Energy Partnership Program between

Vietnam and Denmark (DEPP3)

Demonstration audit PVCFC Fertilizer (Ca Mau)

xxx, 2025

Report:	**Demonstration audit PVCFC Fertilizer (Ca Mau)**
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Content

Sections in PVCFC Energy Audit Report

The overall objective of the assignment aim is to conduct an Energy Audit report with the following targets:

- Conduct energy audit and prepare an energy audit report with potential energy-saving solutions based on circular 25/2020/TT-BCT related to "Regulations on planning and reporting on the implementation of plan for economic and efficient energy use; perform energy audit". The audit covers overall information of Petrovietnam Camau Fertilizer Joint stock company regarding annual energy consumption data and costs, introduction to manufacturing process and production equipment, overall mapping of energy consumption and breakdown of energy usage, and assessment of energy efficiency potentials.
- Because over 95% of the energy consumption related to heating and cooling, intensive investigations of the cooling system, main heat exchangers, and waste heat sources are realized as suggested in PVCFC_Annex B - Work. Heat exchangers are grouped in terms of location and functions to reduce the number of heat exchangers involved while can still be representative for the specific heat exchanger network.
- Evaluating and developing the energy management system as required by Circular 25/2020/TT-BCT, the evaluation of energy management is just based on the Vietnam requirement of energy management system of SEU.
- Energy saving opportunities will be presented in two types of projects at Level A and B. During the energy audit process, many observations will be made which could have potential energy savings through a large screening list can be created. This list of observation could be referred to as level B projects, where the potential energy savings and investment are evaluated based on estimates if possible. The screening list of level B opportunities should be evaluated and should be selected for further development. These projects will be called level A projects and should be developed enough for making a decision of whether to carry out a pre-feasibility study.

Contents of audit report	Requirements
Chapter 1: Summary	
Summary of results from audit	Overall annual energy consumption data and costs should be presented A table with identified energy efficiency projects, related savings and investments and payback-period. The identified energy efficiency projects shall be given priority and should be ranked in terms of importance Proposed further steps should be described
Chapter 2: Introduction	
Introduction to the energy audit	Overall company information Break down of company structure and production modes Definition of scope and success criteria for the energy audit

<table>
<tr><th colspan="2">Chapter 3: Affairs of the company</th></tr>
<tr><td>Overall history of the company, their products and operating data</td><td>Annual production outputs

Overall annual energy consumption (3 years)

Overall assessment of focus areas for energy audit and necessary competences and specialists to involve

PVCFC consumes approx. 500 mills. m3 natural gas per year, counted for 95% of the total energy consumption. The high consumption of natural gas is caused by the fact that the gas partly (65%) used as raw material for fertilizer production, partly (35%) used as fuel to heat the processes at the facility. So that the heating and cooling process will be the main focus of the audit.

Based on Annex B – Agreed work plan PVCFC, the focus of demonstration audit is:
– Rehabilitation of cooling water systems
– Utilization of waste heat and delta-T-hunting</td></tr>
<tr><th colspan="2">Chapter 4: Description of procedures in technology processes</th></tr>
<tr><td>Introduction to manufacturing process and production equipment</td><td>Principle diagrams for significant energy users

Flow diagrams for production flow and energy usage:
– Ammonia plant
– Urea plant
– NPK plant
– Utility (including water cooling system, steam system, compressed air system …)</td></tr>
<tr><th colspan="2">Chapter 5: Energy demands and supply capacity</th></tr>
<tr><td>Mapping of energy consumption and breakdown of energy usage</td><td>Equipment lists, significant energy users

Breakdown of energy usage by end-use:
– Mapping of processes and heat exchangers
– Mapping of cooling exchangers
– Identification related to potencial of heat recovery and re-structuring of cooling water system</td></tr>
<tr><th colspan="2">Chapter 6: Financial – technical obligations</th></tr>
<tr><td>Economic framework for energy efficient solutions</td><td>Energy prices and relevant taxation

Legal framework for energy efficiency</td></tr>
</table>

	Fuel and energy data
Chapter 7: Energy-saving solutions	
Assessment of energy efficiency potentials	Technical analysis of saving potentials via a variety of methodologies Level B projects: – Rehabilitation of cooling water systems: Direct use of cooling tower water for: Lean solution cooling, Ammonia condenser, Synt. Gas compressor intercooler, E04510A/B, E04303, E04306 – Apply coils sprayed local cooling towers for certain process – Optimization of E21201H-T heat exchanger – Use of VSDs control for pumps and fans – Establishment of a biomass auxillary boiler (approx. 40 MW) to replace a natural gas fired boiler operated today – Establishment of CCS-systems on reformers Proposed Level A projects: – Rehabilitation of cooling water systems: Direct use of cooling tower water for: Lean solution cooling, Ammonia condenser, Synt. Gas compressor intercooler, E04510A/B, E04303, E04306 – Apply coils sprayed local cooling towers for certain process Technical and financial assessment of relevant investment projects Overview of non-energy benefits

Table1: Checklist of requirements for energy audits

1 Summary

The PVCFC fertilizer plant was established in the period 2008-2011 with a first launch of commercial products early 2012. The fertilizer plant is designed with use of modern, western technology:

- The ammonia unit has been licensed from Haldor Topsoe, Denmark
- The urea unit has been delivered by Saipem, Italy
- The granulation unit has been delivered by Tec (Toyo), Japan
- The NPK unit has been delivered by Espindesa, Spain

Next to these main suppliers, equipment from international suppliers such as Siemens, Alfa Laval and BASF are applied for several purposes.

As such, PVCFC fertilizer is operated close to international best practices with an energy consumption and productivity among the top 10% best fertilizers plants worldwide.

1.1 Annual energy consumption and costs

1.1.1 Annual production outputs

- Urea product is the main product, accounting for the largest proportion in the production model of Ca Mau Fertilizer Plant.
- NPK products were put into production by the Plant from April 2021.
- NH3 product is an intermediate product to create other products of the Company.

Product data statistics for the period 2021 - 2023 are presented in the following table:

Table 1.1 Product data for the period 2021 – 2023

Product	2021	2022	2023
NH3	508,537	520.29	541,517
Urea	894,385	917,782	949.13
NPK	48,132	114,331	150,092

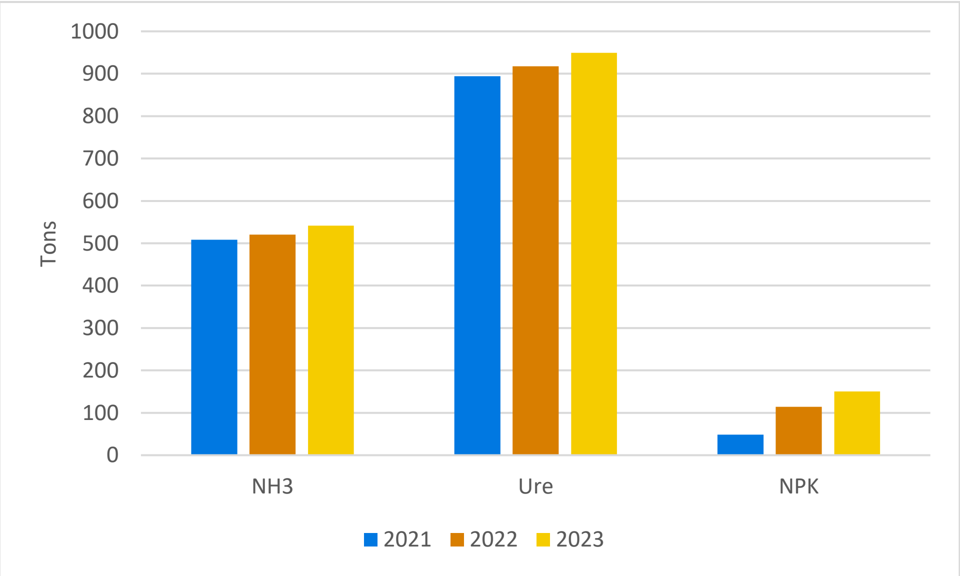


Figure 1.1. Product output chart for the period 2021 - 2023

1.1.2 Annual energy usage

Based on the energy consumption database provided by the Plant, statistics on energy and water consumption data for the period 2021 - 2023 are presented in the table below:

Table1.2. Energy and water consumption statistics for the period 2021 - 2023

No	Energy and water	Unit	Total consumption		
			2021	2022	2023
1	Electricity	kWh	174,510,354	166,734,110	170,122,888
2	Natural gas	GJ	19,849,137	20,078,263	20,750,348
3	Permeate Gas	GJ	450,209	455,043	520,325
4	Water	m³	1,124,436	1,147,821	1,195,548

From the aggregated data and the energy conversion factor regulations (presented specifically in section 6.2), the energy consumption in TOE units (To compare different energy types with different units, the energy types will be converted to a standard unit of TOE - tons of oil equivalent) is shown in the following table:

Table1.3. Energy consumption converted to TOE units in the period 2021 - 2023

No	Energy	Conversion factor	TOE Unit Conversion		
			2021	2022	2023
1	Electricity	0.1543 TOE/MWh	26,927	25,727	26,249
2	Natural gas	0.026 TOE/GJ	527,783	512,084	529,225
Total			533,541	538,189	554,710

Energy consumption chart converted to TOE units:

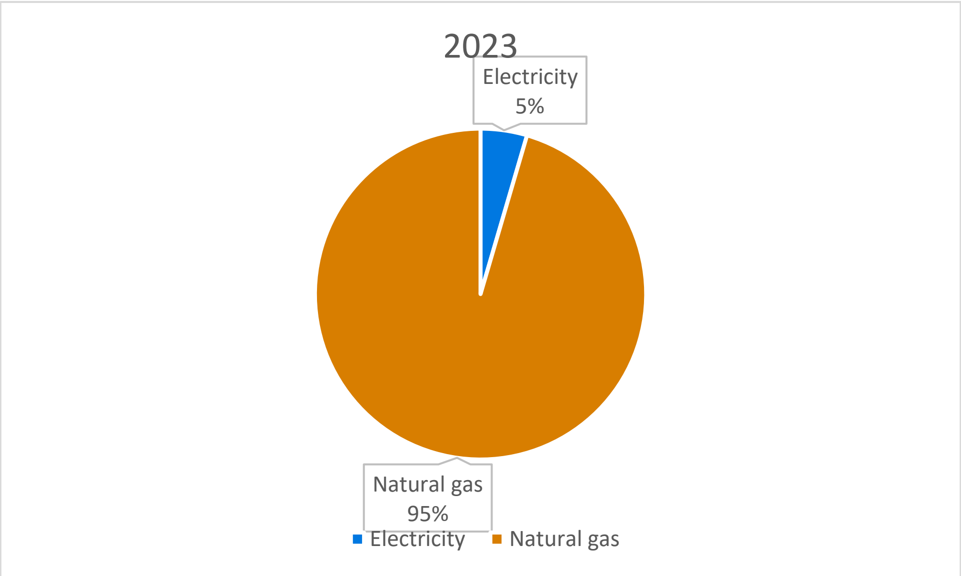


Figure 1.2. Energy chart converted to TOE units for the period 2021 - 2023

The high consumption of natural gas (approximately 500 million m³ per year) is due to the fact that the gas is partly (65%) used as a raw material for fertilizer production and partly (35%) used as fuel to heat processes at the facility.

Of the 35% of natural gas used for heating purposes mainly for reforming reaction, its distribution across various sections is illustrated in the figure below.

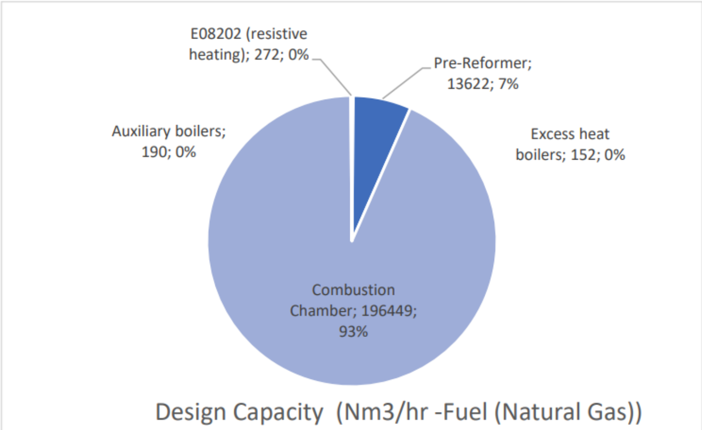


Figure 1.3. Fuel natural gas usage

The "combustion chambers" are the secondary reform steps in the ammonia plant.

1.1.3 Annual energy cost

Total energy consumption costs for the period 2021 - 2023 are calculated as follows:

Table1.4Total energy costs for the period 2021 – 2023

No	Energy	Total energy costs (million VND)		
		2021	2022	2023
1	Electricity	301,749	296,952	312,077
2	Natural gas	2,949,505	3,479,453	4,443,377
3	Water	11,453	11,679	12,171
Total		**3,262,707**	**3,788,084**	**4,767,625**

The chart of the percentage of energy costs in the period 2021 - 2023 is shown in the following figure.

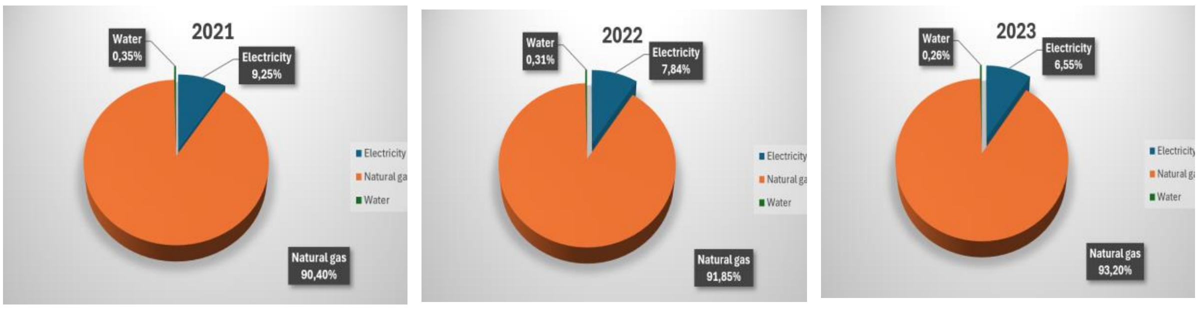


Figure 1.4. Cost ratio of energy types in the period 2021 - 2023

Natural gas costs account for a large proportion of the energy and water cost structure with over 90%, electricity accounts for second with about 7%, and the rest is water with a small proportion.

In the period 2021 - 2023, the energy cost ratio will change slightly depending on the demand and unit price. That partly shows the stability in the management of the Plant's consumption rate, thereby clearly showing the effectiveness of the policies on energy and raw materials that have been issued and applied.

The average energy cost rate is determined based on consumption data and energy cost statistics provided by the Plant.

Table 1.5 Average price list for the period 2021 - 2023

Energy and water	Unit	Average price by stage		
		2021	2022	2023
Electricity	VND/kWh	1,729.1	1,781.0	1,834.4
Natural gas	VND/GJ	148,596.2	173,294.5	214,135.0
Water	VND/m³	10,185.5	10,175.2	10,180.5

1.1.4 Specific energy consumption

Below the specific energy consumption for PVCFC is shown.

