2026) is reflected, the total abatement cost of achieving carbon neutrality through NCC electrification is estimated at approximately USD 75.6 billion (KRW 112 trillion) cumulatively between 2025 and 2050.

By contrast, if the government's petrochemical industry restructuring plan succeeds in achieving its maximum reduction target, resulting in a 25% reduction in NCC capacity relative to current levels, the estimated total abatement cost is projected to decline to approximately USD 61.2 billion (KRW 91 trillion) by 2050. Furthermore, if production capacity is reduced by 40% compared to current levels, the total transition cost is expected to further decrease to approximately USD 55.5 billion (KRW 82 trillion) by 2050. However, it should be noted that abatement cost estimates for each scenario may vary depending on actual RE-PPA prices and the impact of industrial restructuring.

In contrast, when NCC hydrogen technology using green hydrogen is adopted, higher abatement costs are required under the same production scenarios—approximately USD 148.8 billion (KRW 219 trillion), USD 123.4 billion (KRW 183 trillion), and USD 110 billion (KRW 163 trillion), respectively.

These cost differences between transition technologies are primarily driven by (1) differences in the scale of additionally required energy infrastructure, and (2) differences in energy conversion efficiency. When the capital costs of domestic green hydrogen production facilities are taken into account, directly using renewable electricity has more economic advantage than producing and supplying green hydrogen.

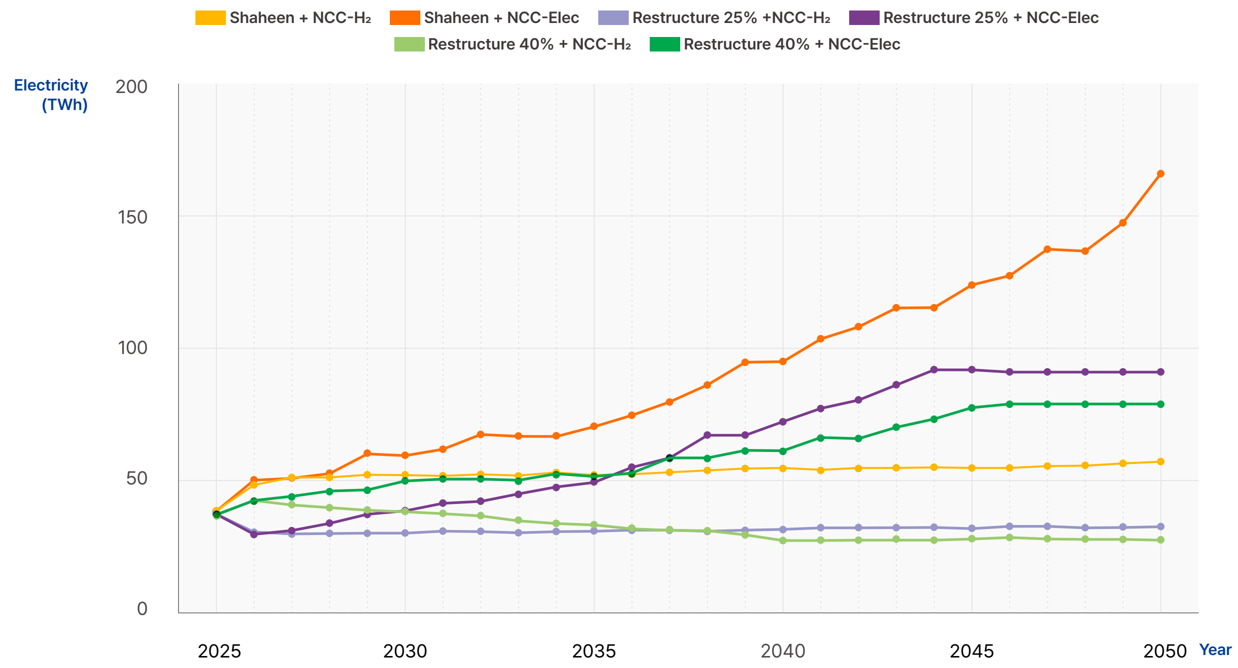
ii. Importance of Production Reduction

Even within a single transition technology, total abatement costs for the petrochemical industry to reach carbon neutrality vary significantly depending on the production reduction scenario, ranging from approximately USD 55.5 billion (KRW 82 trillion) to USD 75.6 billion (KRW 112 trillion). This underscores the critical role of production reduction in achieving carbon neutrality **[Table 3]**.

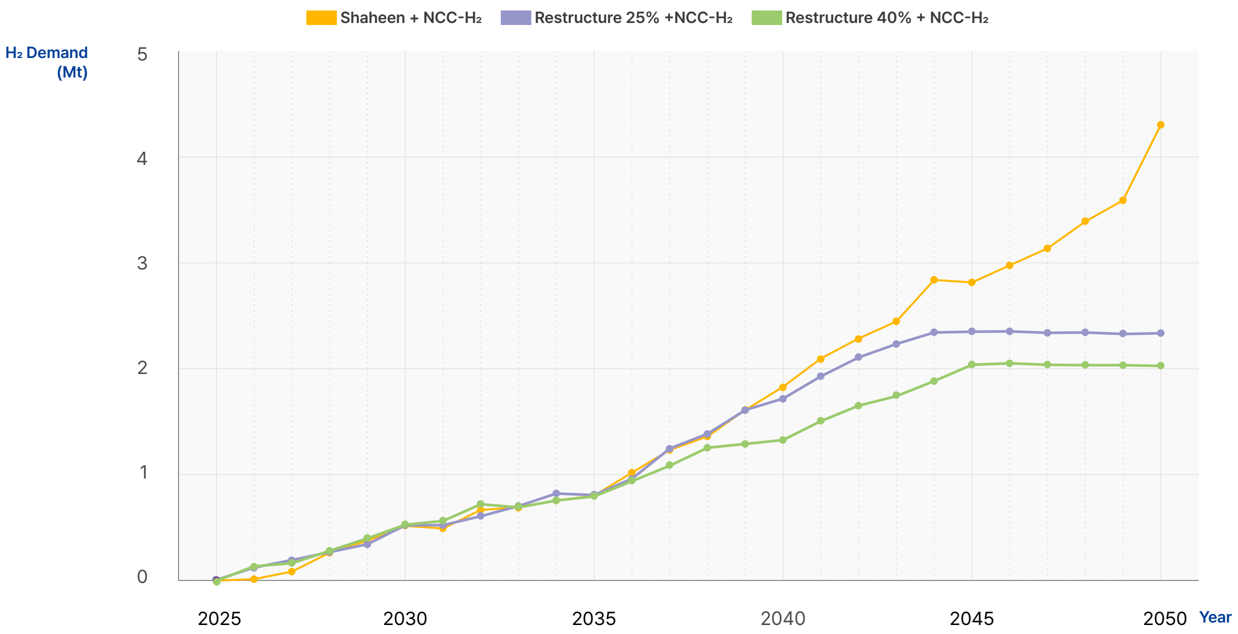
In addition to the abatement cost, differences are also observed in terms of the need for securing renewable electricity. Under the 25% production reduction scenario with NCC electrification, the annual peak electricity demand in 2050 will be approximately 72.8 TWh lower than in the scenario where current production levels are maintained and capacity from the Shaheen Project is added. It is interpreted that maintaining current production levels may cause substantially higher costs for securing renewable energy infrastructure compared to the 25% production reduction scenario.

[Figure 4] and **[Figure 5]** illustrate the trajectories of renewable electricity and green hydrogen demand required for each scenario. While no hydrogen demand arises under NCC electrification scenarios, electricity demand necessary for heat pumps and low-carbon BTX high-temperature process technologies is concurrently calculated in NCC hydrogen scenarios.