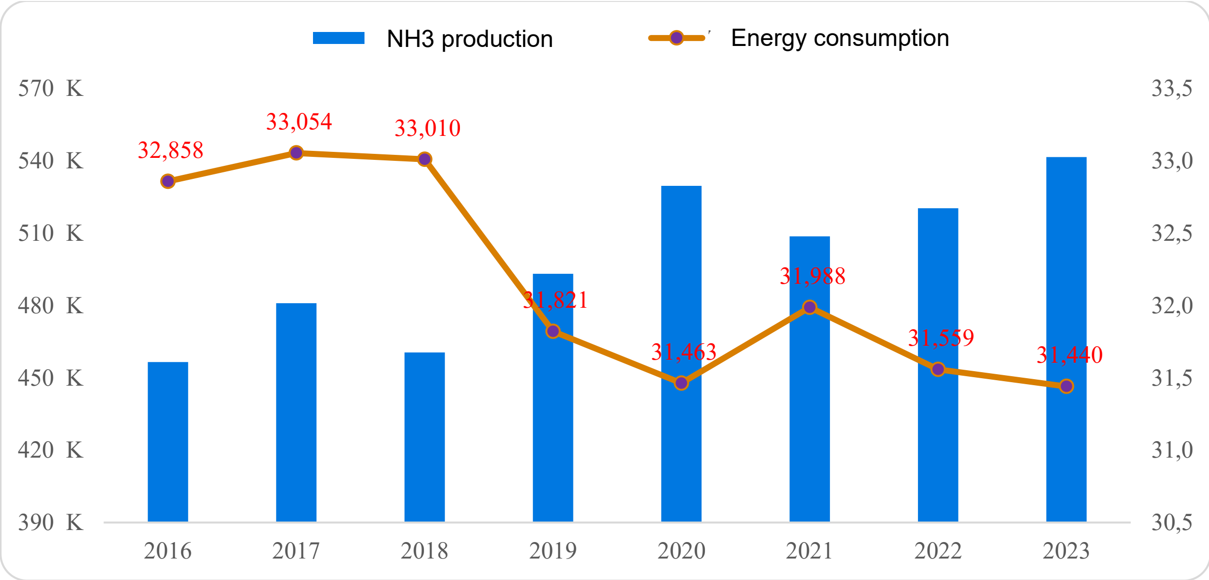


Figure 1.5. Specific Energy consumption of NH3 production per year (GJ/T.NH3)

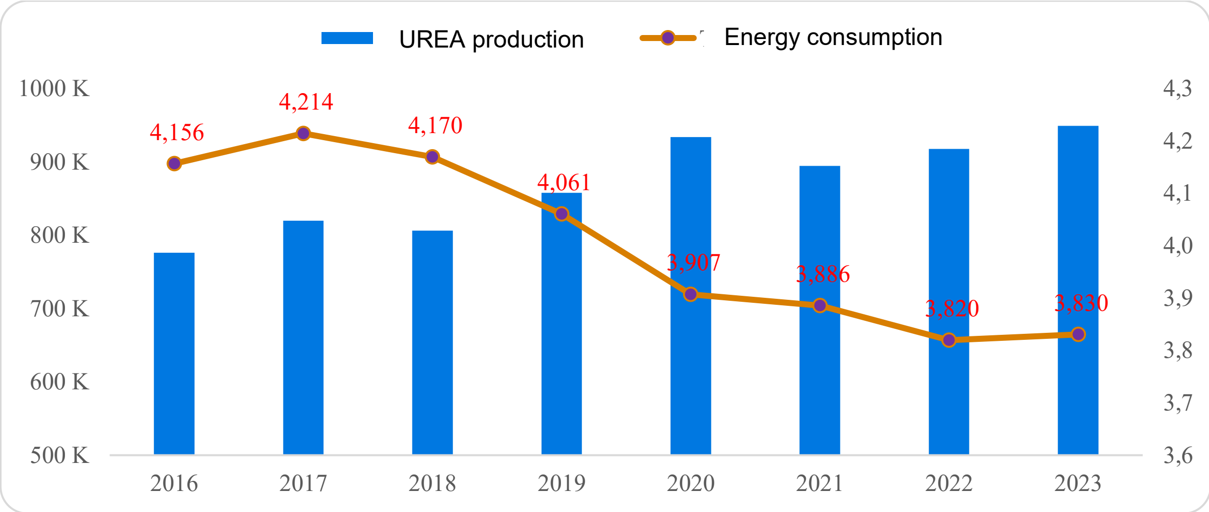


Figure 1.6. Specific energy consumption of Urea production per year (GJ/T.Urea)

For the ammonia part of the facility, the specific energy consumption is 31.4 GJ/ton, which with recent optimization projects at the facility is currently reduced to 30.6 GJ/ton and PVCFC aim at further reductions via recent upgrade-projects proposed by Haldor Topsøe.

1.2 Recommended energy efficiency projects

Table1.6: Energy saving potential and investment cost estimates (level A projects)

No.	Project	Saving			Investment budget (USD)	Simple payback (year)
		Energy (GJ/year)	CO2 (ton/year)	Financial (USD/year)		
1	Optimization of Plate Heat exchangers E21201H-T	9,811	550	98,112	150,000	1.5
2	Replacement of Ammonia Refrigeration Condenser by Evaporative Condenser	38,806	2,134	388,000	300,000	0.77
3	Increase E04503 capacity to reduce energy loss at E04504	131,400	7,227	1,314,000	2,000,000	1.52
4	Direct use of cooling tower water for intercooler of compressors	49,055	2,750	490,560	500,000	1.02

Details of level B and level A projects referred to section 7.

1.3 Further steps

Pre-feasibility and considerations studies for projects report in table 1.6 need to be elaborated in order to prepare the company management for Final Investment Decisions (FID).

2 Introduction

2.1 Overall company information

Company name	:	Petrovietnam Ca Mau Fertilizer Joint Stock Company
Address	:	Lot D, Industrial Park Ward 1, Ngo Quyen Street, Ward 1, Ca Mau City. Phone: 0290.3819000 Fax: 0290.3590501
Year of establishment	:	March 24, 2011
General Director	:	Mr. Van Tien Thanh
Type of ownership	:	Joint Stock Company
Main products	:	Nitrogen fertilizers, complex fertilizers, organic fertilizers, microbial fertilizers and nitrogen compounds for agricultural production.
Number of working days	:	365 days/year

2.2 Company structure

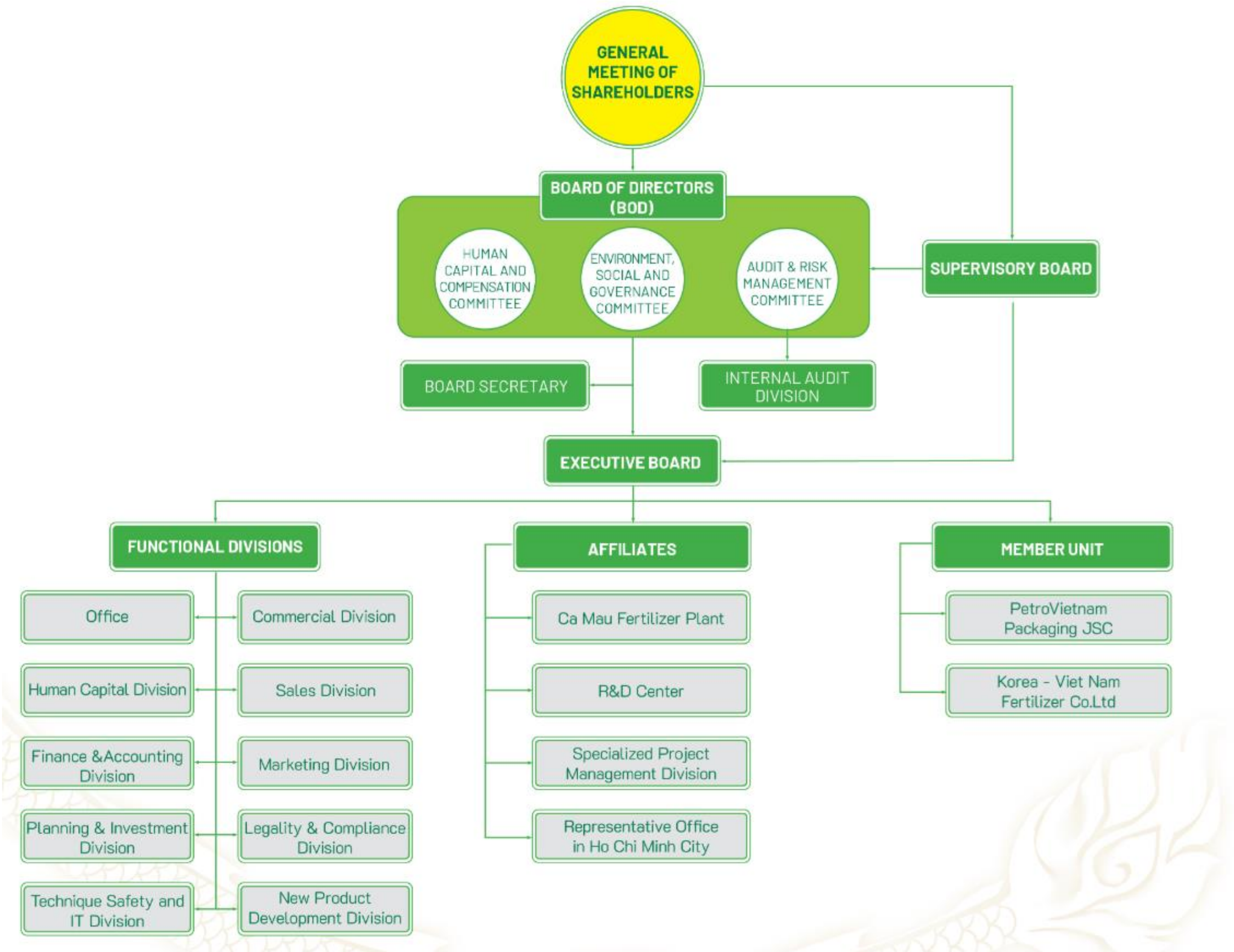


Figure 2.1. Organizational chart of the Company

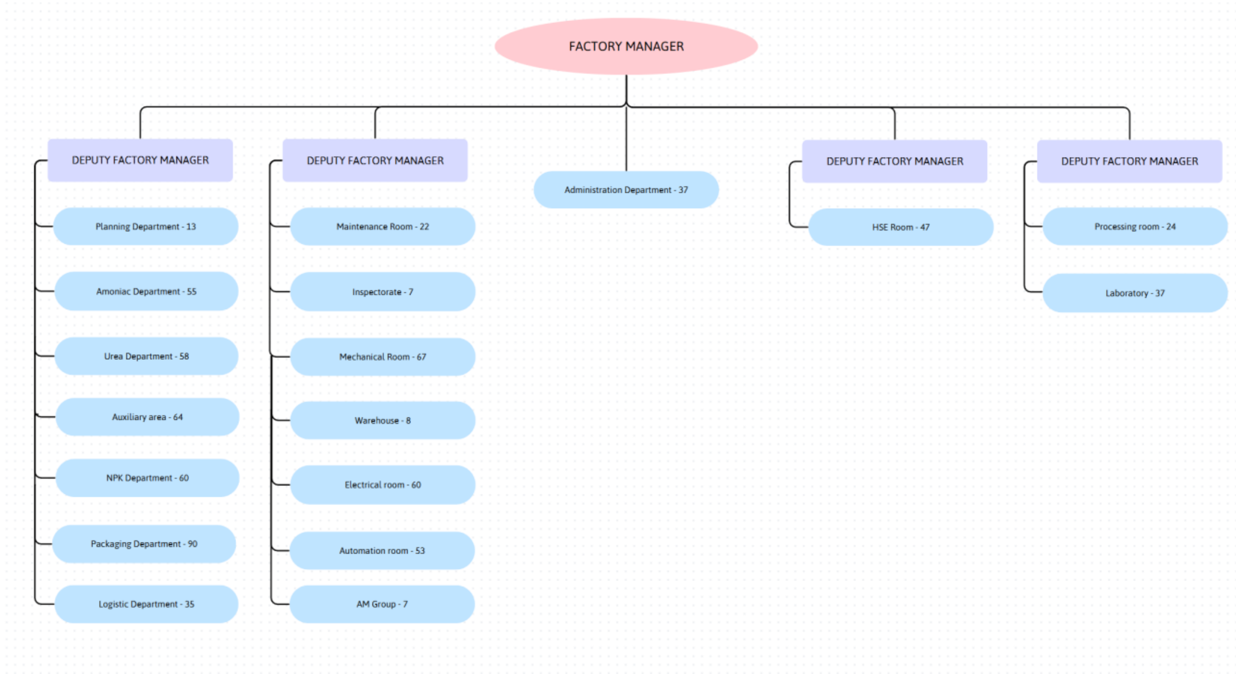


Figure 2.2. Organizational chart of the Plant

2.3 Production modes

Specific statistics on working hours of some areas are shown in detail in the following table:

Table2.1. Summary table of operating hours of some energy-using areas

No	Area	Time of operation average (hours/year)
1	Office area	2,560
2	Auxiliary Workshop	8,760
3	Ammonia Workshop	8,760
4	Product Workshop	8,760
5	NPK Workshop	8,760

The operating mode of the equipment systems depends on the working time in each area, specifically:

- The system of compressors, pumps, fans and auxiliary equipment for production operates 24 hours/day;
- Air conditioning systems operate at different times depending on the area. Equipment serving production needs operates 24 hours a day, while office equipment operates an average of 8 hours a day.
- Office systems and equipment operate 8 hours/day during business hours.
- Production lines are designed to perform different production stages. The production line system is mainly automatic and semi-automatic lines. Workers play the role of operating, supervising, handling incidents during the production process and loading and unloading output products. In the production area, energy consumption accounts for the majority of the total energy consumption of the entire Plant. The operation of machinery and equipment is carried out according to the equipment management process issued by Ca Mau Fertilizer Plant.

The functional structure diagram of Ca Mau Nitrogenous Fertilizer Plant is shown in the following figure:

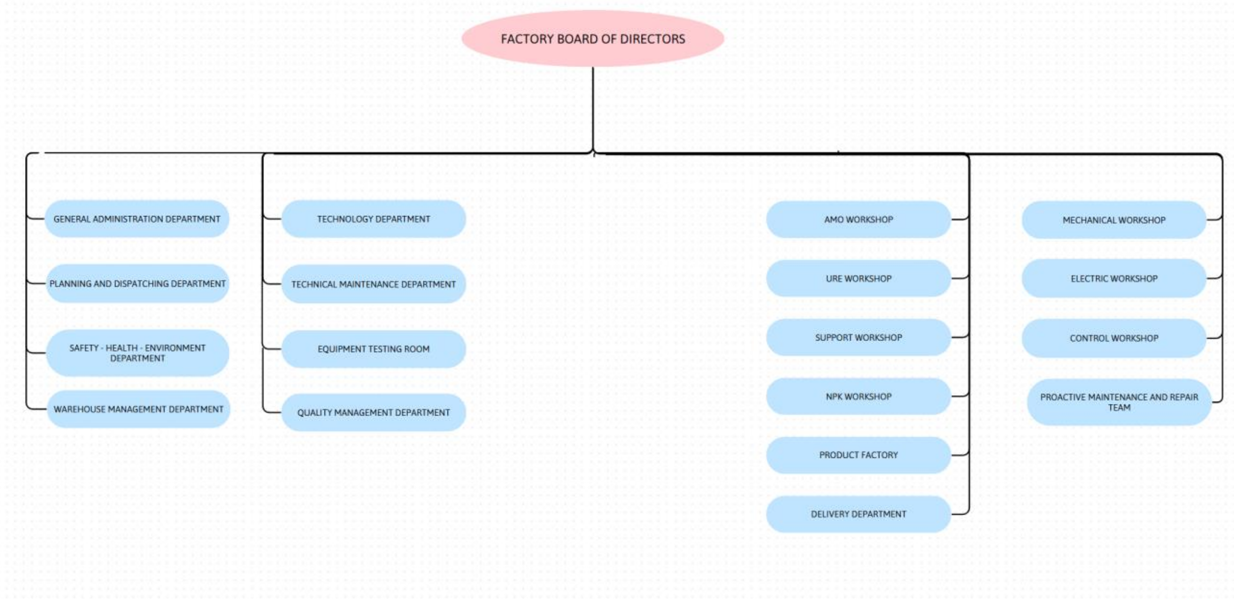


Figure 2.3. Functional structure diagram of the Plant

2.3.1 Overall objectives of the Assignment

The overall objective of the assignment aim is to conduct an Energy Audit report with the following targets:

- Conduct energy audit and prepare an energy audit report with potential energy-saving solutions based on circular 25/2020/TT-BCT related to “Regulations on planning and reporting on the implementation of plan for economic and efficient energy use; perform energy audit”. The audit covers overall information of Petrovietnam Camau Fertilizer Joint stock company regarding annual energy consumption data and costs, introduction to manufacturing process and production equipment, overall mapping of energy consumption and breakdown of energy usage, and assessment of energy efficiency potentials.

- Because over 95% of the energy consumption related to heating and cooling, intensive investigations of the cooling system, main heat exchangers, and waste heat sources are realized as suggested in PVCFC_Annex B - Work. Heat exchangers are grouped in terms of location and functions to reduce the number of heat exchangers involved while can still be representative for the specific heat exchanger network.

- Evaluating and developing the energy management system as required by Circular 25/2020/TT-BCT, the evaluation of energy management is just based on the Vietnam requirement of energy management system of SEU.

- Energy saving opportunities will be presented in two types of projects at Level A and B. During the energy audit process, many observations will be made which could have potential energy savings through a large screening list can be created. This list of observation could be referred to as level B projects, where the potential energy savings and investment are evaluated based on estimates if possible. The screening list of level B opportunities should be evaluated and should be selected for further development. These projects will be called level A projects and should be developed enough for making a decision of whether to carry out a pre-feasibility study.

2.3.2 Scope of the assignment

The scope of cooperative activities is limited to:

- Petrovietnam Camau Fertilizer Joint Stock Company

  Office address: Lot D, Industrial Zone Ward 1, Ngo Quyen, Ward 1, Ca Mau City

  Plant address: Khanh An, U Minh District, Ca Mau City

- Conduct energy audit complying with the referred to MOIT energy audit guideline and Energy Mapping User guide from DEPP3 project.
- Working with Denmark Experts to carry out the Energy Audit Report with the Energy Mapping according to guideline, evaluating and developing the energy management systemand project development at levels A and B.

3 Affairs of the company

3.1 Overall history of the company

Established in 2011, Ca Mau Petroleum Fertilizer Joint Stock Company (PVCFC, Hose: DCM) is proud to be the leading and only manufacturer of granular Urea fertilizer in Vietnam. As of 2023, Ca Mau Fertilizer's products are present in about 18 countries around the world, with export output in 2023 reaching 344 thousand tons, accounting for about 26% of total consumption output, export value reaching 136 million USD, accounting for about 25% of fertilizer product revenue. Of which, Cambodia is the largest export market with output and export value accounting for more than 60%.

Figure 3.1. Company Image

With clear orientation and goals, the brand Ca Mau Fertilizer - Golden Season Pearl has gradually affirmed its position in Vietnam and the region, contributing significantly to stabilizing the fertilizer market and ensuring national food security. The Plant is committed to continuing to invest in research and development, gradually launching new product lines in an environmentally friendly direction for a more sustainable and prosperous Vietnamese agriculture.

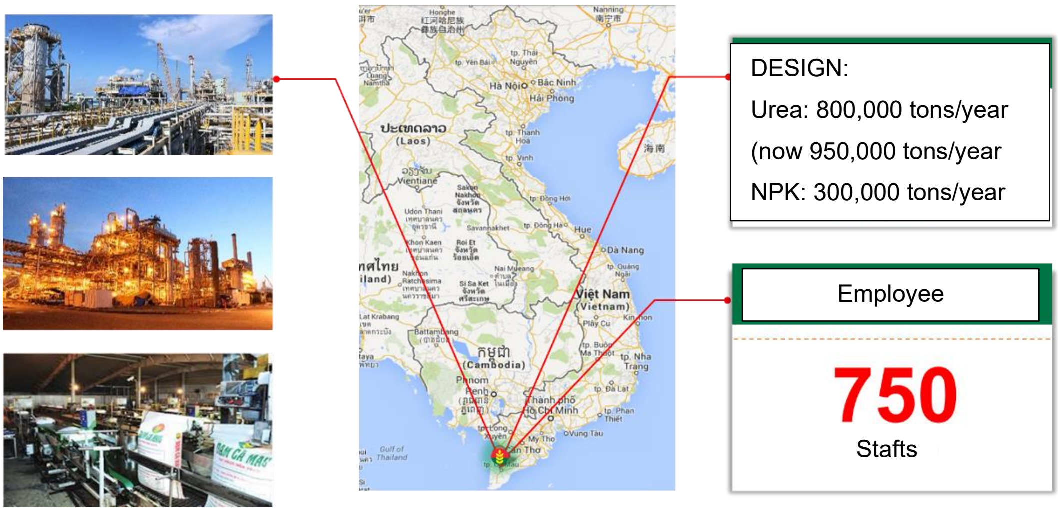


Figure 3.2. Overview of Ca Mau Fertilizer Plant

Throughout 13 years of formation and development, the Company has gone through the following important milestones:

- **2008:**Ca Mau Fertilizer Plant officially started construction with a total initial capital of more than 900 million USD, designed capacity of 800,000 tons/year.
- **2011:**March 9, 2011, Established Ca Mau Petroleum Fertilizer Company Limited (under Vietnam National Oil and Gas Group).
- **2012:**Ca Mau Fertilizer Plant has its first commercial product. On April 24, 2012, the plant was completed and handed over to Vietnam Oil and Gas Group/PetroVietnam Ca Mau Fertilizer Company Limited (PVCFC) for commercial operation.
- **2014:**PVCFC is officially recognized as a National Brand.
- **2023:**On December 7, 2023, Ca Mau Fertilizer reached the milestone of 10 million tons of converted Urea.

Figure 3.3. Plant Milestones

3.2 Production outputs

3.2.1 Urea products

Urea product is the main product, accounting for the largest proportion in the production model of Ca Mau Fertilizer Plant.

Urea product data statistics for the period 2021 - 2023 are presented in the following table:

Table 3.1. Urea product data for the period 2021 - 2023

Month	Urea products		
	Unit:	Ton	
	2021	2022	2023
1	75,236	82,204	83,253
2	73,721	74,451	75,227
3	68,683	82,662	85,478
4	78,240	79,615	81,540
5	81,823	74,769	83,375
6	78,771	79,448	81,540
7	79,322	82,841	83,590
8	80,311	45,871	49,185
9	78,424	68,475	79,760
10	81,242	83,417	83,660
11	42,593	79,859	80,596
12	76,020	84,170	81,925
Total	**894,385**	**917,782**	**949,130**

Monthly Urea Product Output Chart ofThe Plant is shown in the figure below:

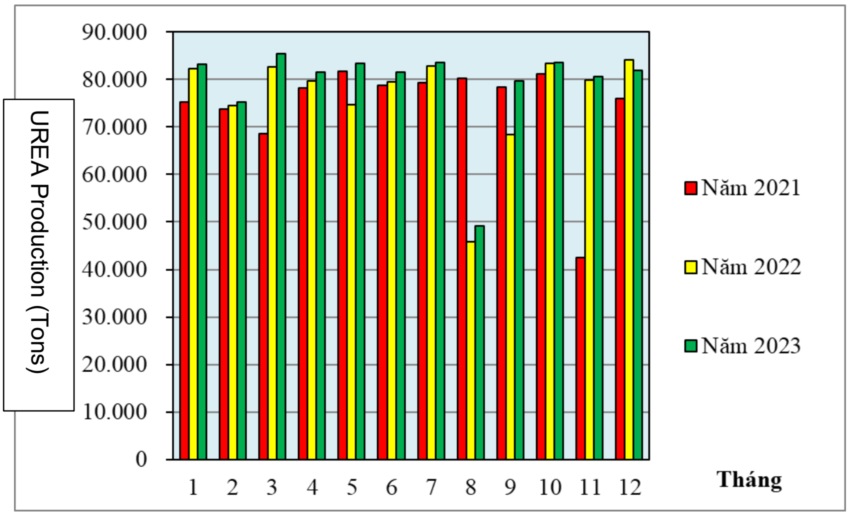


Figure 3.4. Urea production chart for the period 2021 - 2023

Urea products account for the largest proportion of the Plant's products. Due to the maintenance of the gas platform supplying the Ca Mau Gas, Power and Fertilizer Industrial Complex, production output was interrupted in certain months (November 2021 and August 2022, 2023). In general, Urea output always increased in the period 2021 - 2023. This shows the production efficiency and stable development of the Ca Mau Fertilizer Plant in recent times.

3.2.2 NPK products

NPK products have been put into production by the Plant since April 2021. Total NPK output over the years is shown in the following table:

Table 3.2NPK product data for the period 2021 - 2023

Year	2021	2022	2023
NPK output	48,132	114,331	150,092
Unit	Tons of NPK		

NPK products are one of the main products in the Company's diversified product chain. NPK output has not been stable over the years due to the new production line being put into operation, unstable technology, and insufficient raw material sources to meet production requirements. In addition, the NPK market is unique and fluctuates erratically, causing many difficulties in stabilizing the supply chain. However, NPK output tends to increase over the years, thereby showing the stable development in NPK production of the Plant.

3.2.3 NH3 product

NH3 product is an intermediate product to create other products of the Company. NH3 output produced in the period 2021 - 2023 is shown in the following table:

Table 3.3. NH3 product data for the period 2021 - 2023

Month	NH3 product		
	Unit:	Ton	
	2021	2022	2023
1	41,966	46,752	47,642
2	41,774	42,367	42,787
3	38,198	46,960	48,208
4	44,829	45,455	46,315
5	46,392	42,055	47,798
6	44,962	45,444	46,264
7	45,147	46,919	47,475
8	46,110	26,411	28,412
9	44,592	38,161	46,535
10	46,011	47,022	47,911
11	25,288	45,030	46,670
12	43,267	47,713	45,500
Total	**508,537**	**520,290**	**541,517**

The chart of NH3 product output over the months is shown in the figure below:

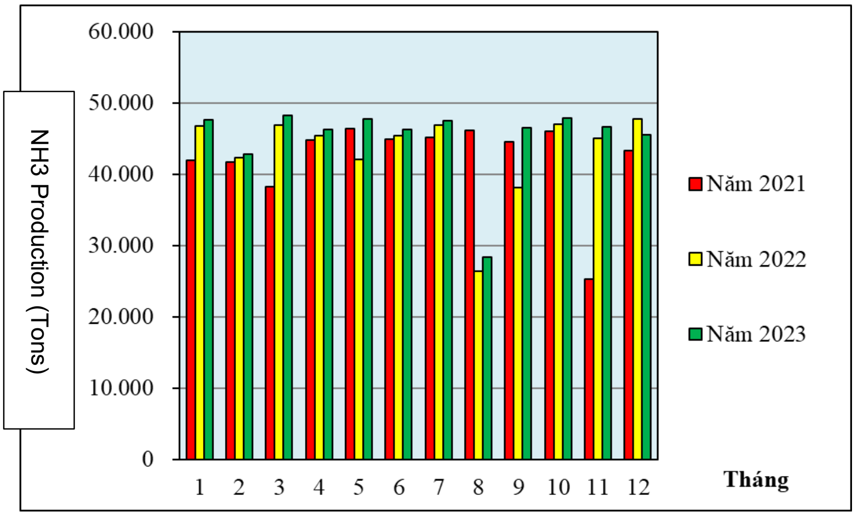


Figure 3.5. NH3 production chart for the period 2021 - 2023

NH3 product is an intermediate product for the production process of the Plant, playing an important role in the production of Urea and NPK. The NH3 production output of the Plant is maintained at a stable level and increased over the years.

Comparing production output over the months in the period 2021-2023, it can be seen that production output is always higher than the design load (100% load) and total output over the years always increases. Some months have low output due to the characteristics of the overall maintenance work of the Plant, which is carried out annually according to the periodic maintenance plan of the gas supply platform.

3.3 Energy consumption

Based on the energy consumption database provided by the Plant, statistics on energy and water consumption data for the period 2021 - 2023 are presented in the table below:

Table 3.4. Energy and water consumption statistics for the period 2021 - 2023

No	Energy and water	Unit	Total consumption		
			2021	2022	2023
1	Electricity	kWh	174,510,354	166,734,110	170,122,888
2	Natural gas	GJ	19,849,137	20,078,263	20,750,348
3	Permeate Gas	GJ	450.209	455,043	520,325
4	Water	m³	1,124,436	1,147,821	1,195,548

Table 3.5. Comparison of planned and actual energy production and consumption output in the period 2021 - 2023

Year		Output (thousand tons/year)		Electricity Consumption (kWh)	Gas Consumption (GJ)
		Urea	NPK		
2021	Plan	860	155	177,950,000	20,161,341
	Reality	894,385	48,132	174,510,354	19,849,137
2022	Plan	860	80	175,000,000	22,875,045
	Reality	917,782	114,331	166,734,110	20,078,263
2023	Plan	882	160	175,000,000	23,623,333
	Reality	949,130	150,092	170,122,888	20,750,348

Compared with the annual energy saving and efficient use plan that the Company reported on dataenergy.vn, it shows that the output of main products mostly exceeds the plan. Moreover, the actual energy consumption is lower than the plan. This shows the efficient and economical use of energy at PVCFC.

From the aggregated data and the energy conversion factor regulations (presented specifically in section 6.2), the energy consumption in TOE units (To compare different energy types with different units, the energy types will be converted to a standard unit of TOE - tons of oil equivalent) is shown in the following table:

Table 3.6. Energy consumption converted to TOE units in the period 2021 - 2023

No	Energy	Conversion factor	TOE Unit Conversion		
			2021	2022	2023
1	Electricity	0.1543 TOE/MWh	26,927	25,727	26,249
2	Natural gas	0.026 TOE/GJ	527,783	512,084	529,225
Total			533,541	538,189	533,541

Energy consumption chart converted to TOE units:

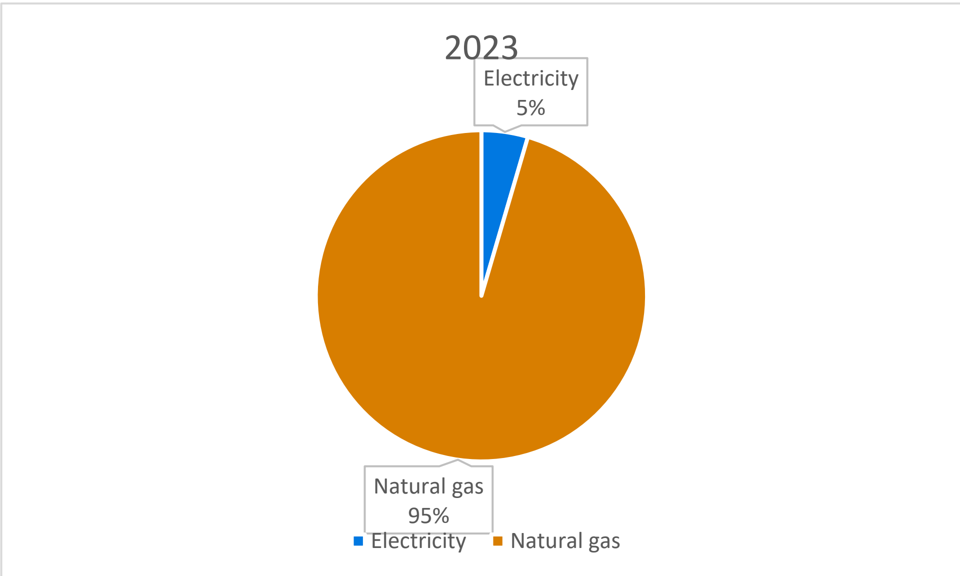


Figure 3.6. Energy chart converted to TOE units for the period 2021 - 2023

The proportion of energy sources used converted to TOE units has fluctuated little over the years, in which natural gas still accounts for the largest proportion of energy used, with more than 94% of the total converted energy; electricity accounts for the remainder.

To improve efficiency and reduce operating costs, the Plant may consider energy-saving solutions for the natural gas system and the electrical system.

Overall, the TOE conversion energy usage ratio chart shows the stability in the Plant's operations. This increases the sustainability and operational efficiency of the Plant.

3.4 Energy management status

The Energy Management Matrix has 6 columns and 5 rows. Each column represents one of the 6 aspects of energy management:

- Corporate Energy Policy
- Energy management organizational structure
- Incentive mechanisms to achieve higher energy efficiency
- Energy management information system
- Energy saving marketing
- Investing in energy conservation standards

The ascending rows (0 – 4) represent the level of acceptance of each energy management aspect (0 being the lowest and 4 being the highest). The cells are completed according to the opinions of the senior leaders of the enterprise.

Analyzing a company's energy management dashboard will reveal its strengths and weaknesses in energy management. The following are the criteria used to evaluate an energy management system:

1. Energy policy

Level	Energy policy	
4	Energy policy, action plan and regular review, with management commitment as part of strategy	
3	There is an energy policy, but no active commitment from top leadership	
2	Informal energy policies are established by the energy manager or senior managers of the departments.	x
1	An unwritten set of principles	
0	No clear policy	

2. Organization

Level	Organization	
4	Energy management is fully integrated into the management structure. Clear responsibility for energy consumption and energy costs is assigned.	
3	The energy manager is responsible to an energy management team representing all users, headed by a member of senior management.	
2	Contact with users is primarily through an ad-hoc committee, led by a senior department manager.	x
1	Informal communication between engineers and a few users	
0	No contact with user	

3. Motivation

Level	Motivation	
4	Formal and informal traditional channels are used regularly by energy managers and energy management staff at all levels.	
3	The energy management team is used as a main channel with direct contact with large energy consumers.	
2	Contact with users is primarily through an informal management team headed by the department's senior management.	x
1	Informal communication between engineers and a few users	
0	No contact with user	

4. Energy Management Information System

Level	Energy management information system	
4	Comprehensive system with targets, consumption monitoring, error identification, savings quantification and budgeting, tracking	x
3	Target monitoring reports are based on energy meters at each consumer, but savings are not communicated to consumers.	
2	Target monitoring reports are based on NL meters at source. Energy Costs are informally mentioned in the budget.	
1	NL costs are reported based on invoices only. Engineers prepare reports for internal use within the engineering department only.	
0	No information system. No energy consumption calculation.	

5. Marketing of energy conservation achievements

Level	Marketing of energy conservation achievements	
4	Marketing to effectively promote human resources and human resource management inside and outside the enterprise.	
3	Employee awareness programs and regular advertising campaigns	
2	There is some informal training on employee awareness.	x
1	Informal contacts to promote effective NL	
0	Not promoting NL effectively	

6.Invest in criteria for saving/improving energy efficiencyquantity

Level	Investment	
4	Actively raise environmental awareness with detailed investment due diligence programs for all new and improvement opportunities	x
3	Use the payback period criteria as for all other investments.	
2	Investing using only short-term payback period criteria	
1	Only low cost measures are used.	
0	No investment in improving energy efficiency	

Based on the results of interviews and investigations to evaluate the energy management system at the Plant, an assessment table of the current energy management system was developed, specifically as follows:

Table 3.7. Results of assessment of the current status of the energy management system

Level	Energy policy	Organization	Motivation	Information system	Marketing	Investment
4				x		x
3						
2	x		x		x	
1		x				
0						

Below is the matrix of results of the energy management system assessment survey:

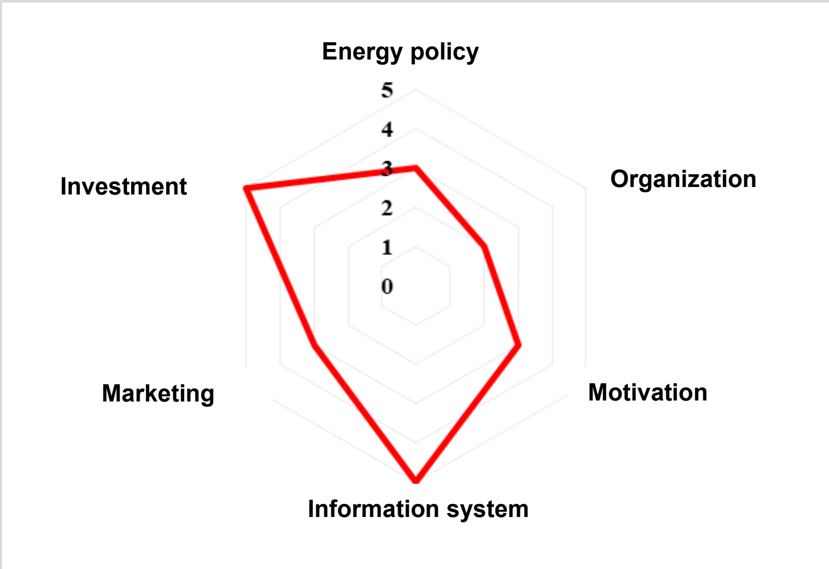


Figure 3.7.Chart of the survey to evaluate the quality management system

The energy management system of Ca Mau Fertilizer Plant is currently at an average level. At the end of 2023, the Company issued a decision to establish an energy management team and have an energy manager. However, due to the short time it was established, the energy management system still has many limitations and does not have specific policies and plans. Energy saving activities are currently localized, at a time when they have not been widely disseminated and synchronized throughout the Plant. This raises an urgent need to quickly put the energy management system into effective operation.