[Figure 4] Electricity Demand by Scenario



[Figure 5] Green Hydrogen Demand by Scenario



iii. Timing for Introduction of Key Transition Technologies to Achieve Cost-Effective Carbon Neutrality

To achieve carbon neutrality in a cost-effective manner, this study assumes different timelines for introducing transition technologies based on Technology Readiness Level (TRL). In other words, technologies that are already at the commercial deployment stage are available for earlier adoption, whereas technologies requiring additional demonstrations are considered for later deployment. Both NCC electrification and NCC hydrogen technologies are assumed to become deployable starting in 2030. While the actual deployment timing varies by scenario, the study assumes that most domestic production facilities transition to renewable energy-based or green hydrogen–based facilities between 2035 and 2040. Heat pumps and low-carbon technologies for BTX high-temperature processes are assumed to be introduced beginning in 2026, given the TRL.

5. Analysis of Decarbonization Pathways and Costs by Region for Major Petrochemical Industrial Complexes

a. Overview of Regional Outlooks

Petrochemical production facilities in Korea primarily clustered in major industrial complexes, notably Yeosu, Ulsan, and Daesan. With an aim to decarbonize the petrochemical sector, this study simulates regional GHG abatement costs by applying NCC electrification, the most cost-effective transition technology identified in preceding analyses. Since production items, facility configuration, and the number of facilities are different by region, reduction pathways also vary by region under each production scenario. Nevertheless, the regional analyses indicate that carbon neutrality by 2050 (100% emissions reduction) is achievable across all scenarios.

Accordingly, this study estimates ① carbon neutrality costs by region and production scenario, and ② electricity and hydrogen demands required for transition. The analysis focuses on Yeosu, Ulsan, and Daesan where the major petrochemical complexes are located.

b. Regional Abatement Cost Analysis by Production Scenario in Major Petrochemical Complexes

This study analyzes the MACs, total GHG abatement costs, and expected GHG emission reductions through NCC electrification for Korea's major petrochemical clusters in Yeosu, Ulsan, and Daesan under six scenarios. In particular, the analysis evaluates the feasibility of achieving decarbonization by 2050 in each region by comprehensively examining scenario-specific MACs and reduction pathways.

As presented in **[Table 4]**, the results indicate that all regions—Yeosu, Ulsan, Daesan, and other clusters —can achieve carbon neutrality, a 100% reduction in GHG emissions compared to BAU by 2050. This finding suggests that achieving net-zero emissions is technically and economically feasible across Korea's major petrochemical industrial clusters.

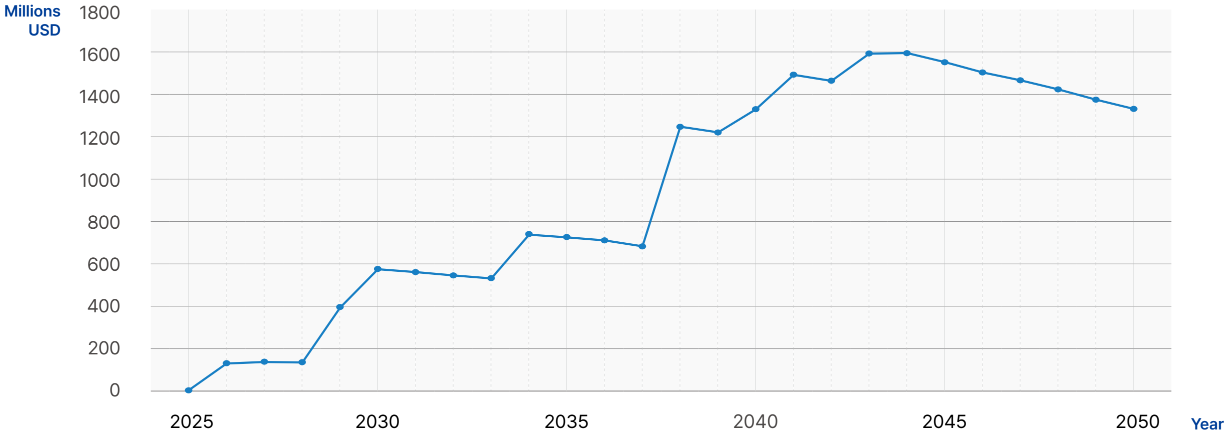
An examination of cumulative GHG abatement costs through 2050 by region-specific production scenario shows that the cumulative investment required between 2025 and 2050 to achieve carbon neutrality ranges from approximately KRW 23 trillion (Ulsan) to 36 trillion (Yeosu) (based on the assumption of achieving a 25% production reduction resulting from industrial restructuring). These figures imply the need for bold investment and support for achieving carbon neutrality from both private and public sectors. Across all three regions, reducing production (facility capacity) by 25% or more compared to current levels results in a significant reduction in total abatement costs. More specifically, the analysis finds that a 25% production reduction, compared to scenarios in which current production levels are maintained, can save costs of approximately KRW 7 trillion in the Yeosu complex, approximately KRW 4 trillion in the Ulsan complex, and approximately KRW 10 trillion in the Daesan complex.

[Table 4] **Summary of Regional Carbon Neutrality Costs**

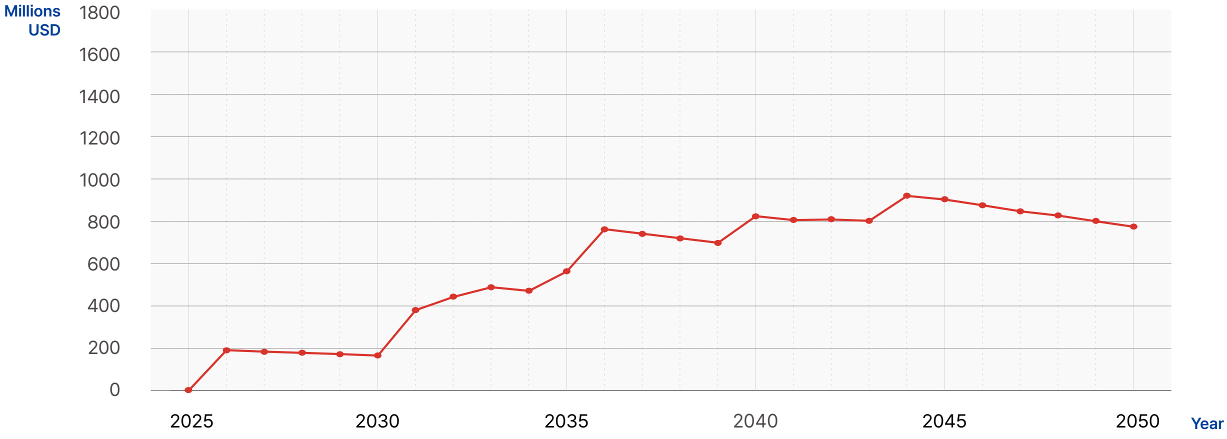
Category	BAU Carbon Emissions (Mt)	2050 Net Zero Target (%)	Total GHG Abatement Costs by Production Scenario (Cumulative Cost for 2026~2050, $B)		
			Maintaining Current Production Level (including the Shaheen Project)	25% production reduction compared to current level	40% production reduction compared to current level
Yeosu	22.37	Achievable	29.1 (KRW 43 trillion)	24.5 (KRW 36 trillion)	22.5 (KRW 33 trillion)
Ulsan	18.87	Achievable	18.6 (KRW 27 trillion)	15.4 (KRW 23 trillion)	12.6 (KRW 19 trillion)
Daesan	16.84	Achievable	27.9 (KRW 41 trillion)	21.2 (KRW 31 trillion)	20.4 (KRW 30 trillion)
Others	0.30	Achievable	0.013 (KRW 19.1 billion)	0.06 (KRW 88.4 billion)	0.04 (KRW 64.7 billion)

A closer examination of the annual abatement cost trajectory shows that, if the petrochemical industry successfully achieves a 25% reduction in production capacity compared to current levels and NCC electrification based on renewable electricity is deployed, the resulting total abatement cost follows the trend illustrated in **[Figure 6]**. Following the full-fledged deployment of NCC electrification in 2035, abatement costs will increase moderately and reach a peak around 2044, after which total abatement costs are projected to gradually decline. A similar pattern is observed in the Ulsan and Daesan complexes, where annual abatement costs also peak around 2044 and then enter a downward trend **[Figure 7, 8]**.