To overcome these challenges and improve efficiency in energy management, the auditor recommended that Ca Mau Fertilizer Plant should synchronize and accelerate the process of setting up plans, targets and risk assessment processes, as well as provide a framework for continuous assessment and improvement.

In addition, the auditor also recommended that Ca Mau Fertilizer Plant send its staff to attend awareness classes or training courses on energy efficiency and conservation in accordance with the law. Training staff on energy-saving methods and technologies will help increase awareness and the ability to implement energy-saving measures in the production process.

3.5 Overall assessment of focus areas for energy audit

PVCFC consumes approx. 500 mills. m3 natural gas per year, counted for 95% of the total energy consumption. The high consumption of natural gas is caused by the fact that the gas partly (65%) used as raw material for fertilizer production, partly (35%) used as fuel to heat the processes at the facility. So that the heating and cooling process will be the main focus of the audit.

During the site visit, a number of focus areas for further energy audit activities were identified and discussed with key-staff at the facility:

1. Rehabilitation of cooling systems
2. Use of VSDs to control the capacity of large fans and pumps
3. Increased power production with ORC
4. Rehabilitation of boiler feedwater preheating system
5. Delta-T-hunting and improved heat recovery
6. Assessment of potential for use of biomass, CO2-capture and green hydrogen
7. Rehabilitation of condensers in ammonia chiller system to improve COP
8. Optimization of compressed air systems operation
9. New KPIs to monitor operation of instrument air systems and cooling tower systems

After discussions, the following areas were concluded to be most important:

- Rehabilitation of cooling water systems
- Utilization of waste heat and delta-T-hunting

3.6 Competences and organization of the energy audit

Information about the energy audit unit

Company name	:	Bach Khoa Energy Conservation Joint Stock Company
Address	:	North: 27, lane 262B, Nguyen Trai, Thanh Xuan District, Hanoi. South: 156 Nam Ky Khoi Nghia, District 1, Ho Chi Minh City.
Year of establishment	:	2013
General Director	:	Mr. Bui Thanh Hung
Services provided	:	Energy audit, GHG inventory, energy manager training,…
Competency and experience	:	10 years of experience in the field of energy auditing, the team includes PhDs, Masters who are currently lecturers at Hanoi University of Science and Technology and engineers in energy management, thermal engineering and energy technology.

The energy audit program was conducted by Bach Khoa Energy conservation Joint Stock Company in collaboration with technical staff and production operation staff of Ca Mau Fertilizer plant.

Bach Khoa Energy Conservation Joint Stock Company

Full name	Position	Main mission
Do Manh Hung	- Team leader - Energy auditor - Energy saving expert	- General management - Project quality control - Build and calculate energy saving solutions - Write energy audit report
Ha Quang Thinh	- Project management - Coordinator	- Contact the Plant - Project progress control
Ho Huu Phung	- Energy auditor - Heat exchanger expert	- Data collection - Analyze collected data - Build and calculate energy saving solutions - Write energy audit report
Nguyen Ba Chien	- Energy auditor - Cooling system expert	- Analyze collected data - Write energy audit report - Field inspection and measurement
Vu Tien Dat	- Member	- Analyze collected data - Write energy audit report
Tran Quang Anh	- Member	- Analyze collected data - Write energy audit report
Vu Duc Anh	- Member	- Analyze collected data - Write energy audit report

Ca Mau Fertilizer Plant

Full name	**Position**	**Main mission**
Tran Ngoc Thanh	- Chief specialist in charge of Technology	- Project progress management - Support field inspection and measurement process - Provide relevant information for the energy audit process
Nguyen Tung Quan	- Technical Specialist	- Support field inspection and measurement process - Provide relevant information for the energy audit process

4 Description of procedures in technology processes

4.1 General production process

The product of Ca Mau Fertilizer Plant is Urea with a capacity of 2,385 T/day ~ 800,000 T/year.
The Plant's production process diagram is shown as follows:

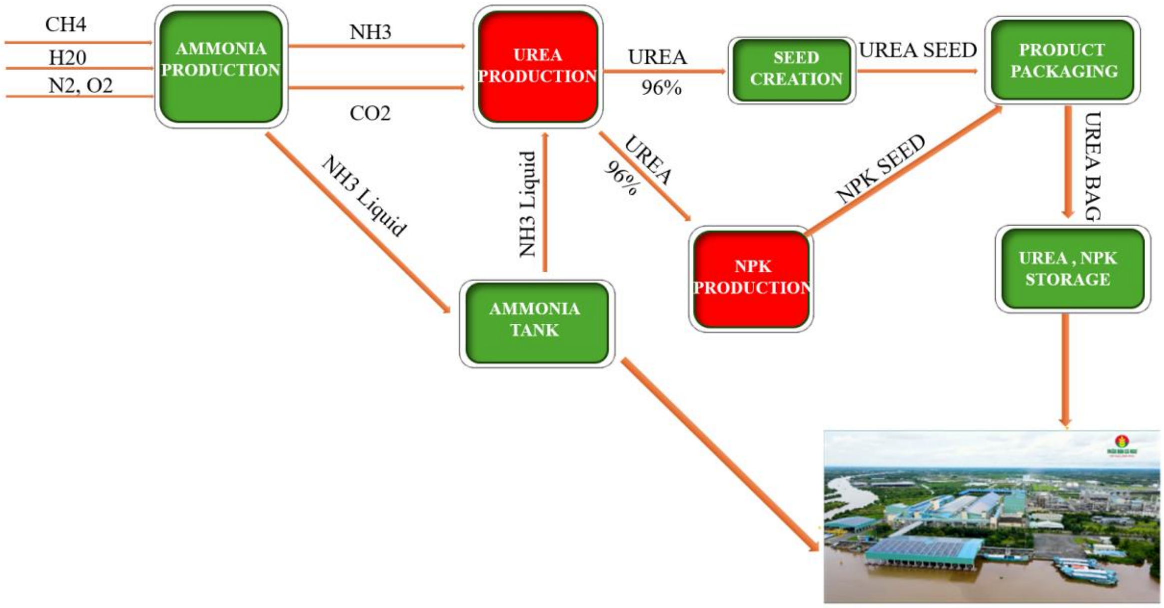


Figure 4.1.General production process of the Plant

The raw material source is natural gas exploited from mines in the overlapping sea area of Malaysia - Vietnam, brought to Khanh An Industrial Park, U Minh District, Ca Mau Province. Gas is transported by 18-inch diameter pipeline with a total length of 325km (undersea 298km, onshore 27km).

Natural gas after entering the Plant is used for the boiler of the Auxiliary workshop. The Auxiliary boiler produces high pressure steam, mixed with steam produced from the excess heat steam boiler to provide steam for consumers in the whole Plant.
In addition, natural gas is supplied to the Ammonia plant to be used as fuel in the primary Reforming furnace and as raw material to synthesize NH3 (the main raw material for Urea production).

4.2 Ammonia Production Plant

In the Plant, ammonia is produced from synthesis gas containing hydrogen and nitrogen in a ratio of approximately 3:1. In addition to the above compounds, the synthesis gas also contains a limited amount of inert gases such as argon and methane. The H2 supply is from demi-water and hydrocarbons in natural gas. The N2 supply is from air. In addition to ammonia, the plant also produces a quantity of CO2, the CO2 supply is from hydrocarbons in natural gas.

The operation of the Ammonia plant is briefly described in the figure below:

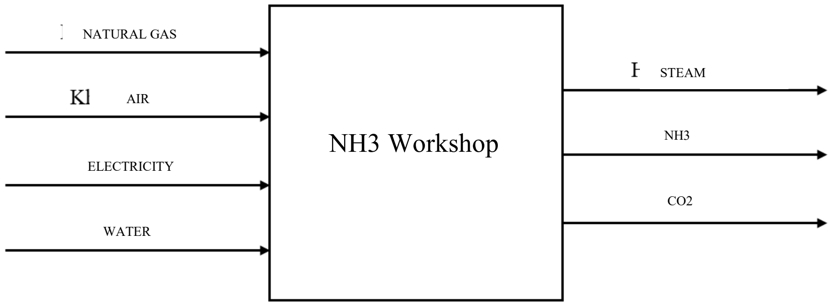


Figure 4.2.Summary of Ammonia Plant Operations

The steps required to produce ammonia from the above mentioned raw materials are as follows:

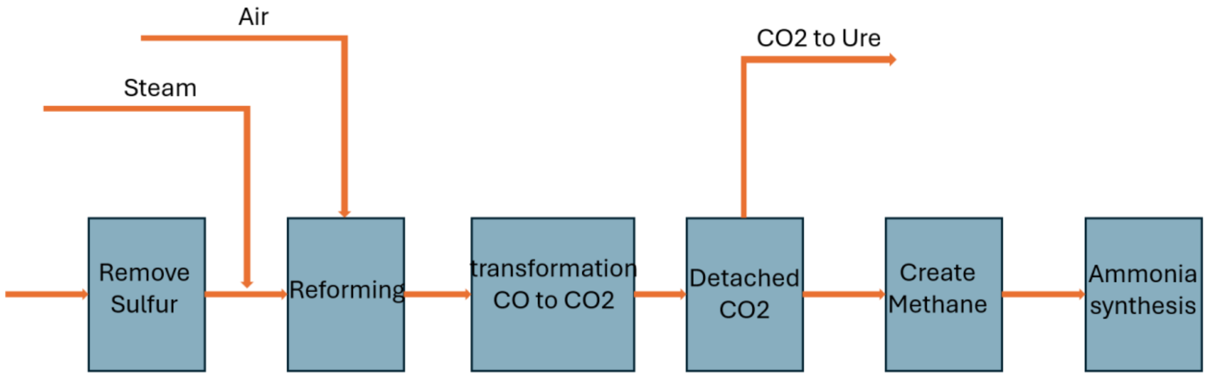


Figure 4.3.Steps required to produce Ammonia

Natural gas is desulfurized in the desulfurization unit to parts per million (0.05 ppm). The desulfurized gas participates in the reforming reaction with steam and air to form process gas. The composition of process gas mainly includes gases such as: H_2, N_2, CO, CO_2 and steam.

During the gas cleaning stage, CO is converted to CO_2. CO_2 is then separated from the process gas at the CO_2 separation unit. The remaining CO and CO_2 in the process gas are converted to methane in the methanizer by reacting with H_2 before entering the synthesis loop.

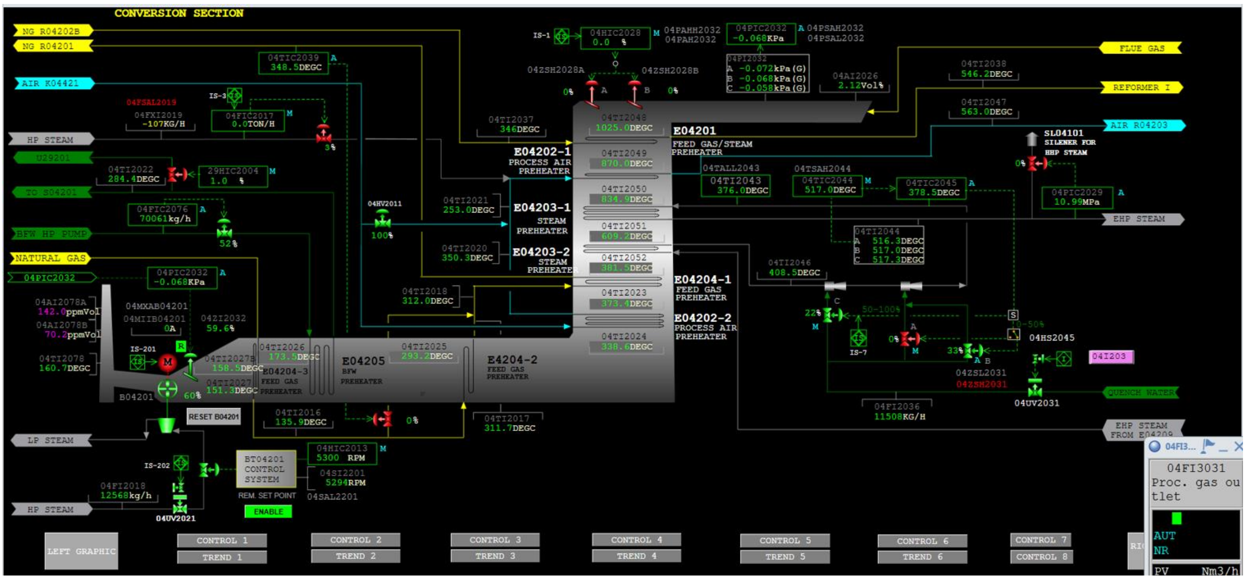


Figure 4.4.Reformer heat recovery system

Synthesis gas is compressed to high pressure and fed into the ammonia synthesis tower, where it reacts to form ammonia.

To limit the accumulation of argon and methane in the synthesis loop, a small stream of gas is vented. The liquid ammonia is depressurized and the inert and dissolved gases are released. The capacity of the ammonia plant is 1,350 MTPD ammonia and 1,790 MTPD CO_2. The ammonia plant can be operated and ammonia can be exported in two ways:

- Method 1: Ammonia product is brought to the urea production plant at a temperature of 25oC and a pressure of 2.45 MPag.
- Method 2: Product ammonia is transferred to an ammonia tank at -32oC and 5 MPag pressure.

4.3 Urea production plant

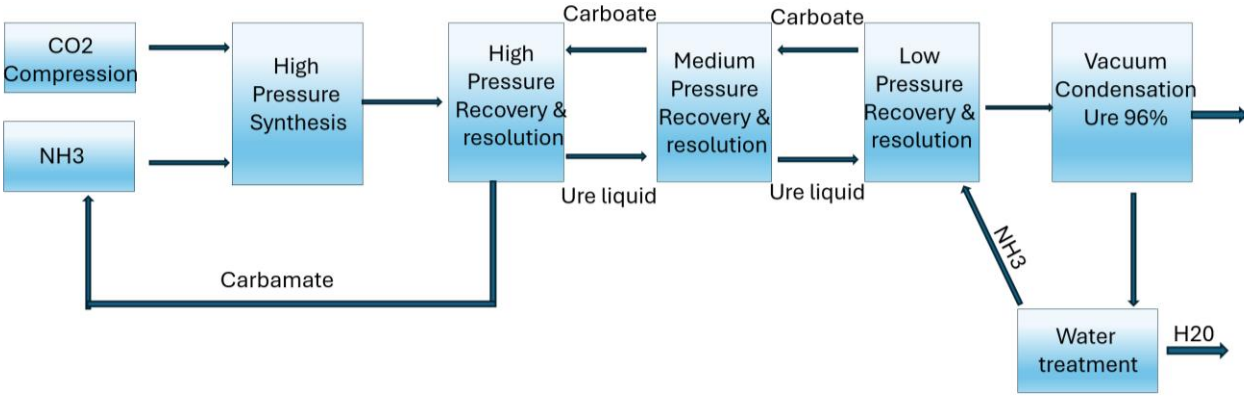


Figure 4.5.Production process at Urea workshop

This process is characterized by operating the Urea synthesis cluster at a pressure of about 15.6 MPa (G), with a molar ratio of NH_3/CO_2 in the reactor of about 3.1~3.6. This allows the conversion of CO_2 in the reaction tower to Urea to be 60~63%, the designed perforated discs have the effect of preventing backflow and promoting the absorption of gas into liquid. There are two types of reactions occurring simultaneously in the Urea synthesis unit.

$2NH_3 + CO_2 \rightarrow NH_2COONH_4$ + 32560 kcal/kmol carbamate (0.1013 MPa; 250oC) (1)

$NH_2COONH_4 \rightarrow NH_2CONH_2 + H_2O$ – 4200 kcal/kmol Urea (0.1013 MPa; 250oC) (2)

Reaction (1) is strongly exothermic, reaction (2) is slightly endothermic and occurs in the liquid phase at a slow reaction rate. The synthesis is followed by the decomposition (and recovery) of the unconverted substances and is carried out in three stages: high-pressure decomposition in the Stripper, medium-pressure decomposition in the medium-pressure decomposition, low-pressure decomposition in the low-pressure decomposition. The decomposition reactions are the reverse reactions of reaction (1):

$NH_2COONH_4 \rightarrow 2NH_3 + CO_2$ (– Q).

From the reaction equation, it can be seen that the reaction is promoted by reducing pressure and heating. The Urea solution from the synthesis device enters the stripper device under equivalent pressure. Here, the carbamate part that is not converted into Urea will be decomposed. Thanks to the stripping effect of NH_3, the overall efficiency of the high-pressure synthesis cluster for CO_2 reaches about 80 - 85%.