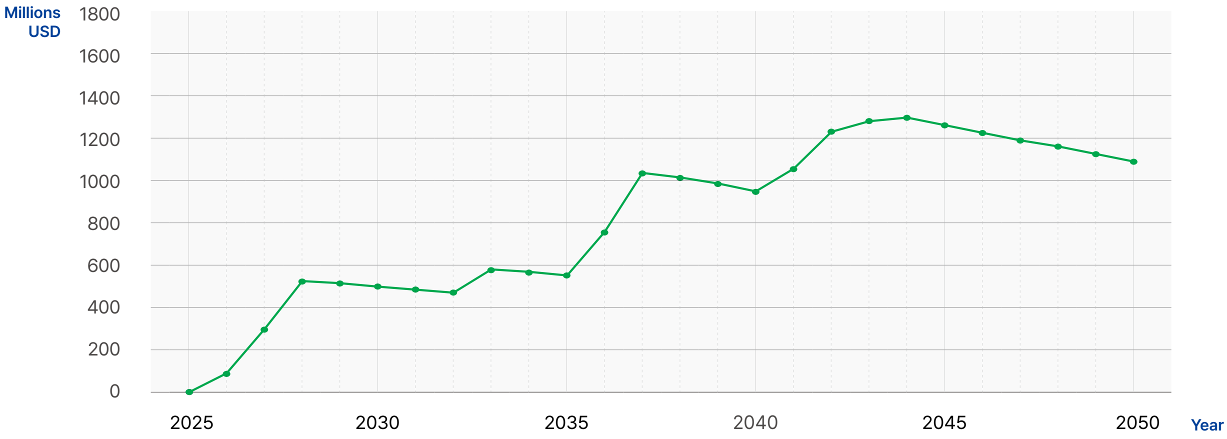
[Figure 6] Annual Abatement Cost Trajectory for Yeosu, 2025–2050



[Figure 7] Annual Abatement Cost Trajectory for Ulsan, 2025–2050

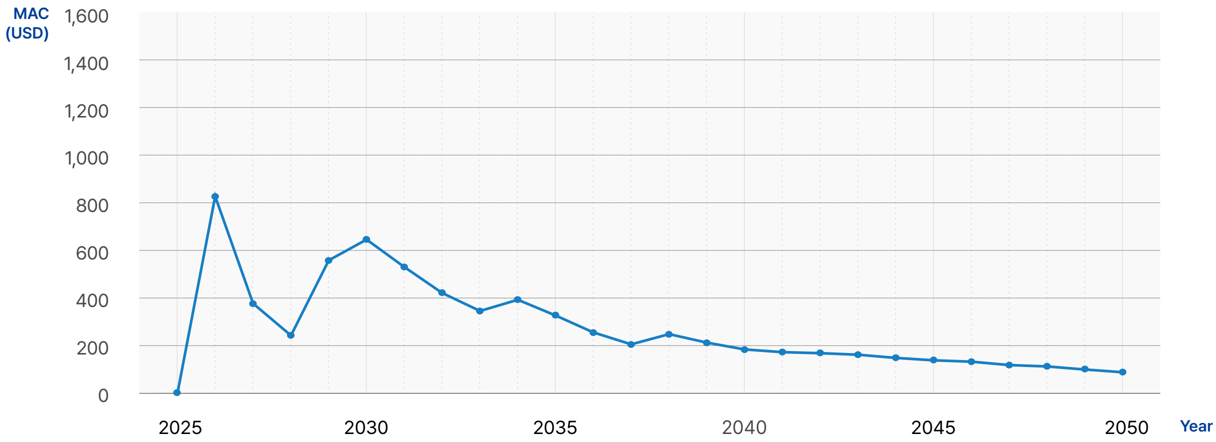


[Figure 8] Annual Abatement Cost Trajectory for Daesan, 2025–2050

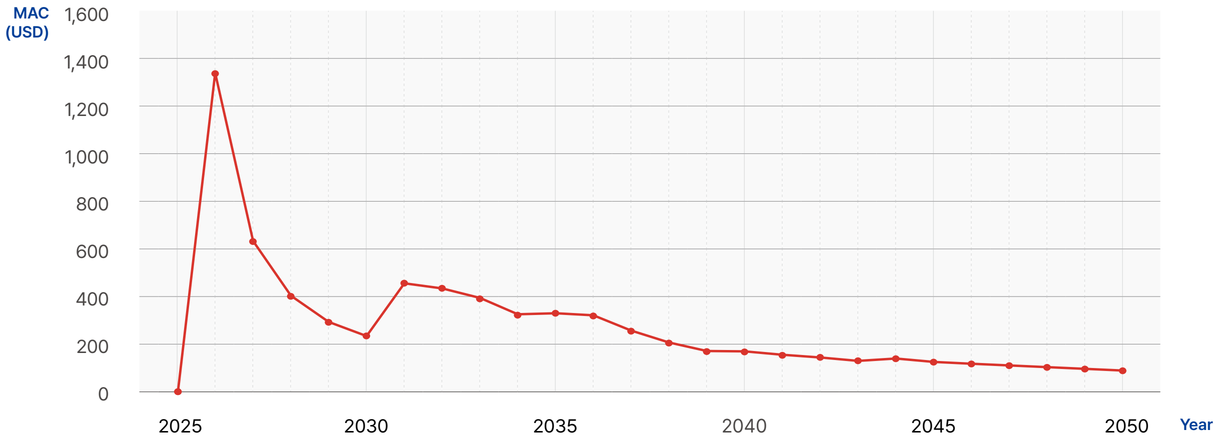


These results may appear to suggest that the costs required for reducing GHGs continue to rise, increasingly placing an economic burden on each region over time. However, the results indicate that the MAC, the cost of reducing an additional ton of GHG, continuously decreases after reaching a peak in 2026. The MAC is one of the key indicators that compares cost effectiveness between GHG reduction options. An examination of the MAC trajectories by region until 2050 shows that all three regions of Yeosu, Ulsan, and Daesan are projected to experience overall reduction of MAC starting from 2026 as presented in **[Figure 9, 10, 11]**. This trend indicates that, as the transition progresses, the GHG reductions increase compared to the costs for facility deployment, leading to a continuous declining cost of reducing one additional ton of GHG emissions.

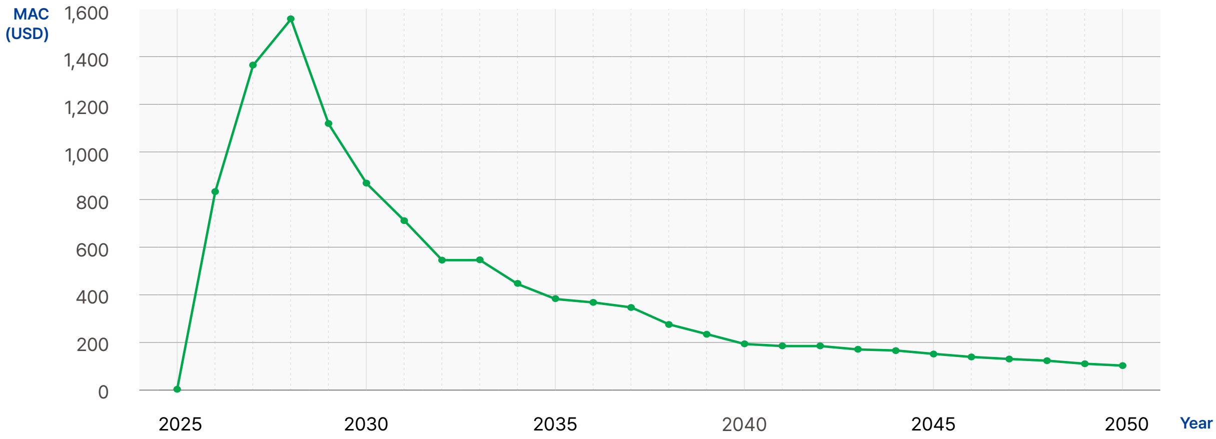
[Figure 9] **Marginal Abatement Cost (MAC) Trajectory for Yeosu, 2025-2050**



[Figure 10] **Marginal Abatement Cost (MAC) Trajectory for Ulsan, 2025-2050**



[Figure 11] Marginal Abatement Cost (MAC) Trajectory for Daesan, 2025-2050



In other words, considering the cost trajectory of reducing one additional ton of GHGs, climate response costs may increase in the early stages due to upfront capital investments, but shows a continuous downward trend over time.

c. Need for Renewable Energy Infrastructure to Achieve Carbon Neutrality in Regional Petrochemical Complexes

In addition, this study analyzes total energy demand required in the decarbonization transition for each regional petrochemical complex. The results identify the need to proactively build renewable energy-based power infrastructures to support the transition toward carbon neutrality in regional petrochemical complexes.

The projected range of electricity demand for each scenario is presented in **[Table 5]**. As a result of analysis, among the major petrochemical clusters, Yeosu, having the largest share of NCC capacity, exhibits the highest electricity demand under the NCC electrification scenario. If current production levels are maintained, the Yeosu complex is expected to require up to 62.50 TWh of electricity per year in 2050. In contrast, if a 25% reduction in production capacity (facility capacity reduction) is achieved, the maximum electricity demand under NCC electrification is projected to reach approximately 37.5 TWh per year in 2050, indicating a distinct decrease in electricity demand.

[Table 5] Transition Scenario and Estimated Range of Renewable Electricity Demand (TWh), 2025–2050

Transition Technologies	Production Level Scenario	Yeosu	Ulsan	Daesan	Others
NCC Electrification	Maintaining Current Production Outlook (Including the Shaheen Project)	15.28 - 62.50	13.26 - 52.74	9.75 - 48.01	0.48 -0.91
	25% production reduction compared to current level	15.28 - 37.5	12.12 - 24.42	9.75 - 28.85	0.48 - 0.55
	40% production reduction compared to current level	15.28 - 32.61	12.12 - 21.21	9.75 - 25.05	0.48
NCC Hydrogen	Maintaining Current Production Outlook (Including the Shaheen Project)	15.28 - 21.28	13.26 - 20.00	9.75 - 14.82	0.48 -0.91
	25% production reduction compared to current level	12.79 -15.28	10.73 - 12.12	8.90 - 9.75	0.48 - 0.55
	40% production reduction compared to current level	11.10-15.28	9.32 - 12.12	7.73 - 9.75	0.48

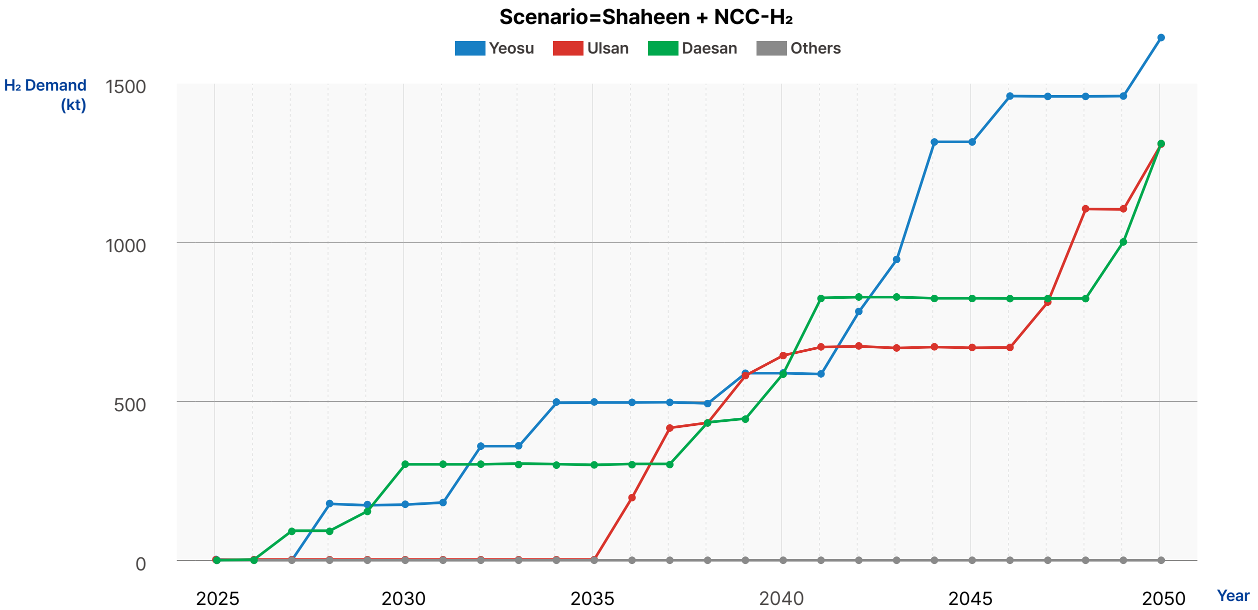
The Ulsan and Daesan complexes display similar patterns. With a focus on the transition technology of NCC electrification, under a scenario where current production level is maintained and total output is increased due to commercial operation of the Shaheen Project in 2026, the electricity demand in Ulsan is estimated to reach up to 52.74 TWh per year in 2050. On the other hand, under a 25% production reduction scenario, the electricity demand in Ulsan declines to a maximum of 24.42 TWh per year.

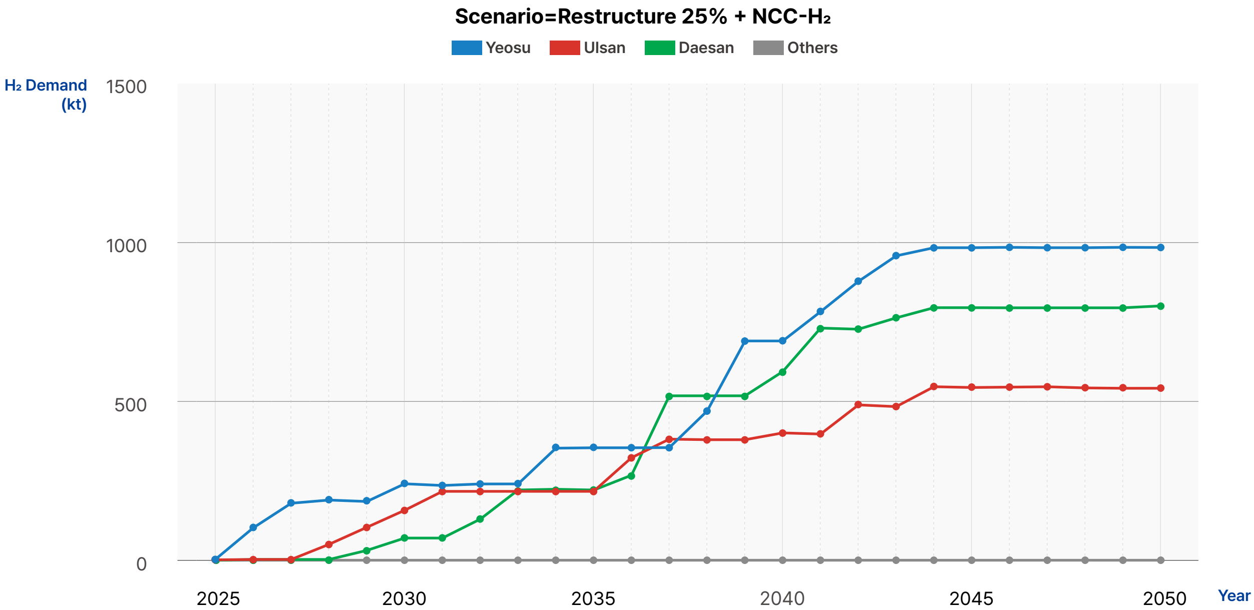
As for Daesan, electricity demand reaches a maximum of 48.01 TWh per year in 2050 when production levels are maintained. With a 25% reduction in production capacity, up to 28.85 TWh per year of renewable electricity is required under NCC electrification. Similar to Yeosu, this indicates that reduction of facility capacity can significantly reduce electricity demand.