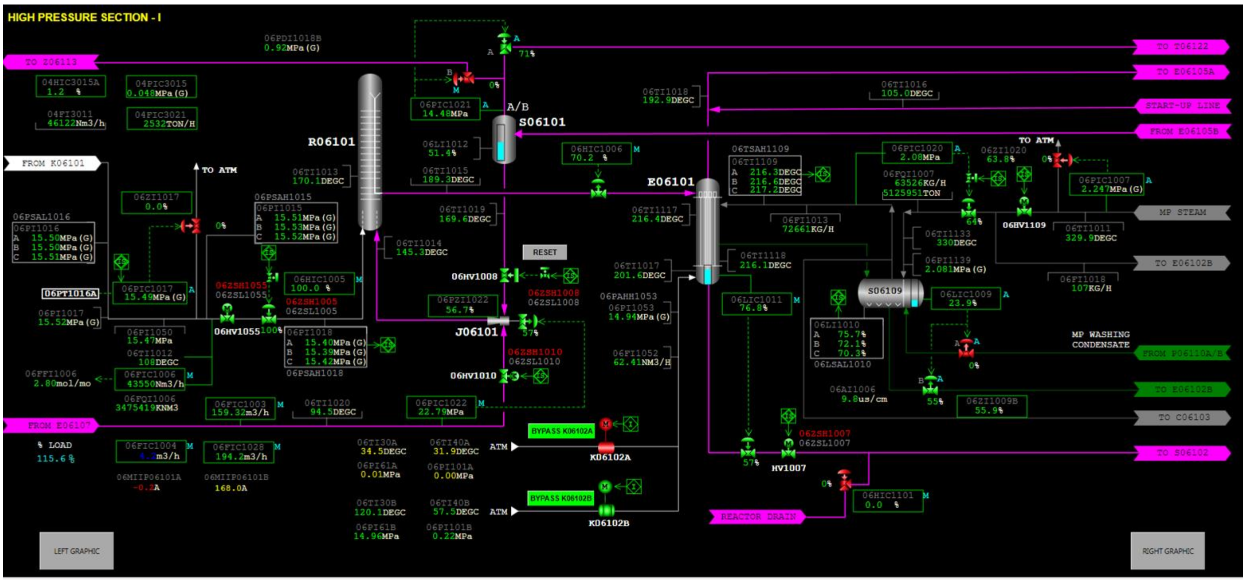


Figure 4.6. High pressure assembly

After leaving the stripper, the remaining carbamate and ammonia will be recovered in two stages under the pressure of 1.95 MPa (G) (medium pressure stage) and 0.4 MPa (G) (low pressure stage) respectively. NH3, CO2 gas coming out from the top of the stripper will be mixed with the circulating carbamate liquid from the intermediate pressure stage and condensed in the first and second carbamate condensers under the same pressure as the Stripper pressure. Here, MLP (medium pressure saturated steam) and LP (low pressure saturated steam) are also generated. The produced steam will be used in the downstream sections. The inert gas after separation will be sent through the MP (medium pressure) stage, the final carbamate liquid is circulated to the bottom of the synthesis device through a liquid/liquid jet pump using the high pressure ammonia stream fed into the synthesis tower as a driving force. This ejector and the above mentioned carbamate condensers allow horizontal arrangement, which is one of the main features of Snamprogheti technology.

The heat recovered thus allows significant savings in total steam and clean water consumption:

- Preheat the Ammonia stream before entering the synthesis unit by the gas stream from the low pressure decomposition stage and the water treatment stage.
- Heating the vacuum pre-concentrator by the heat released from the absorption of the gas stream from the intermediate pressure digestion stage and the carbonate liquor stream.
- Recover all condensate technologically as boiler feed water.
- The high pressure carbamate stream circulates back to the high pressure synthesis loop preheated by the process condensate stream after treatment leaving the distillation tower.

The main steps in the synthesis of Urea include:

- Urea synthesis and recovery of NH3, CO2 at high pressure.
- Purify Urea solution and recover NH3 and CO2 gases in medium and low pressure stages;
- Vacuum concentration;
- Create seeds;
- Condensate treatment technology;
- Auxiliary system: steam network, washing water network.

4.4 NPK production workshop

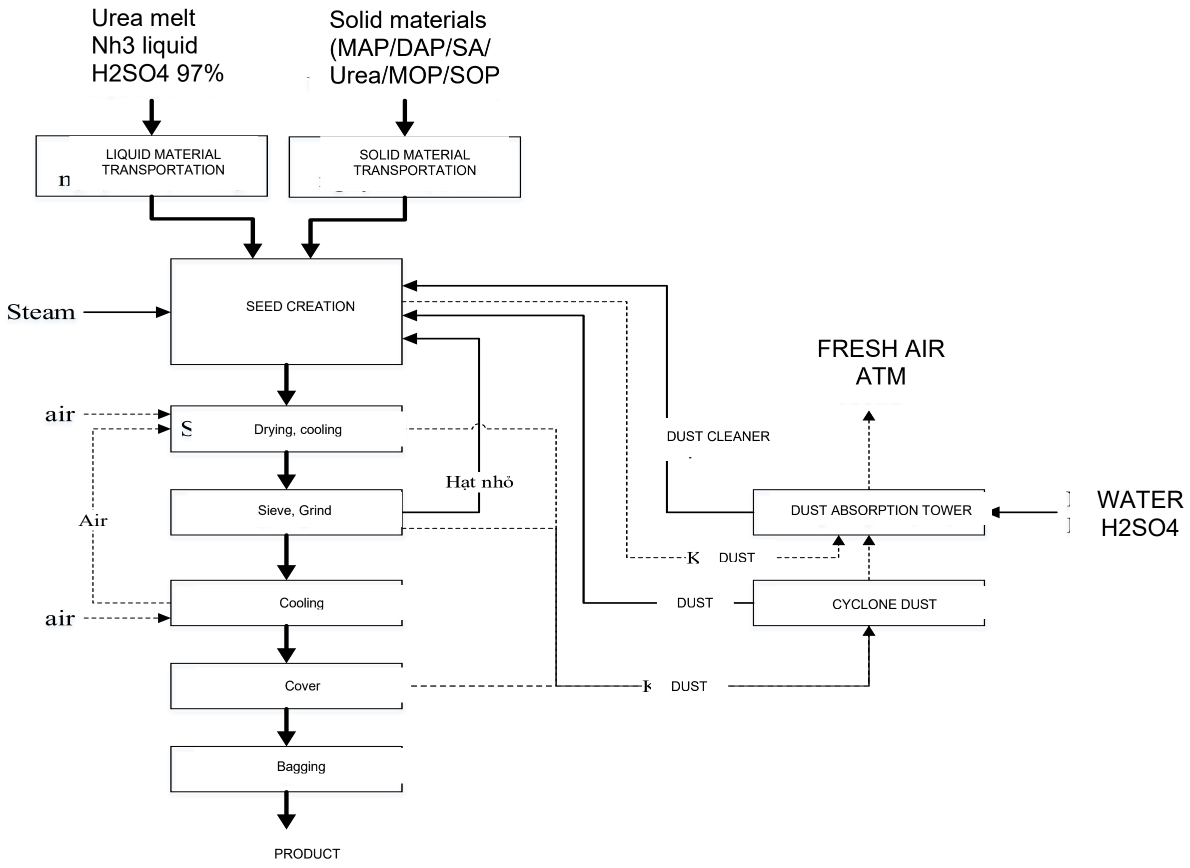


Figure 4.7.Production process at NPK workshop

NPK fertilizer is a type of fertilizer obtained by mixing finished fertilizers together. The input materials include liquefied Urea, liquid NH3, concentrated sulfuric acid (H2SO4), solid Urea, Potassium, MAP, DAP, and other trace elements mixed together. Then the mixture is sent to the granulation tower, where the mixture is heated by steam at a fixed temperature to form a homogeneous liquid mass. Then the liquid mass is dropped into the centrifugal granulator, at this time the liquid particles are shot out and fall freely in the tower, the high-speed fan system is blown from bottom to top to reduce the falling speed of the particles, both cooling and drying the particles. Then, the particles are sent to the sieve/grinder. Particles that are too large will be crushed, while particles that are too small will be returned to the granulation tower for melting. Dust is also collected during this process. After size processing, the granules are completely cooled by the fan system and then transferred to the film coating system to avoid clumping, then packaged into finished products.

4.5 Auxiliary workshop

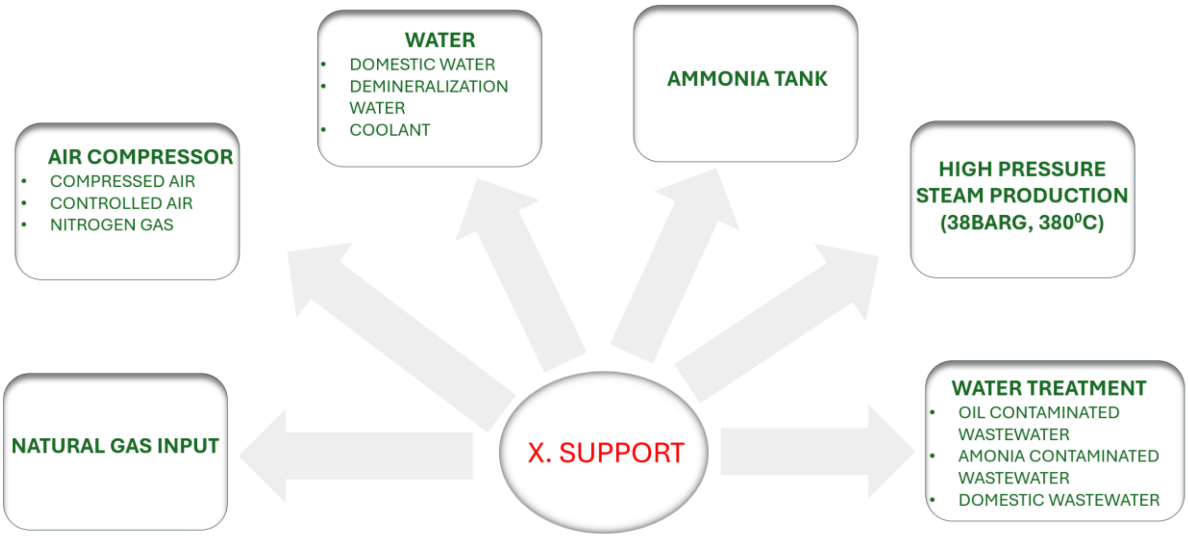


Figure 4.8.Auxiliary workshop production diagram

The Auxiliary Workshop is responsible for supplying gas, steam and water to the production lines; helping the production lines operate stably. In addition, the Auxiliary Workshop also plays a role in transporting oil-contaminated wastewater, ammonia-contaminated wastewater and domestic wastewater to the wastewater treatment system.

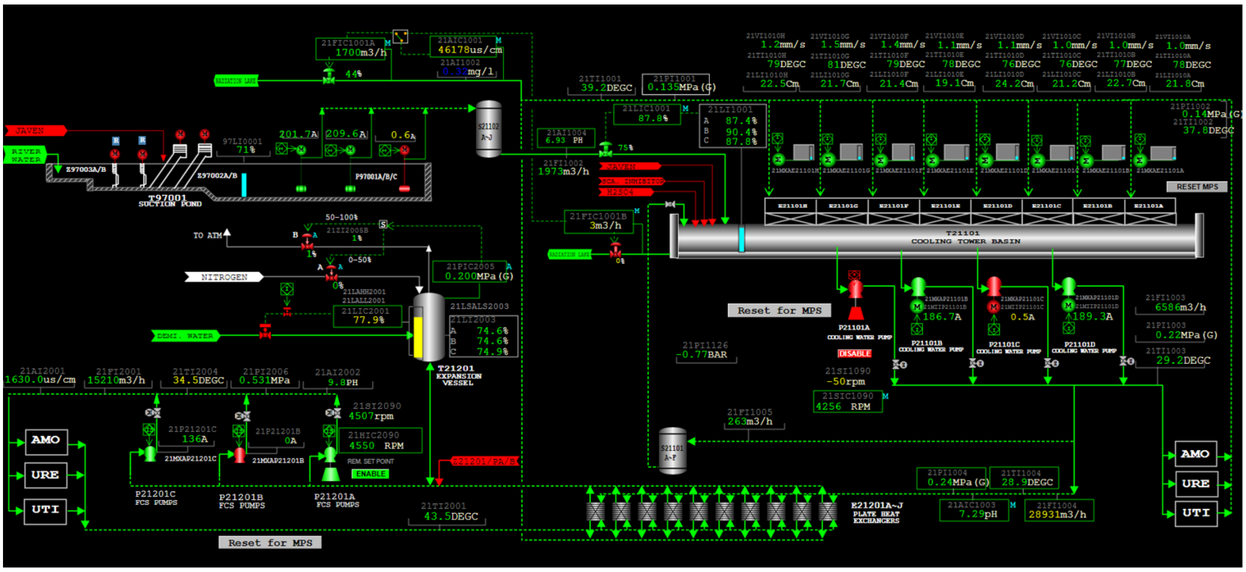


Figure 4.9. Cooling water system

5 Energy demands and supply capacity

5.1 Energy supply system

5.1.1 Electrical system

Electricity serves the machinery and equipment system in the production line and supplies other auxiliary systems. The parameters and technical characteristics of the transformer system are presented in the table below:

Table 5.1.Plant transformer information

No	Load name	Power (kVA)	Secondary voltage (kV)	Primary voltage (kV)
1	MAIN TRANSFORMER 1 (MBA TR01)	25	6.6	20
2	MAIN TRANSFORMER 2 (MBA TR02)	25	6.6	20
3	AMMONIA TRANSFORMER (MBA TR03)	2.5	0.4	6.6
4	AMMONIA TRANSFORMER (MBA TR04)	2.5	0.4	6.6
5	UREA AND GRANULATION TRANSFORMER (MBA TR05)	2.5	0.4	6.6
6	UREA AND GRANULATION TRANSFORMER (MBA TR06)	2.5	0.4	6.6
7	CIRCULATION COOLING WATER TRANSFORMER (MBA TR07)	1.6	0.4	6.6
8	CIRCULATION COOLING WATER TRANSFORMER (MBA TR08)	1.6	0.4	6.6
9	UREA HANDLING AND STORAGE (MBA TR09)	1.6	0.4	6.6
10	UREA HANDLING AND STORAGE (MBA TR10)	1.6	0.4	6.6
11	SERVICE FACILITY (MBA TR11)	1.25	0.4	6.6
12	DIESEL GENERATOR (Urea Power Station Diesel Generator)	1.5	0.4	0.4
13	NPK Substation (TR08101)	1600	0.42	6.6
14	NPK Substation (TR08102)	1600	0.42	6.6
15	Bagging NPK Substation (TR08201)	500	0.42	6.6
16	22/6.6Kv extended MBA	12500	6.6	22

Table 5.2: Evaluation table of transformer system performance quality

No	Parameter	Average value	Comment
1	Operating capacity	166 kW - 11,730 kW	The transformer operates at an average power equivalent to 17-45% of the load. The auditing unit conducts measurements and checks the power quality at distribution cabinets. Transformer load is operating at normal level.
2	Power factor cosφ	0.91 – 0.94	Ensure the requirements of Electricity (power factor cosφ not less than 0.9) according to Circular 25/2016-TT BCT.

Transformers operate at an average load of 17.45%, which is low. Transformers are typically most efficient at 50-75% load, so operating at 17.45% leads to higher losses relative to energy transferred. Review load allocation among transformers to potentially operate closer to optimal efficiency curves. For long-term savings, evaluate energy-efficient transformer options or automated switching systems that match load demand. Power factor (0.91-0.94) meets regulatory requirements (>0.9).

5.1.2 Heating furnace system

Table 5.3: Kiln system, furnace, drying equipment

No	Name, type	Fuel type	Design capacity (ton/hour)	Fuel and energy consumption (kg,kWh/ton product)	Exhaust temperature (°C)	Average operating hours (hours/day)
1	Pre-Reformer	NG	13,622	0.243	165	24
2	Combustion Chamber	NG	196,449	0.109	N/A	24
3	E08202	Electricity	272	4	48	24

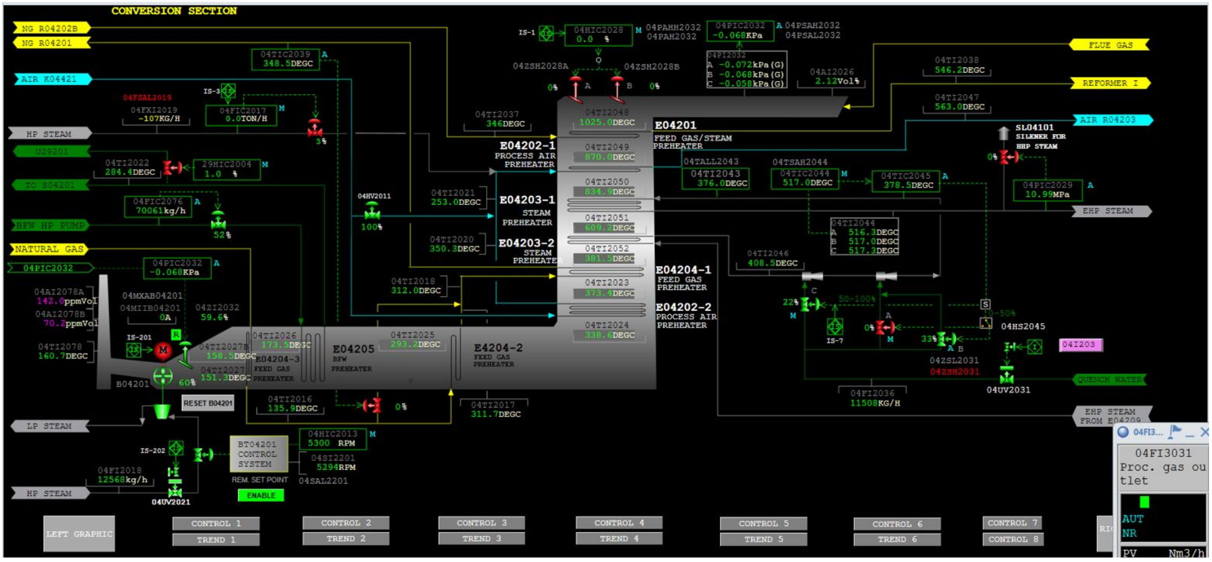


Figure 5.1. Pre-reformer exhaust gas system

There is exhaust flue gas from the pre-reformer furnace with a temperature of about 160°C and a flow rate of approximately 200,000 m³/h, indicating a significant heat recovery potential. However, due to the lack of space for increasing the size of heat exchangers or installing new ones for heat recovery, this option needs to be reconsidered in the future.