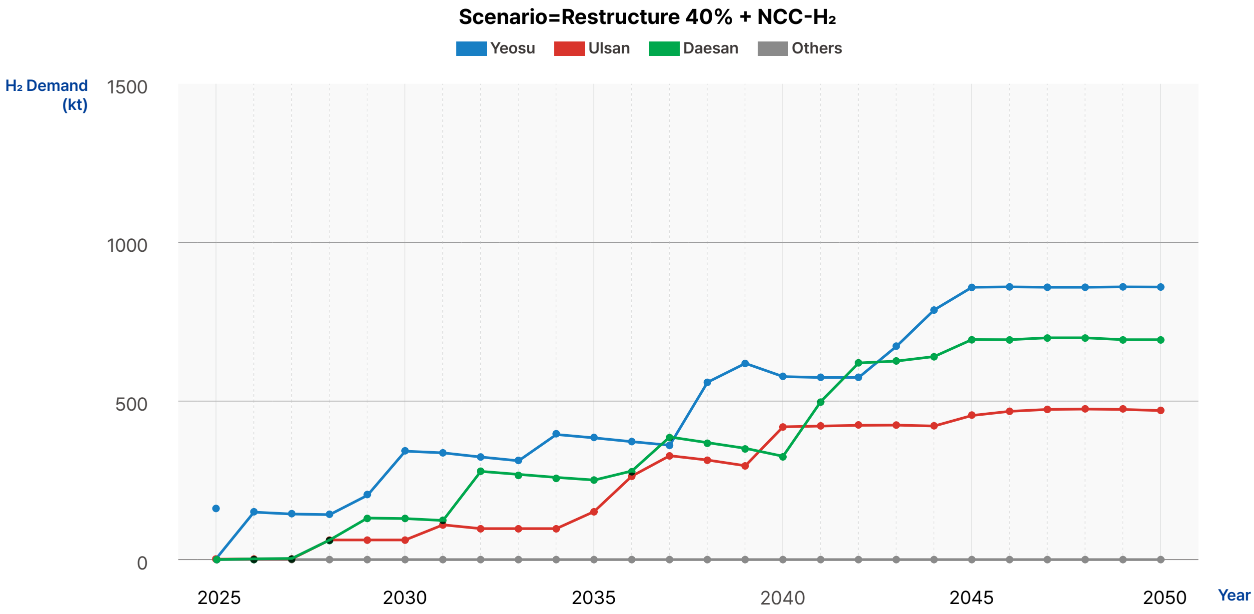
Meanwhile, for all NCC green hydrogen scenarios presented in this study, the electricity demand excludes the electricity directly used for NCC fuel substitution with hydrogen, and considers electricity used for other facilities and processes required additionally in the transition of processes (e.g. heat pumps, BTX low-carbon technologies for high-temperature processes).

Looking at the hydrogen demand required for NCC hydrogen, when a 25% production reduction is achieved, hydrogen demand is expected to reach a maximum of 989.1 kt in Yeosu, 546.8 kt in Ulsan, and 796.5 kt in Daesan. These figures exhibit a substantial reduction in hydrogen demand in all regions, compared to estimated hydrogen demands (1,646.1 kt in Yeosu, 1,307.5 kt in Ulsan, and 1,325.6 kt in Daesan) under a scenario where current production level is maintained due to a failure of restructuring **[Figure 12]**.

[Figure 12] **Transition Scenario and Estimated Hydrogen Demand by Region 2025-2050**







d. Key Findings

As a result of analysis on GHG reduction pathways by region, the study indicates that carbon neutrality by 2050 is both technically and quantitatively achievable across Korea's major petrochemical industrial complexes in Yeosu, Ulsan, and Daesan.

At the same time, the most central task in the process of introducing transition technologies such as NCC electrification is to secure policy support at both the national and local government levels to facilitate demonstration and commercialization of transition technologies as well as financial investment to back such policies. The total regional GHG abatement costs estimated in this study may provide an indicative benchmark for the scale of financial investment required for each region.

Finally, given the analysis results of the energy demand presented in this study, the expansion of regional renewable electricity infrastructure and supply capacity is an indispensable action for achieving carbon neutrality in the petrochemical sector.

6. Conclusions and Policy Recommendations

a. Need for Bold Investment to Accelerate Demonstration and Commercialization of NCC Electrification Technology

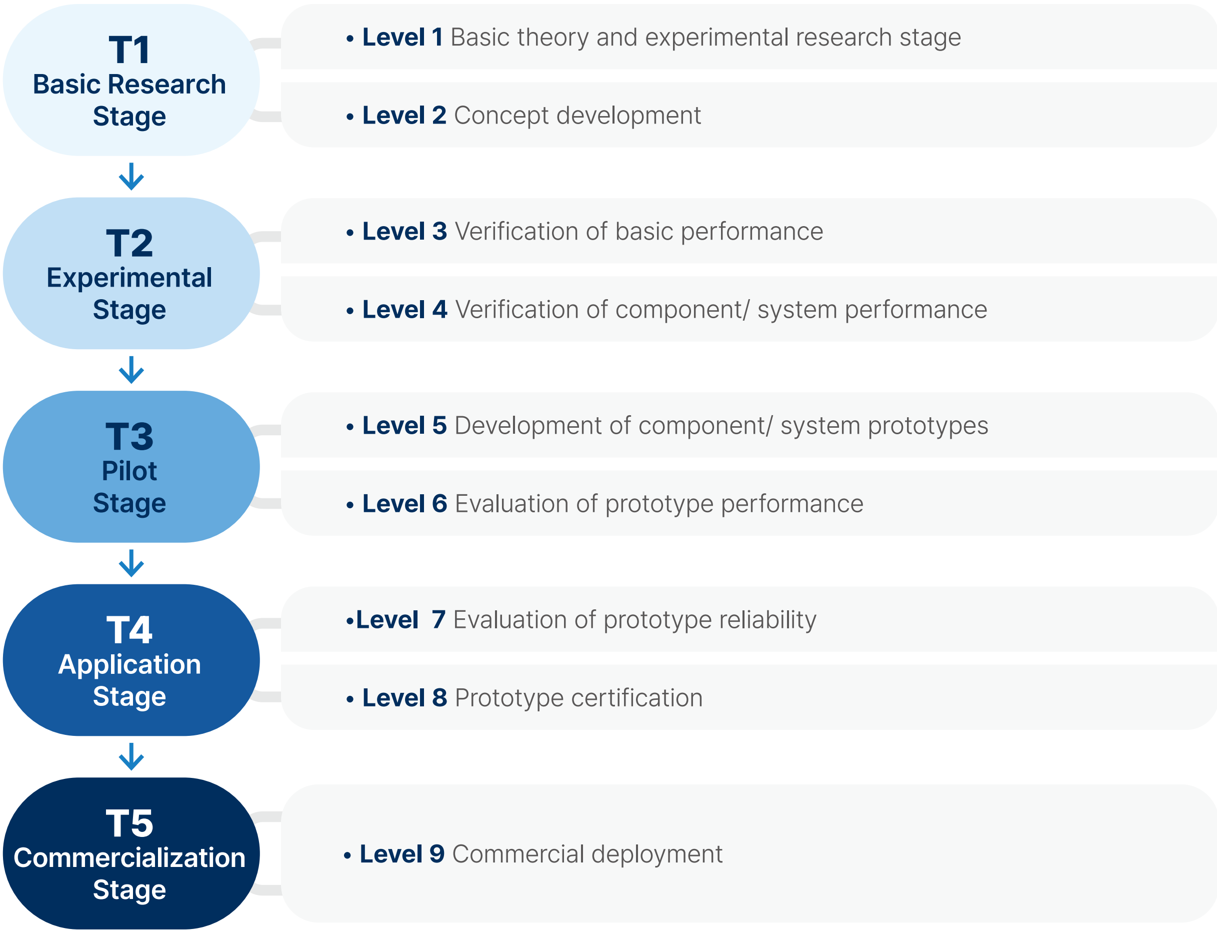
As demonstrated above, achieving carbon neutrality in the petrochemical industry is feasible, with NCC electrification identified as a core enabling technology. However, even under cost-effective decarbonization pathways, substantial costs are required to achieve carbon neutrality. A key finding of this study is that the MAC, the cost of reducing an additional ton of GHG emissions, declines steadily as the transition progresses. This indicates that with the progress of transition, GHG emissions reductions will increase compared to the costs invested for facility deployment. Therefore, to achieve carbon neutrality, preemptive investment is required in introducing core carbon neutral technologies at early stages because such upfront investment leads to lower MACs. To create an environment where companies make such a bold investment, the government should provide proper supports for the industry's decarbonization efforts.