5.1.3 Boiler system

Table 5.4: Boiler system

No	Boiler type	Fuel type	Design capacity (ton/hour)	Working pressure (barg)	Exhaust temperature (oC)	Average operating hours (hours/day)
1	Auxiliary boiler	NG	200	39	120	24

2	Waste heat boiler	Waste heat	250	110	-	24

The steam network system at the Plant is supplied from 2 sources:

- Auxiliary Boiler, burning Natural gas to generate high pressure steam, current capacity at the Plant is 50 - 60 tons/hour.

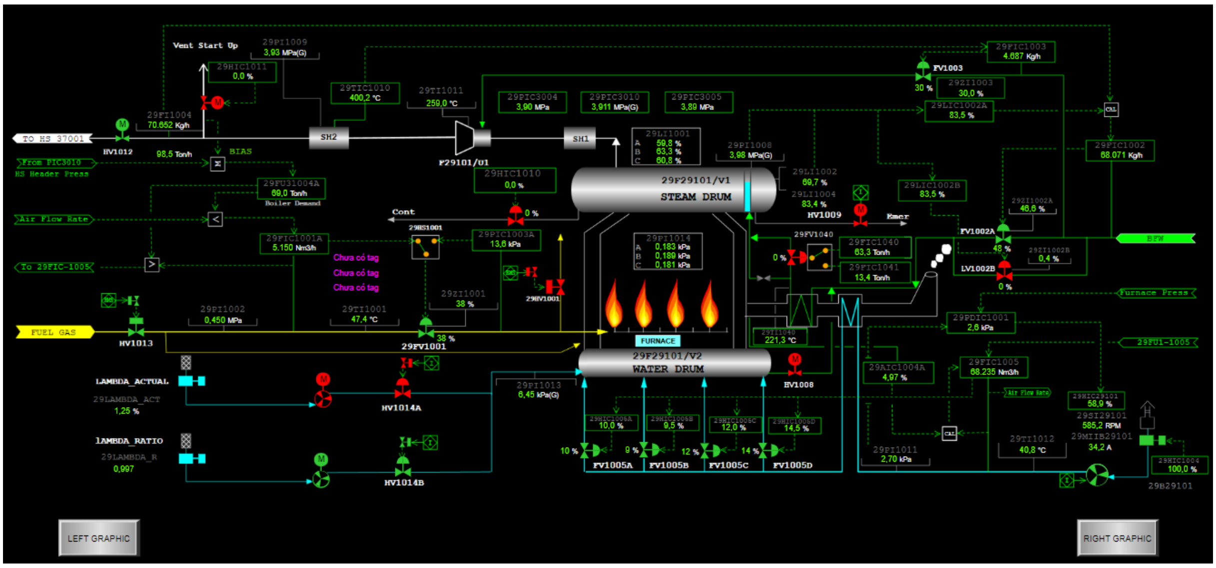


Figure 5.2.Auxiliary boiler graphic image

- Excess heat boiler, recovers heat from NH3 production process to generate super high pressure steam (110 barg, 520^{0}C) to supply 2 Turbines: KT04431 drives synthetic gas compressor (160 tons/h) and KT04441 drives ammo compressor (90 tons/h).

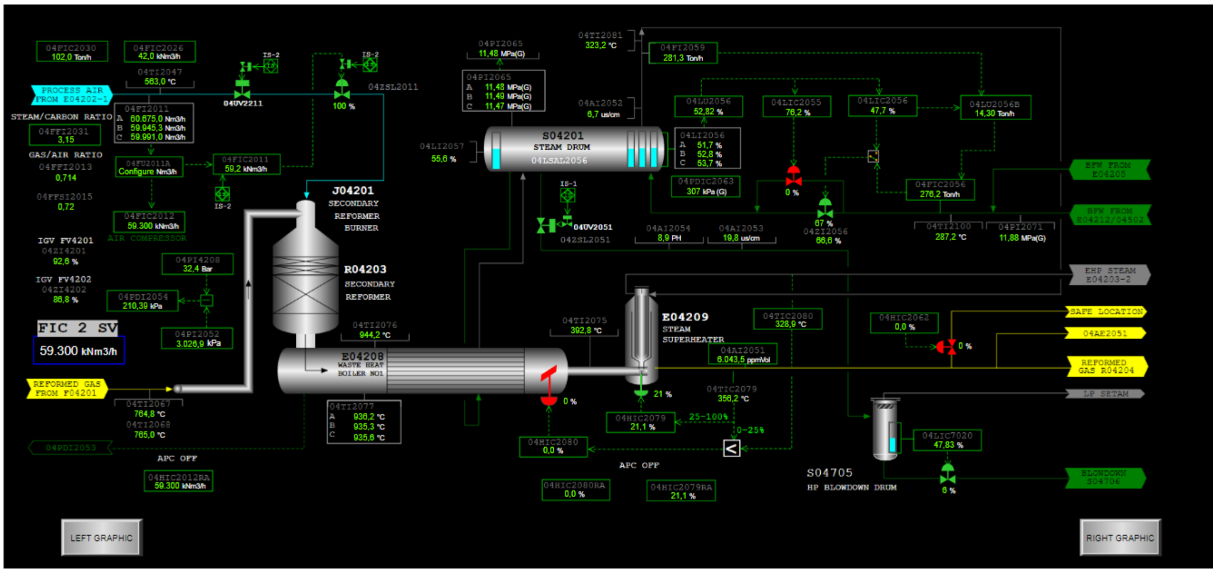


Figure 5.3.Amo workshop waste heat boiler graphic image

Figure 5.4.Image of auxiliary boiler area

Flue gas from the furnace after heating the feed water will be discharged into the environment after passing through the inlet air heater and exhaust flue gas treatment equipment. Exhaust temperature of 120°C, the excess air coefficient is quite high around 4%, and the furnace trips when %O_2 is less than 1.5%. The high excess air coefficient is due to the current low load of the auxiliary boiler (~25% of full load) and the flexible application of turbine/motor switching.

There is potential to use biomass for the auxiliary boiler as a replacement for natural gas (NG). However, this option could impact plant operations and requires further research. Therefore, it is not a priority at this time.

5.2 Main equipment lists

5.2.1 Refrigeration and air conditioning systems

The Plant's cooling system includes a Plant-level air conditioning system and a chiller system that supplies cold water to technological machines. The Plant cooling system includes a central air conditioning system and a local air conditioning system. Both systems have the task of providing fresh air and air conditioning to the Plant areas, ensuring temperature and humidity for the warehouse area.

The chiller system supplies cold water to the technological machine and is responsible for cooling the technological machine system in the production line.

Table 5.5: Catalog of refrigeration and air conditioning systems

No	Brand	Cooling capacity (Hp)	Quantity	Average operating time (hours/day)
1	Midea	3	19	8
		5	16	8
		1.5	7	8
		5.5	2	8
2	Samikura	3	1	24
		5	3	24

No	Brand	Cooling capacity (Hp)	Quantity	Average operating time (hours/day)
		2.5	1	24
3	Gree	2	1	24
		3	6	24
		4	2	24
		1.5	6	24
4	Yatai	5	6	12
5	Bartec	2.5	2	8
6	Daikin	1.5	11	8
		2	16	8
		3	11	8
		4	2	8
		5	14	8
		13	1	24
		5.5	11	8
7	Rittal	1.5	8	24
8	Hitachi	1.5	1	24
9	Kangning	12	3	24
10	LG	2	2	24
11	Mitsubishi	1.5	4	8
12	Reteech	1.5	8	8
13	X60001A/B	268	2	24
14	X54001	77.8	1	24
15	X55003	310	1	24

5.2.2 Compressor system

The pneumatic system – control air includes 6 Atlas Copco air compressors with a capacity of 200 kW, the set pressure of the air compressors is 8.9 – 9.3 bar. Currently being adjusted and divided into loads according to the IS8 system to ensure sufficient pressure when controlling.

In addition, the Plant also uses air compressors, synthetic gas compressors, Ammonia compressors, CO2 compressors... in the Ammonia Workshop and Urea Workshop areas.

Table 5.6: Technical specifications of the compressors

No	Device Name	Quantity	Rated power (kW)	Working compression pressure (bar)	Operating time (hours/day)
Auxiliary workshop					
1	Air Compressor K31001A~F	6	200	9	-
2	Ammonia Compressor K40401A/B	2	141.5	18.01	24
Ammonia Workshop					
1	Air Compressor K04421	1	9,738	32.6	24

2	K04431 Synthetic Air Compressor	1	16,629	130.7 - 138.3	24
3	Ammonia Compressor K04441	1	6,176	18	24
4	Ammonia Booster Compressor K04451	1	500	200	-
5	Compressor K04204	1	75	40	-
6	CO2 recovery compressor K04301	1	630	29	-
Urea Workshop					
1	CO2 Compressor K06101	1	11.04	157	24
2	Air Compressor K06102A/B	2	37	160	24

5.2.3 Fan system

The Plant's fan system includes:

- Exhaust fan system;
- Fan system;
- Cooling fan system.

Table 5.7: fan system list and operating time

No	Device Name	Symbol	Quantity	Design and installed capacity (kW)	Operating time (h/day)
1	FORCED FAN FOR	B07601	1	315	24
2	FORCED FAN FOR	B07602	1	1.6	24
3	FAN DUST SCRUBBER	B07603	1	1.8	24
4	FAN FOR PRODUCT COOLER	B07605	1	450	24
5	FLUE GAS BLOWER	B04201	1	1	24
6	FORCED DRAFT FAN	B29101	1	900	24
7	BLOWER IN CIRCUIT	K04203	1	250	-
8	Dust collection blower	MB07604	1	37	24
9	COOLING TOWER	ME21101	8	200	24
10	Granulator Fan	B08101	1	75	24
11	COMBUSTION AIR FAN	B08102	1	30	24
12	COOLER DRUM FAN	B08104	1	110	24
13	DRYER FAN	B08105	1	420	24
14	DEDUST FAN	B08106	1	132	24
15	FBC OUTLET FAN	B08107	1	110	24
16	FBC INLET FAN	B08108	1	110	24
17	FBC RECIRCULATION FAN	B08109	1	110	24
18	DEDUSTING AIR HEATER FAN	B08110	1	22	24
19	COOLER DRUM OUTLET FAN	B08111	1	315	24
20	DUST REMOVAL FAN	B08201	1	37	24
21	DUST REMOVAL FAN I	B08001	1	37	24
22	DUST REMOVAL FAN II	B08002	1	11	24
23	DUST REMOVAL FAN III	B08003	1	11	24
24	DUST REMOVAL FAN IV	B08004	1	22	24

No	Device Name	Symbol	Quantity	Design and installed capacity (kW)	Operating time (h/day)
25	MIXED BLOWER FOR NEUTRALIZATION PIT	MB20202	2	37	interruption
26	DUMP CONDENSER	ME29201	6	11	interruption

5.2.4 Pumping system

The pumping system of the Plant accounts for a high proportion of energy use, including: Cooling water pumping system and pumping system for the production process.

Table 5.8: List of pump systems of the Plant

No	Device	Device symbol	Quantity	Design capacity (kW)	Actual flow (m3/h)	Average operating time (hours/day)	Area
1	Semilean Solution Pump	P04301	2	3.3	2450 t/h	24	Amo Workshop
2	Lean Solution Pump	P04302	2	700	460 t/h	24	Amo Workshop
3	HP BFW PUMPS (Pump A driven by Turbine, Pump B driven by Motor	P29201	2	1870	272000 t/h	24	Amo Workshop
4	Hp Circulation Pump	P04551	4	37	3342 t/h	24	Amo Workshop
5	Lp Circulation Pump	P04552	2	22	1089 t/h	24	Amo Workshop
6	Main Oil Pump For K04421	P04422	2	55	60	24	Amo Workshop
7	LO Main Pump for K04431	P04431	2	75	83	24	Amo Workshop
8	Ammonia Compressor Lube Oil Pump	P04441	2	30	30	24	Amo Workshop
9	Split Stream Pump	P04303	2	75	490.1 t/h	24	Amo Workshop
10	Process Condensate Pump No 1	P04305	2	75	58.5 t/h	24	Amo Workshop
11	Condensate Water Pump	P04401	2	75	90	24	Amo Workshop

No	Device	Device symbol	Quantity	Design capacity (kW)	Actual flow (m3/h)	Average operating time (hours/day)	Area
12	Solution Drain Pump	P04307	1	18.5	50	-	Amo Workshop
13	Solution Transfer Pump	P04308	1	18.5	50	-	Amo Workshop
14	Ammonia Product Pump	P04501	2	55	99	-	Amo Workshop
15	Ammonia Drain Pump	P04504	1	11	10	-	Amo Workshop
16	Emergency Oil Pump For K04421	P04421	1	15	20	-	Amo Workshop
17	Liquid NH3	P06101	2	1.8	140	24	Urea Workshop
18	Carbamate Translation	P06102	2	800	87	24	Urea Workshop
19	Urea Solution 45%	P07602	2	220	1400	24	Urea Workshop
20	Carbamate Translation	P06103	2	75	28	24	Urea Workshop
21	Liquid NH3	P06105	2	75	140	24	Urea Workshop
22	Urea 83% Solution	P06106	2	30	97	24	Urea Workshop
23	Urea 96% Solution	P06108	2	75	90	24	Urea Workshop
24	Condensate	P06110	2	55	7	24	Urea Workshop
25	Condensate	P06113	2	30	57	24	Urea Workshop
26	Process condensate water	P06114	2	37	48	24	Urea Workshop
27	Process condensate water	P06115	2	200	58	24	Urea Workshop
28	Condensate	P06204	2	55	25	24	Urea Workshop
29	Condensate	P06206	2	75	20	24	Urea Workshop
30	Condensate turbine	P06118	2	37	40	24	Urea Workshop
31	CO2 compressor oil	P06201	2	55	975 l/h	24	Urea Workshop

No	Device	Device symbol	Quantity	Design capacity (kW)	Actual flow (m3/h)	Average operating time (hours/day)	Area
32	COOLING WATER PUMP	P21101	3	2000	-	24	Auxiliary Workshop
33	FRESH WATER PUMP	P21201	2	1400	-	24	Auxiliary Workshop
34	No.1 RAW WATER PUMP	P20101	2	30	100	24	Auxiliary Workshop
35	No.2 RAW WATER PUMP	P20102	2	110	-	-	Auxiliary Workshop
36	FILTERED WATER PUMP	P20201	3	37	150	24	Auxiliary Workshop
37	BACK-WASH PUMP FOR ACF	P20202	2	45	170	24	Auxiliary Workshop
38	DEGASIFIER PUMP	P20203	3	30	150	24	Auxiliary Workshop
39	DEMINERALIZED WATER PUMP	P20206	3	75	161	24	Auxiliary Workshop
40	DEIONIZED WATER PUMP	P20204	2	55	340	24	Auxiliary Workshop
41	NEUTRALIZED WATER PUMP	P20210	2	15	-	Interruption	Auxiliary Workshop
42	CONDENSATE PUMP FOR P21101A	P21102	2	30	-	24	Auxiliary Workshop
43	DISSOLVED AIR FLOATATION PUMP	P27014	2	15	-	Interruption	Auxiliary Workshop
44	AMMONIA TRANSFER PUMP	P40001	2	132	-	Interruption	Auxiliary Workshop
45	AMMONIA CRACKING PUMP	P40002	1	22	-	Interruption	Auxiliary Workshop
46	INTAKE WATER PUMP MOTOR	P97001	3	160	950	24	Auxiliary Workshop
47	MP BFW PUMPS	P29202	2	560	50	24	Auxiliary Workshop
48	POTABLE WATER PUMP	P20103	2	11	13	-	Auxiliary Workshop
49	CONDENSATE PUMPS	P29203	2	11	-	24	Auxiliary Workshop

No	Device	Device symbol	Quantity	Design capacity (kW)	Actual flow (m3/h)	Average operating time (hours/day)	Area
50	Scrubber Pump	P08103	2	132	687	24	NPK Workshop

The facility currently operates a large number of pumps and fans, where capacity is controlled using valves and dampers, resulting in significant operational losses:

- Cooling water pumps
- Feed water pumps
- Fans in the granulation system
- Ammonia pumps

For the cooling water pump system, PVFC has already optimized operations by reducing one pump in the river water system and one pump in the freshwater system.