Meanwhile, the commercialization of transition technologies such as NCC electrification cannot be achieved overtime; it is achieved through a multi-stage process, encompassing technology development, test run, demonstration, and eventual deployment at individual production facilities. In this process, Technology Readiness Level (TRL) is widely used to assess the maturity and readiness to deploy such technologies.

At present, a government project targeting the pilot stage of NCC electric cracking furnace technologies is underway; however, no field demonstration projects have been implemented to date, suggesting that the technology remains at the experimental stage. For the application of such technologies to commercial plants, further efforts should be made to advance to pilot and demonstration stages (TRL 5-6). Generally, pilot plant operation falls under TRL 5-6, which constitutes a critical intermediate phase to validate technical and economic feasibility prior to full-fledged commercialization **[Figure 13]**.

As for the overseas cases, the joint NCC electric steam cracking furnace project by BASF, SABIC, and Linde was initiated through signing of the joint development and demonstration agreement in 2021 and have already reached TRL 5-6 by completing a demonstration plant in 2024. Given that domestic TRL level for the same technologies remains only at the R&D stage, such divergence between domestic and international TRL levels suggests that Korea's technology development relatively lags behind the international competitors.

[Figure 13] **Definition of Technology Readiness Level (TRL)**



Source: Reconstructed data from the National Balanced-Development Information System (NABIS) [16]

Based on international precedent of the BASF–SABIC–Linde joint NCC e-furnace project, it is expected that at least several additional years might be required for domestically-developed NCC e-furnace technologies to reach a commercialization stage[17]. The analytical model employed in this study assumes that NCC electrification technology becomes deployable

16 National Balanced-Development Information System (NABIS)

17 BASF (2024). Press release: "BASF, SABIC, and Linde Start up the demonstration plant of the world's first large-scale electrically heated steam cracking furnace"

from 2030 and is fully applied to facilities by 2040 at the latest. Against this backdrop, to accelerate the advancement of domestic NCC electrification technologies from current TRL to a commercialization and actual operation stages, it is essential to secure proactive investment of petrochemical companies and the government's systematic plans and sustained policy supports.

i. Need for a National Medium- to Long-Term Strategy

While this study concludes that NCC electrification is a core technology for achieving carbon neutrality in the petrochemical sector, NCC electrification is not achieved through mere technology development. It requires the structural transformation that involves multiple implementation steps including process transformation, equipment replacement, and expansion of renewable energy infrastructure. Given these characteristics, there should be a comprehensive strategy at the national level that encompasses support for rapid demonstration and commercialization of transition technologies, development of related infrastructure, and creation of favorable investment environment.

In specific, there should be expanded financial and policy supports for NCC electrification pilot projects to facilitate the decarbonization, development of infrastructures and institutional frameworks to secure sufficient renewable electricity at the commercialization stage, and the government's medium- to long-term strategies to provide comprehensive supports.

Although the investment in core transition technology may not yield immediate and visible reductions in the short term, preemptive investment and supports at this point of time constitutes an indispensable precondition for achieving the long-term goal of carbon neutrality by 2050.

ii. Inclusion of NCC Electrification under "Core Strategic Petrochemical Technologies" and "High Value-Added Transition" in the Enforcement Decree of the Special Act for the Petrochemical Industry

Both government and industry stakeholders recognize the need for decarbonization in the petrochemical sector, and discussions are continuous underway to enhance the industrial competitiveness and develop effective decarbonization strategies. Against this backdrop, the Plenary Session of the National Assembly passed the *Special Act on Enhancing and Supporting the Competitiveness of the Petrochemical Industry* (hereafter, the "Special Act for the Petrochemical Industry") in December 2025. According to the Act, "core strategic petrochemical technologies" are to be specified in the Enforcement Decree of the said Act as necessary technologies for high value-added transition and GHG emissions reduction in the petrochemical industry. The Act will also specify that the government is able to provide support for R&D and policy finance for "core strategic petrochemical technologies (Article 11). Furthermore, "high value-added transition" will be defined in the Enforcement Decree as business innovation activity with high scarcity, profitability, and environmental performance while the government can develop tax incentives (Article 5), fiscal support (Article 6), and regulatory exemptions (Article 7) for "high value-added transition."

This report identifies through the analyses that introducing NCC electric cracking furnace using renewable energy as fuel is a cost-effective, technically and practically feasible core decarbonization technology for the petrochemical sector. Accordingly, NCC electrification should be explicitly included within the scope of both "core strategic petrochemical technologies" and "high value-added transition" to be specified under the Enforcement Decree. Also, beyond regulatory measures, substantive support measures should be in place for demonstration and commercialization of the NCC electrification.

iii. Need for Supporting NCC Electrification Demonstration through the Climate Response Fund

Demonstration of NCC electrification using renewable electricity would enable domestic petrochemical industry to narrow the technological gap with global leaders and lay the important foundation for securing competitiveness in future low-carbon markets. To this end, preemptive investment is needed in demonstration of NCC electrified cracking processes using the renewable energy-based electricity. However, since launching a pilot project requires large investment, it might be difficult to shoulder such investment burden with the financial capacity of individual petrochemical firms. In this respect, overseas countries with high dependency on the manufacturing sector such as Germany and Japan operate the fund at the government level to support the decarbonization efforts of the industry. As for Korea, it also needs to leverage its Climate Response Fund to support industrial decarbonization.

However, when looking at the 2025 government budget, no standalone budget line was identified within the Climate Response Fund, the main financial resource for Korea's industrial decarbonization, which was specifically allocated for NCC electrification demonstration projects. It is found that only a minimal portion of the "Core Carbon-Neutral Industrial Technology Development" program has been injected to research on electrified hydrocarbon cracker in the petrochemical sector.

Meanwhile, as paid allocation of emission permits has expanded under the 4th National Allocation Plan for Korea's Emissions Trading System (K-ETS), it is expected that the scale of Climate Response Fund will increase accordingly, which is mainly financed by the revenues from selling emission permits. In addition, in line with the implementation of the Special Act for the Petrochemical Industry, budgetary support for key emissions reduction technologies will be in place in the sector.