Additionally, it has been observed that large manual valves are installed in multiple locations within the utility systems to regulate flow capacity. Specifically, the following dampers are partially closed: B07602 and B07603 (70%), B07605 (60%), and B07601 (50%). The plant has already planned to install a Variable Speed Drive (VSD) for B07602 to reduce energy consumption. It is recommended that VSDs also be considered for B07603 and B07605 to enhance energy efficiency.

5.3 Overall energy mapping

The energy used in the Plant mainly includes natural gas and electricity. The energy consumption rate in the Plant per year is shown in the following chart:

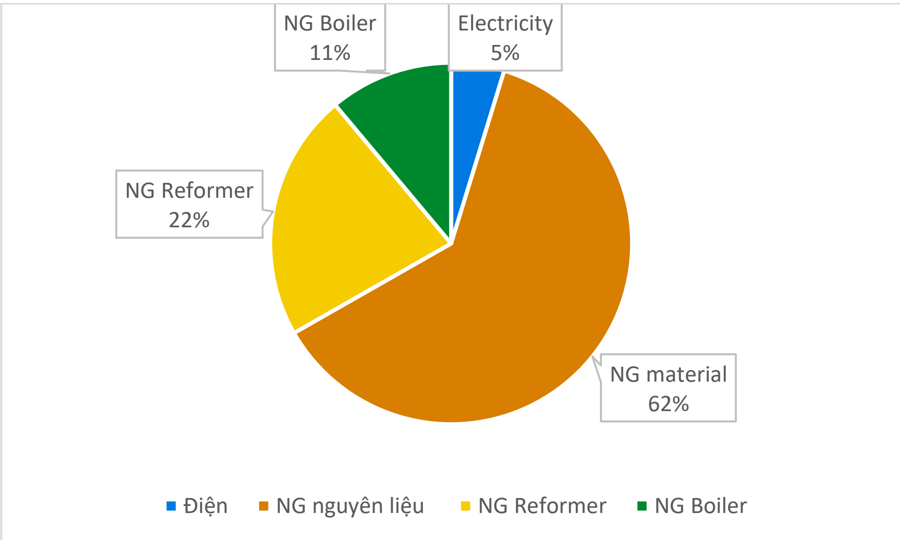
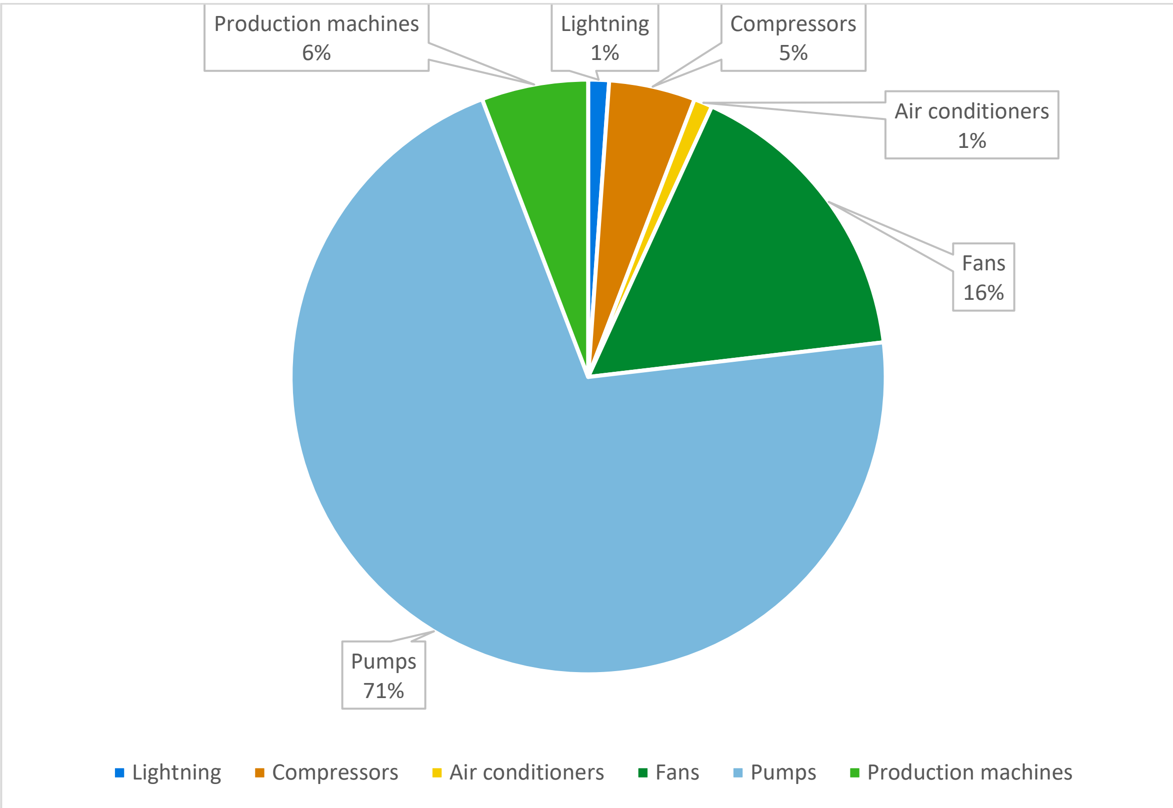


Figure 5.5. Energy usage rate in 2023

It can be seen that NG accounts for 95% of the energy used in the Plant, electricity accounts for only 5%. The high proportion of NG is because NG is used as raw material to produce NH3, fuel for reformer and auxiliary boiler.

Natural gas fuel is mainly used for NH3 production plant and auxiliary boiler, the electricity usage ratio for the areas is shown in the chart below:



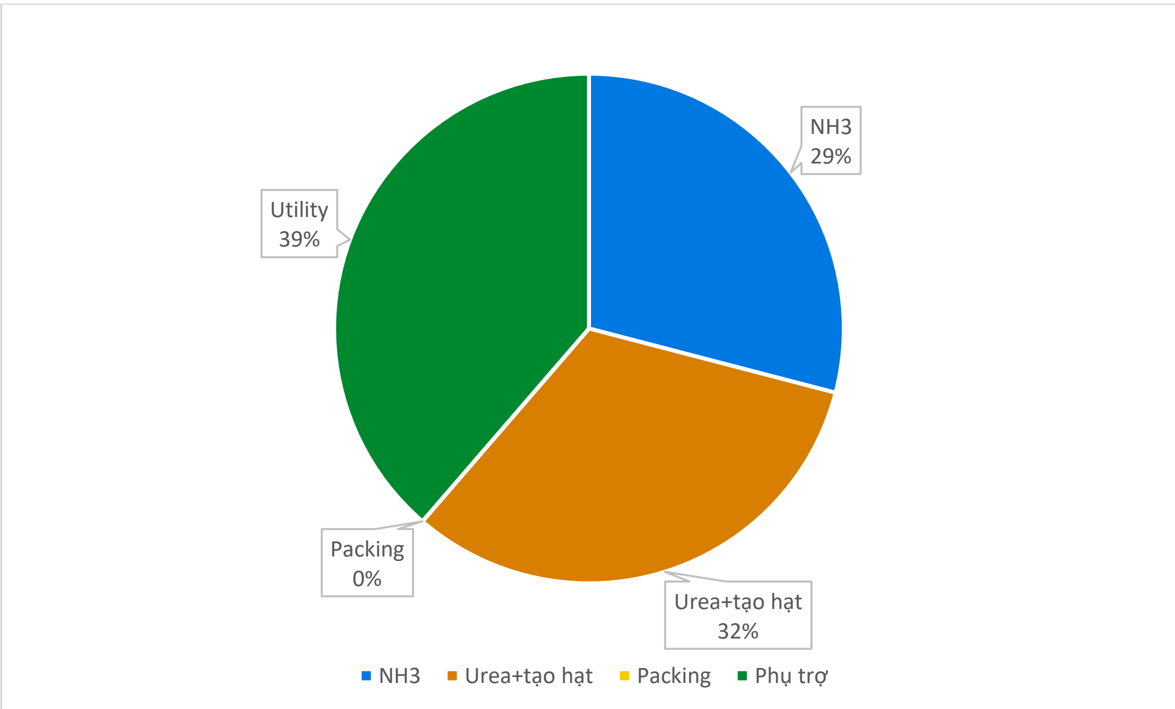


Figure 5.6. Electricity usage rate in 2023

From the chart, we can see that 39% of electricity is used in the auxiliary workshop to serve the cooling water pumping system, compressed air system, refrigeration and air conditioning system..., of which 70% serves the NH3 production workshop and 30% serves the Urea production workshop. The main electricity consumption of the plant is the pump system.

The majority of the energy used in the plant is in the form of heat. During the discussions with ICs and the key-staff at the facility, the following assesments focus on rehabilitation of cooling water systems and utilization of waste heat and delta-T-hunting. So that all cooling consumers at the facility are identified with level-2 energy mapping, i.e. all heat exchangers where cooling water is used are identified and load and temperatures for each of these are mapped on the primary and secondary side.

5.4 Level-2 heat exchanger mapping

It can be observed that large temperature differences between the source and the sink of heating or cooling, so a level-2 mapping is performed where any thermal energy demand (heating and cooling) is mapped by energy demand and temperatures. The purpose of this is to identify potential energy savings potentials through modification of processes or the energy supply systems.

It is important to understand that such large differences in delta-T, ie differences in process demand-temperature and delivered utility-temperature, can represent significant energy saving potentials.

5.4.1 AMO section

Table 5.9.Level-2-mapping for AMO section

No.	Name	Func.	Capacity (KW)	1 Tin	1Tout	2 Tin	2 Tout
1	E04217	FEED&FUEL PREHEATER	520	30	51.1	91.8	81.2
2	E04204-3	FEED GAS PREHEATER	1,670	51.1	135.8	173.5	158.5
3	E04204-2	FEED GAS PREHEATER	3,510	135.8	312.2	338.6	293.2
4	E04204-1	FEED GAS PREHEATER	1,550	312.2	348.7	381.5	373.4
5	E04201	FEED GAS&STEAM PREHEATER	17,480	346	546.2	1023.8	869.9
6	E04202-2	PROCESS AIR PREHEATER	3,060	164	350.2	373.3	338.2
7	E04202-1	PROCESS AIR PREHEATER	4,700	252.7	562	869.8	834.9
8	E04208	WASTE HEAT BOILER No.1	62,270	935.8	387.5	287.2	322
9	E04209	STEAM SUPER HEATER	7,570	387.5	346.3	322	329.1
10	E04210	WASTE HEAT BOILER No.2	10,539	420.9	329.9	286.1	323.3
11	E04211	TRIM HEATER	850	420.9	291.6		

No.	Name	Func.	Capacity (KW)	1 Tin	1Tout	2 Tin	2 Tout
12	E04212A/B	BFW PREHEATER No.1	15,181	329.8	196.9	167	276.6
13	E04212C	BFW PREHEATER UTILITY	-	329.8	190.8		270
14	E04213	BFW PREHEATER No.2	850	220.1	162	132.2	167
15	E04205	BFW PREHEATER	11,350	293.2	173.5	132.2	284.4
16	E04302	STRIPPER REBOILLER	20,740	162	127.8		
17	E04305	DMW PREHEAT NO.2	17,870	127.8	116		
18	E04316	GAS COOLER	-	116	69	34.5	43.3
19	E04311A/B	GAS/GAS HE	850	50.8	288.1	315.9	77
20	E04211	TRIM HEATER	850	288.1	290	420.9	291.6
21	E04311A/B	GAS/GAS HE	850	315.9	77	50.8	288.1
22	E04312	FINAL COOLER	2,369	77	40.9	34.5	43.3
23	E04330	FLASH GAS COOLER	-	88.9		34.5	43.3
24	E04306	LP CO2 FLASH GAS COOLER	4,610	75.7	43.3	34.5	43.3
25	E04301/315/318	SOLUTION HE	16,570	81	102.8	117.6	93.8
26	E04304/13	DEMI WATER PREHEATER NO.1	5,250	93.8	76	54.6	76
27	E04303	LEAN SOLUTION COOLER	11,630	76	50.4	34.5	43.3
28	E04701A/B	P. CONDENDATE FEED HE	9,290	69	222.9	246.5	91.8
29	E04701A/B	P. CONDENDATE FEED HE	-	246.5	91.8		
30	E04217	FEED&FUEL PREHEATER	520	91.8	81.2		51.1
31	E04702	STRIPPED P. CONDENSATE COOLER	2,080	81.2	38.1	34.5	43.3
32	E04431	COMPRESSED S. GAS COOLER 1	4,306	99.4	41.7	34.5	43.3

No.	Name	Func.	Capacity (KW)	1 Tin	1Tout	2 Tin	2 Tout
33	E04432	COMPRESSED S. GAS COOLER 2	4,000	100.4	50	34.5	43.3
34	E04433	COMPRESSED S. GAS COOLER 3	7,719	157.6	37.4	34.5	43.3
35	E04441	C. AMO COOLER	886	76	25.3	34.5	43.3
36	E04510	AMO CHILLER CONDENSER	28,650	102.4	40.6	34.5	43.3
37	E04221	C. AIR COOLER 1	-	124.8	36.5	34.5	43.3
38	E04222	C. AIR COOLER 2	-	122.3	37.2	34.5	43.3
39	E04223	C. AIR COOLER 3	-	131.2	39.6	34.5	43.3
40	E04224	C. AIR COOLER 4	-	138.1	83.8	34.5	43.3
41	E04509	MAKE-UP GAS CHILLER	1,450	37.5	17.7	14.9	
42	E04508	2ND AMONIA CHILLER	8,861	17.7	-7.5	-11.6	
43			-	9.4	-7.5	-11.6	
44	E04507	2ND COLD EXCHANGER	5,811	-7.5	15	18.7	9.4
45	E04505	1ST COLD EXCHANGER	5,180	15	36.4	40	33.2
46	E04503	HOT HEAT EXCHANGER	54,220	46.1	246	280.7	73.7
47	E04501	LOOP WASTE HEAT BOILLER	25,930	445	353.4		
48	E04502	LOOP BFW PREHEATER	14,080	353.4	280.8	167.3	295.6
49	E04503	HOT HEAT EXCHANGER	54,220	280.8	73.7		
50	E04504	WATER COOLER	6,000	73.7	40	34.5	43.3
51	E04505	1ST COLD EXCHANGER	5,180	40	33.2	15	36.4
52	E04506	1ST AMONIA CHILLER	10,020	33.2	18.7		
53	E04507	2ND COLD EXCHANGER	5,811	18.7	9.4	-7.5	15
54	E04514	PURGE GAS CHILLER	369	9.4	-8.4		

A number of heat exchangers have significant delta-Ts (exergy loss), especially no.5 E04201 (FEED GAS&STEAM PREHEATER), and no.9 E04209 (STEAM SUPER HEATER). Heat exchangers no. 5 (E04201) and no.9 (E04202) are used to pre-heat materials (NG, steam, air) before going to the reforming reactor using flue gas. The HEs are working in serial and are designed for a high heat transfer rate (so high delta T).

E04503 (~195 GJ/h) has high delta-T that can be improved to recover heat and reduce cooling load at E04504.

To illustrate energy saving potentials, a temperature vs. load-curve is established. The figure shows all heating demands (red) and cooling demands (blue) in a facility integrated into 2 curves by temperature and load. Overlaps in temperatures can be illustrated in such a figure – in this case indicating a significant potential to recover heat and thus save hot and cold utility.

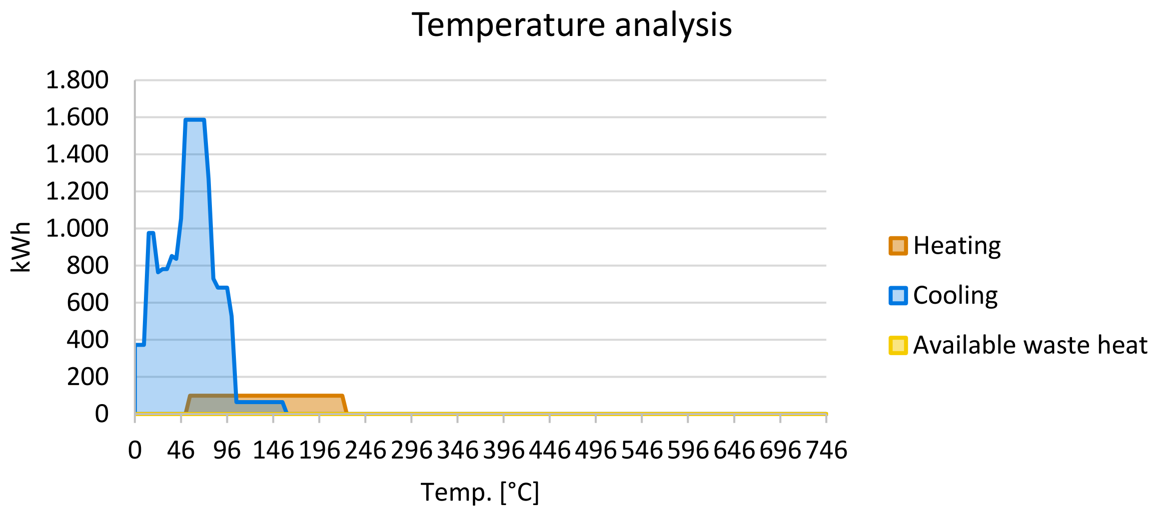


Figure 5.7.Temperature/load-curves for cooling demand (blue) and heating demand (red) for AMO section

Based on the temperature analysis, it can be seen that a significant amount of waste heat—ranging from 50°C to 150°C—is being discharged into the cooling system, indicating strong potential for heat recovery. In particular:

- E04510 AMO Chiller Condenser: Capacity: 28,650 kW; Operating Temperature: 102.4°C
- E04433 Compressed S. Gas Cooler 3: Capacity: 7,719 kW; Operating Temperature: 157.6°C
- E04221-E04224 C. Air Cooler: Operating Temperature: 124.8°C

The AMO section efficiently meets most of its heating requirements through the recovery of heat from the reform reactors. A key external demand arises from the process condensate stripper, which utilizes high-pressure steam at 3.63 MPa. In this crucial process, the condensate is heated to a range of 220-240°C.