Against this backdrop, the 2027 Climate Response Fund budget needs to significantly increase support for demonstration of electrifying NCC thermal cracking processes using renewable electricity. As for the steel sector, another high-emitting industry together with the petrochemical sector, has promoted the "Korean Hydrogen Reduction Steelmaking Technology Demonstration Program" with a total project cost of KRW 814.6 billion (KRW 308.8 billion in government fund), which passed preliminary feasibility assessment in June 2025. As such, the petrochemical industry should actively consider promoting government-supported programs for NCC electrification demonstration, given the electrification is the central decarbonization technology in this sector.

iv. Need for Region-Specific Measures Tailored to Major Petrochemical Complexes

Meanwhile, the petrochemical industry is geographically concentrated, resulting in high industrial dependence on regional economies. Furthermore, as lifespan of facilities and conditions of renewable energy infrastructure vary from region to region, measures should be developed by reflecting different regional conditions. In particular, to effectively commercialize transition technologies such as NCC electrification in each region, sustained support will be essential for securing sufficient renewable energy infrastructure in medium to long term.

Appendix 1. Common Assumptions and Technology-Specific Assumptions for Scenarios

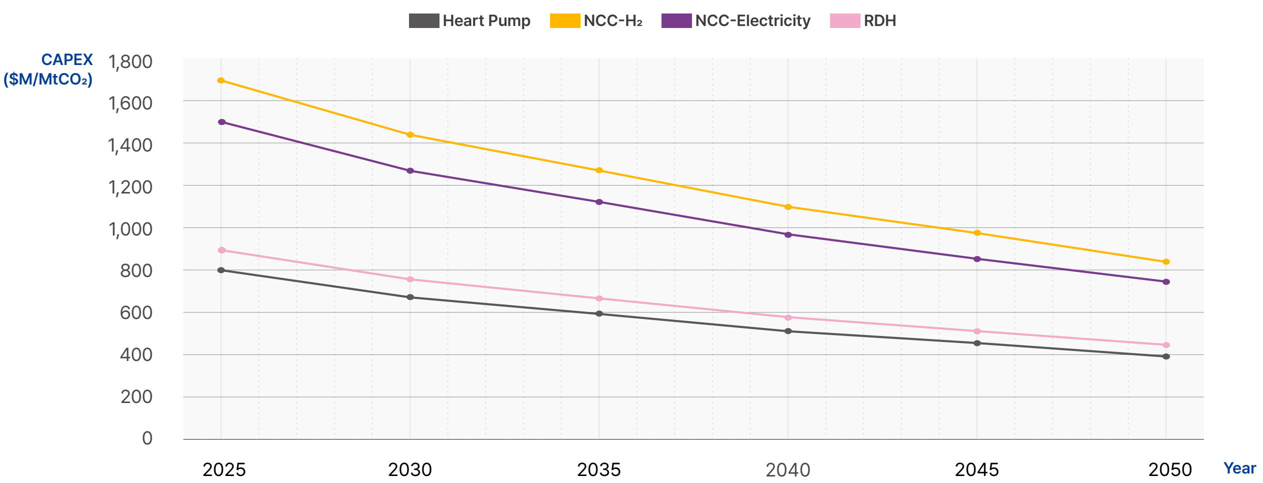
1 Common Assumptions

All scenarios are modelled under the assumption that the operating rate of facilities is fixed at 70% through 2050. Under this assumption, the baseline GHG emissions of the model in this study are determined at 46.34 $MtCO_2$ per year. For each scenario and technology, the abatement cost per ton of CO_2 (USD/tCO_2) is calculated by dividing total annual costs (capital expenditure (CAPEX), operating expenditure (OPEX), and fuel costs) by the corresponding annual emissions reductions [Formula 1]. All transition technologies examined in this study are assumed to reflect a 50% learning curve by 2050. The estimated changes in technology-specific CAPEX to 2050 are presented in Table 14. Annual OPEX for each technology is fixed at 4% of CAPEX. Based on these assumptions, the study applies a Dynamic Marginal Abatement Cost Curve (MACC) framework by year to estimate average abatement costs per ton of CO_2 and analyzes projected abatement costs across scenarios and NCC transition technologies.

[Formula 1] Formula for calculating marginal abatement costs (MAC) of this model

$$MAC = \frac{CAPEX_{annual} + OPEX_{annual} + Fuel\ Cost_{annual}}{Abatement\ (CO_2t)}$$

[Figure 14] Technology CAPEX Learning Curves



2 Technology-Specific Assumptions

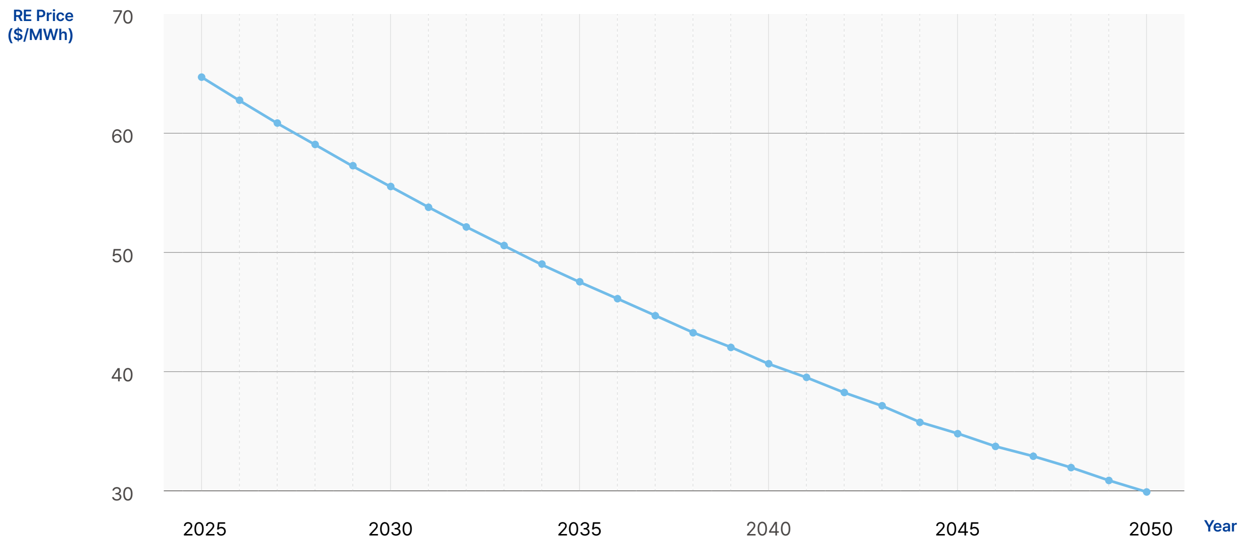
a. NCC Electrification Using Renewable Electricity

In the NCC electrification technology assessed in this study, the essential part is to transition from conventional fossil fuel–based combustion furnaces to to electrically heated furnaces powered by renewable electricity. Conventional NCC fuel combustion results in approximately 1.74 tCO_2 emissions per ton of ethylene produced. On the other hand, when electrification is applied using renewable electricity, direct CO_2 emissions from the corresponding processes are reduced to zero. Accordingly, an abatement effect of 1.74 tCO_2 per ton of ethylene is expected.

This transition holds great significance in that it replaces fossil fuels used for NCC with a zero-carbon energy source, rather than merely switching to lower-carbon fuels. In particular, given that NCCs are widely recognized as the **most carbon-intensive facilities within petrochemical processes**, application of this technology is expected to play a **central role in the decarbonization of the Korean petrochemical industry**.

This study assumes that total electricity supply is met through renewable energy-based electricity through RE-PPA (Renewable Energy Power Purchase Agreements), an electricity purchase agreement under which renewable energy generators and electricity consumers make prior agreements on contract periods and prices. Through the RE-PPA, companies have the advantage of being able to secure renewable electricity required for NCC electrification in a stable manner for the long term. RE-PPA is calculated under the assumption that the renewable electricity price will decline by approximately 54% from USD 65/MWh in 2025 to USD 30/MWh by 2050 [Figure 15]. In addition, assuming that grid power will be converted to 100% renewable electricity by 2050, the grid power can be considered to replace RE-PPA afterwards. It is also specified that the costs for transitioning to NCC electrification may vary depending on actual PPA prices.

[Figure 15] **Renewable electricity PPA price projections used in the model**



Source: IRENA 2024, IEA WEO 2024

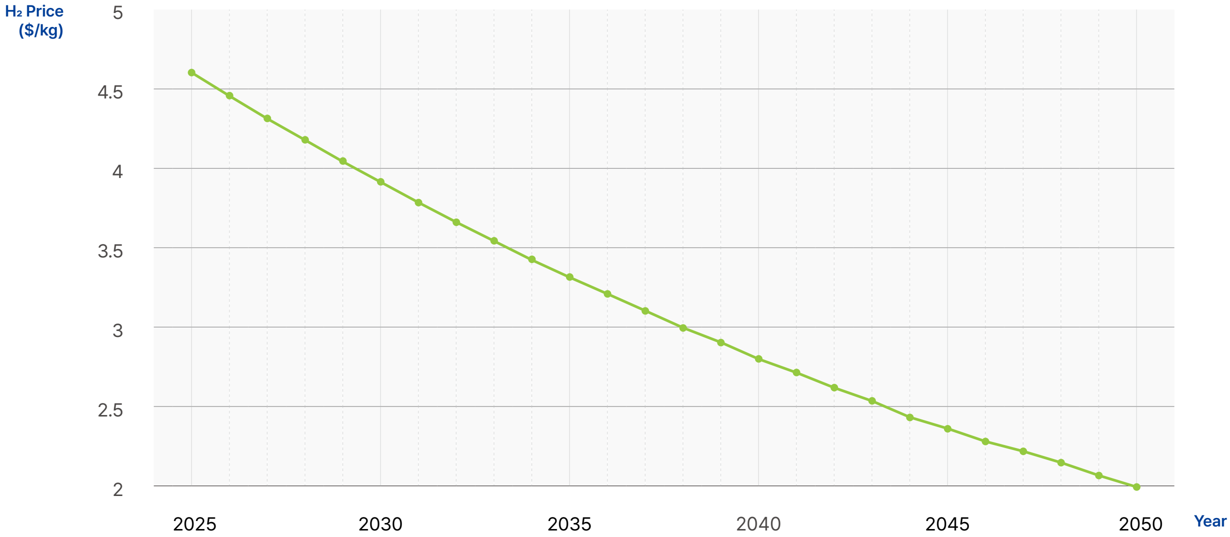
This study further assumes that naphtha feedstock input remains the same (105 GJ/ton), with only the fuel used in the cracking furnace replaced by renewable electricity. Electricity demand in this process is estimated at 5.0 MWh/t-C_2H_4 based on the one ton of ethylene produced by referring to ongoing BASF project. Moreover, the energy conversion efficiency is set at 95% and the facility lifetime is set at 25 years. Taking technological viability, the NCC electrification technology using renewable electricity is assumed to be commercially available from 2030 onward.

b. NCC hydrogen using green hydrogen (Green Hydrogen Furnaces)

This study compared the NCC electrification with the technology using hydrogen as an NCC fuel, another key decarbonization technology. In this technology, producing a ton of ethylene requires approximately 0.2 t-H_2/t-C_2H_4 under the assumption that all hydrogen are green hydrogen. Considering similar technological development phases to the aforementioned e-furnace, commercialization of this technology is assumed to feasible from 2030 onward. The lifetime of a facility is set at 25 years, and the OPEX is fixed at 4% of CAPEX.

The price of green hydrogen used in this model, i.e. the Levelized Cost of Hydrogen (LCOH), is calculated by incorporating price projections for renewable energy (RE-PPA) into the LCOH formula. Furthermore, the model also reflects that with learning curves being taken into account, the efficiency of Electrolyzer CAPEX and Electrolyzer improves over time **[Figure 16]**.

[Figure 16] Green hydrogen price projections used in the model



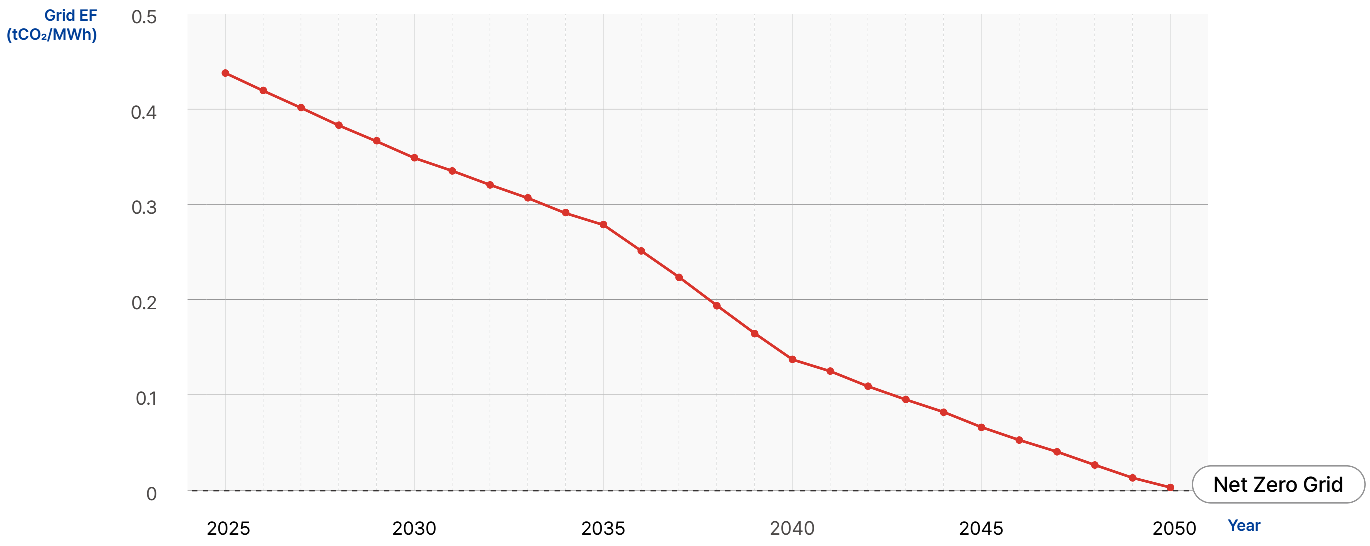
Source: IRENA 2024, IEA WEO 2024

c. Heat Pumps

In this study, heat pumps are utilized to meet the heat demand of low-temperature processes below 165°C, using grid electricity. Given heat pumps have already secured high technological maturity (TRL 9), it is assumed to deploy them immediately from 2025 to replace existing fossil fuel–based heat sources. This includes the premise that heat pumps can replace heat demands of not only low-temperature processes outside NCC facilities, but also low-temperature processes within the NCC processes. The COP of heat pumps is set at 4.0, which means that 1.0 MWh of electricity produces 4.0 MWh of heat. This model reflects the assumption for energy conversion efficiency at 95%, facility lifetime at 20 years, and OPEX at 3% of CAPEX[18]. Furthermore, the electricity required for operating heat pumps is based on price projections for grid power as presented in the 11th Basic Plan for Electricity Supply and Demand. However, until the Korean grid power is fully decarbonized in 2025, using grid power is expected to generate CO2 emissions at the level of **[Table 17]**.

18 Kosmadakis (2020)

[Figure 17] Projected Grid Electricity Emission Factors converging to net zero by 2050



d. Low-Carbon Technologies for High-Temperature BTX Processes

Major assumptions for RotoDynamic Heater (RDH), examined in this study as low-carbon transition technologies in the BTX processes. Accordingly, energy conversion efficiency is set at 93% while annual fixed OPEX is assumed to be 3% of annual CAPEX. While facility lifetime is set at 25 years, the electricity necessary for operating RDH, just as heat pumps, is assumed to use grid price projections in the 11th Basic Plan for Electricity Supply and Demand.

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SFOC

Solutions for Our Climate (SFOC) is an independent nonprofit organization that works to accelerate global greenhouse gas emissions reduction and energy transition. SFOC leverages research, litigation, community organizing, and strategic communications to deliver practical climate solutions and build movements for change.