The analysis above indicates that there is not much potential to directly utilize excess heat from the cooling system for the AMO workshop. However, this excess heat can be transferred via high-pressure hot water to the NPK workshop, where there is a relatively high demand for heat to dry products at approximately 100°C. To implement this, additional heat exchangers and pipelines will be required to transport the waste heat to the consumption site.

These waste heat sources could be harnessed either to generate electricity using an Organic Rankine Cycle (ORC) or to produce chilled water via an absorption chiller.

Electricity Generation Using an Organic Rankine Cycle (ORC) systems convert low- to medium-temperature heat into electrical energy by using an organic fluid with a lower boiling point than water. This solution reduces reliance on external grid power and lowers energy costs by turning waste heat into a productive asset.

Absorption chillers use thermal energy (rather than electrical energy) to drive a refrigeration cycle, producing chilled water for process or space cooling. It will enhance cooling efficiency by using heat that would otherwise be wasted and supports integrated energy management by coupling heat recovery with cooling needs.

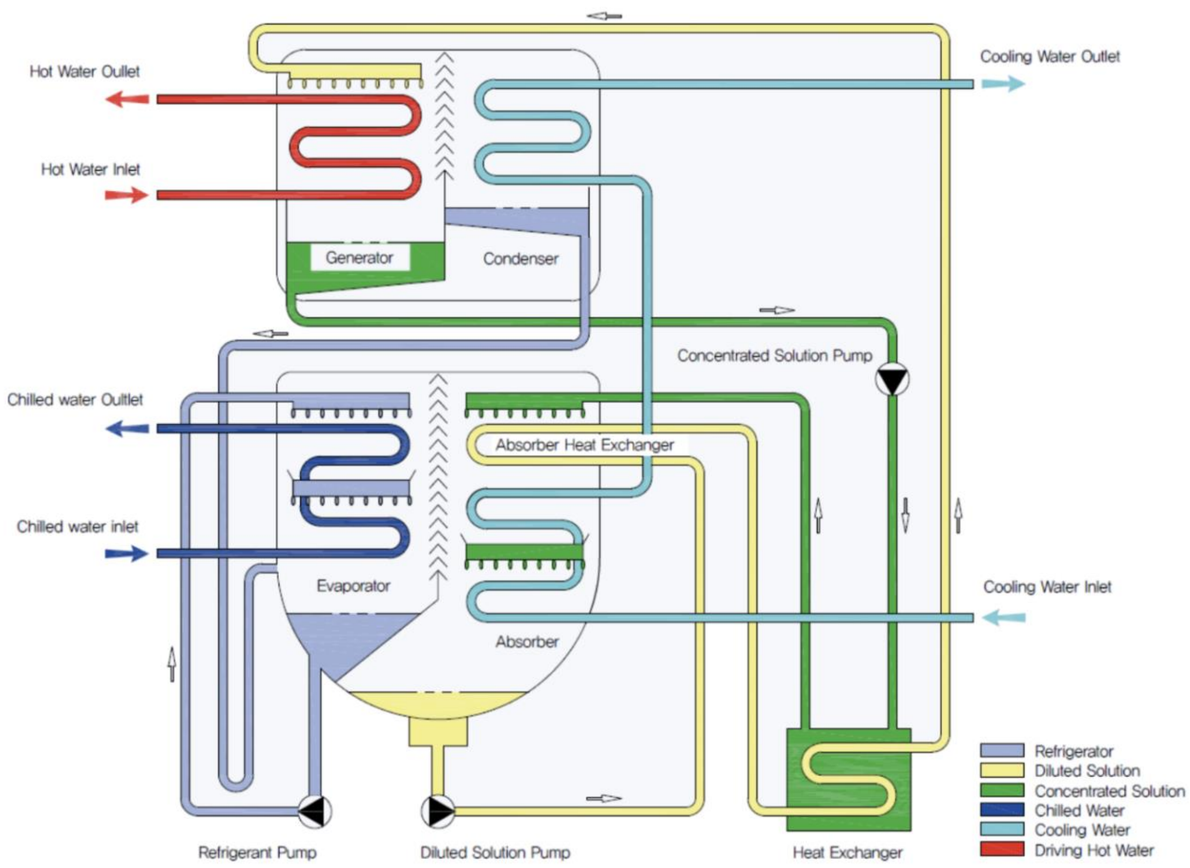


Figure 5.8. Absorption chiller.

5.4.2 URE section

Table 5.10.Level-2-mapping for URE section

No.	Name	Funtion	Capacity (KW)	1 Tin	1Tout	2 Tin	2 Tout
1	E06101	High Pressure Decomposition Equipment	34,161	189.3	192.9		
2	E06102 A	Medium Pressure Decomposition Equipment (installed with S06102/T06122)	11,533	216.1	189		

No.	Name	Funtion	Capacity (KW)	1 Tin	1Tout	2 Tin	2 Tout
3	E06102B	Medium Pressure Decomposition Equipment	4,017	189	161.3	216	
4	E06103	Low Pressure Decomposition Equipment (installed with S06103/T06103)	5,706	161.3	151.1		
5	E06104	Vacuum Pre-Concentrator (installed with S06104/T06124)	13,358	161.3	139.2		
6	E06105 A	First Carbamate Condenser	33,825	216.1	174.9		
7	E06105B	Second Carbamate Condenser	8,656	174.9	145.3		
8	E06106	Medium Pressure Condenser	15,903	139.2	81.9	39.6	68.9
9	E06107	Ammonia Pre-heater	6,100	127.9	97.6	25	94.5
10	E06108	Low Pressure Condenser	10,586	97.6	35.6	34.5	43.3
11	E06109	Ammonia Condenser	9,617	79	34.8	34.5	43.3
12	E06110	Condensate Wash Water Cooler	2,086	120	34.8	34.5	43.3
13	E06111	Medium Pressure Ammonia Absorber (installed with C06103)	469	30	50	34.5	43.3
14	E06112	Low Pressure Ammonia Absorber (installed with T06106&C06104)	283	40	37.8	34.5	43.3
15	E06113	High Pressure Carbonate Solution Pre-heater	2,511			148.7	116.9
16	E06114	Vacuum Evaporator (installed with S06114/T06114)	11,439	101.7	135.7		
17	E06116 A/B	Distillation tower preheater	2,156	40.1	94.9	116.9	68.7
18	E06118 A/B	Hydrolysis tower preheater	4,667	150	214.7	225.7	163.7
19	E06119	CO2 compressor first intercooler (K06101 package)	3,217	170.2	40.9	34.5	43.3
20	E06120	CO2 compressor second intercooler (K06101 package)	3,669	220.8	43.7	34.5	43.3
21	E06121	CO2 compressor third intercooler (K06101 package)	2,722	177	47.3	34.5	43.3
22	E06122	Condensing vapor cooler	3,869		104.3	34.5	43.3
23	E06123	Technological condensate end cooler	2,078	68.7	44.4	34.5	43.3
24	E06140	CO2 compressor turbine condenser	33,333				
25	E06160	Circulating urea preheater	456	44.3	101.7	120	
26	Z061505	Vacuum system	-			34.5	43.3
27	E06124	PRE CONDENSER	37,264			34.5	43.3
28	E06125	INTERCONDENSER	353			34.5	43.3
29	E06126	AFTER CONDENSER	403			34.5	43.3

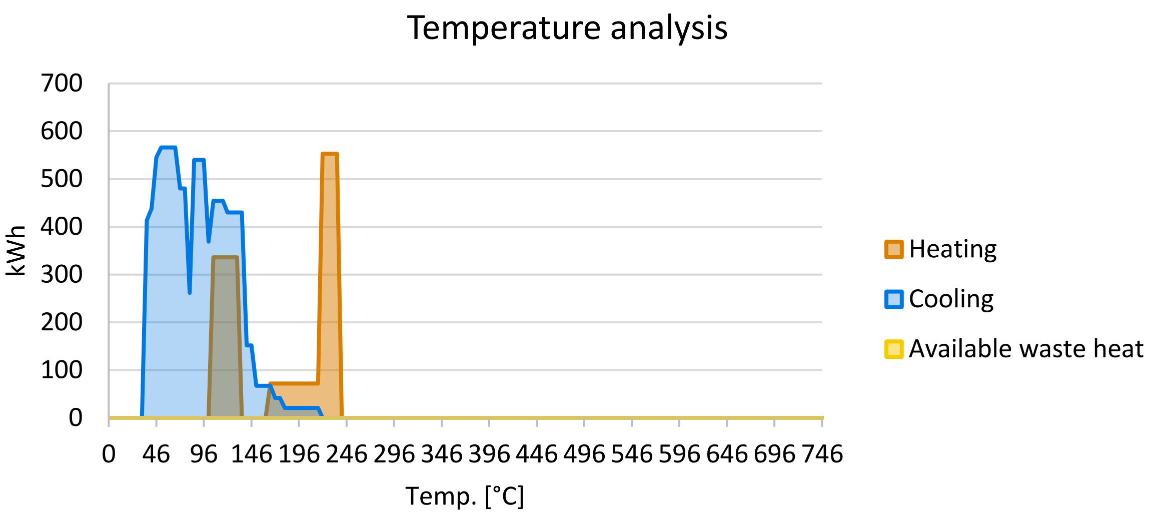


Figure 5.9.Temperature/load-curves for cooling demand (blue) and heating demand (red) for URE section

For URE section, there are several potential heat recovery locations defined using the level-2 mapping above:

- E06119 CO2 compressor first intercooler: Capacity 3,217 kW, temperature in 170.2 °C
- E06120 CO2 compressor second intercooler: Capacity 3,669 kW, temperature in 220.8 °C
- E06121 CO2 compressor third intercooler: Capacity 2,722 kW, temperature in 177 °C.

Main external heating demand arises of URE section from the Carbamate pressure decomposition equipment (E06102 A, E06103), which utilizes high-pressure steam at 3.63 Mpa, working temperatre around 240 °C and Vacuum Evaporator (E06114 - 11.439 kW) using low-presure steam at about 140 °C.

The analysis above indicates that there is opportunity to utilize wates heat from CO2 compressor intercooler (E06119, E06120, E06121) for the Vacuum Evaporator (E06114) to reduce the low-pressure steam consumption.

These waste heat sources also could be harnessed either to generate electricity using an Organic Rankine Cycle (ORC) or to produce chilled water via an absorption chiller.

5.5 Water cooling system mapping

5.5.1 Water Cooling System Description

The Ca Mau Fertilizer Plant's cooling system consists of an open recirculating Riverwater cooling system (21100) and a closed recirculating freshwater cooling system (21200).

- River water is used to supplement lost water in cooling towers (evaporation and bleed)
- River water is not used directly for cooling purposes
- Circulating cooling tower water for certain process cooling purposes
- The cooling tower water also cools the fresh water loop
- Fresh water circulation for other process cooling purposes

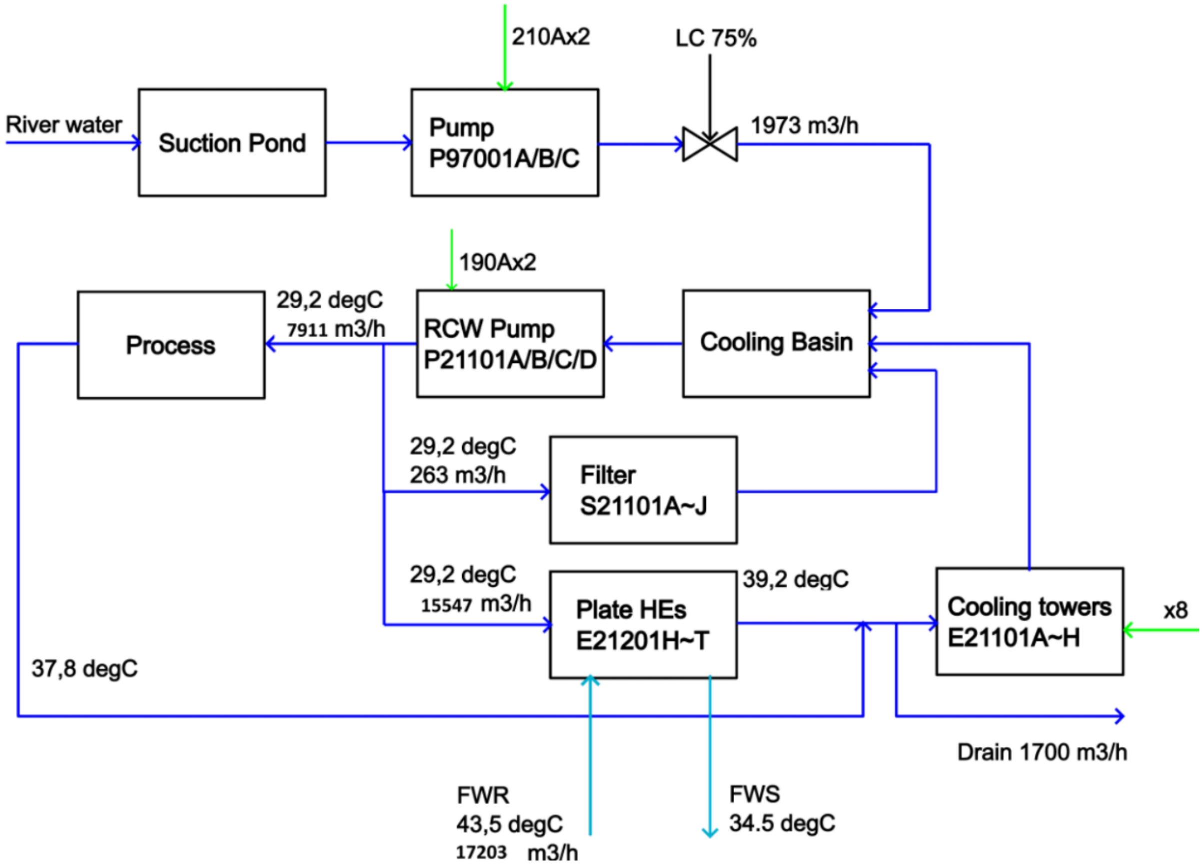


Figure 5.10. Water cooling system

Riverwater Cooling System

Riverwater (Riverwater Cooling System) is directly used in all turbine condensers of the plant to lower the temperature of all process streams. Additionally, it is employed to cool the freshwater cooling system through plate heat exchangers. A small portion is then discharged. The remaining water is treated by a system of cooling towers E21101A~H. The system is replenished with Riverwater by barrier water pumps P97001A~C.

Basic design information has considered the influence of environmental factors such as:

- Inlet/outlet temperature of Riverwater (°C): 34/43
- Wet bulb temperature (°C): 30

The Riverwater cooling system includes 8 cooling towers (capacity of 4700 m³/h per tower). The Riverwater storage tank can maintain 4 hours of operation in case of loss of water supply.

Cooling water is pumped into the turbine condensers of the Amo and Urea plants and plate heat exchangers (E21201A~J) of the freshwater cooling system. The Riverwater cooling system is circulated by 4 pumps P21101A~D (capacity of 12343 m³/h per pump, one standby), three driven by electric motors, and one by a steam turbine. The pumps are installed near the Riverwater storage tank and provide the required pressure for the plant, approximately 4.2 barg.

To ensure the quality of the cooling water, a portion of the cooling water passes through a side-stream filter (S21101A~F) with a flow rate of approximately 1294 m³/h.

Sulfuric acid is used in the cooling water to maintain pH, and anti-scaling agents are used to prevent scale formation in the system. Javel is added to inhibit the growth of microorganisms.
The water supplied to the Riverwater cooling system is sourced from the Cai Tau River. The normal circulation ratio of the system is 1.25, and the design value is 1.5.

The ion concentration in the water is kept stable, and water quality improves with the number of circulation cycles. Suspended solids in the Riverwater are removed by filters (S21101A~J).

Freshwater Cooling System

Freshwater is directly used in condensers and heat exchangers, except for turbine condensers in the plant, to reduce the temperature of process streams. It is then cooled down by Riverwater through Riverwater-freshwater heat exchangers E21201A~J. System leakage is replenished with demineralized water.

Basic design information has considered the influence of environmental factors such as:

- Inlet/outlet temperature of Riverwater (°C): 34/43
- Inlet/outlet temperature of freshwater (°C): 37/46

After heat exchange, freshwater is cooled down to the design value using Riverwater through 10 plate heat exchangers (capacity of each is 2050 m^3/h).

Freshwater is supplied to consumers by freshwater pumps P21201A/B/C (capacity of each pump is 10838 m^3/h, one standby), two driven by electric motors, and one by a turbine. The pumps are installed near the plate heat exchangers and provide water according to the plant's requirements, approximately 5.8-6 barg.

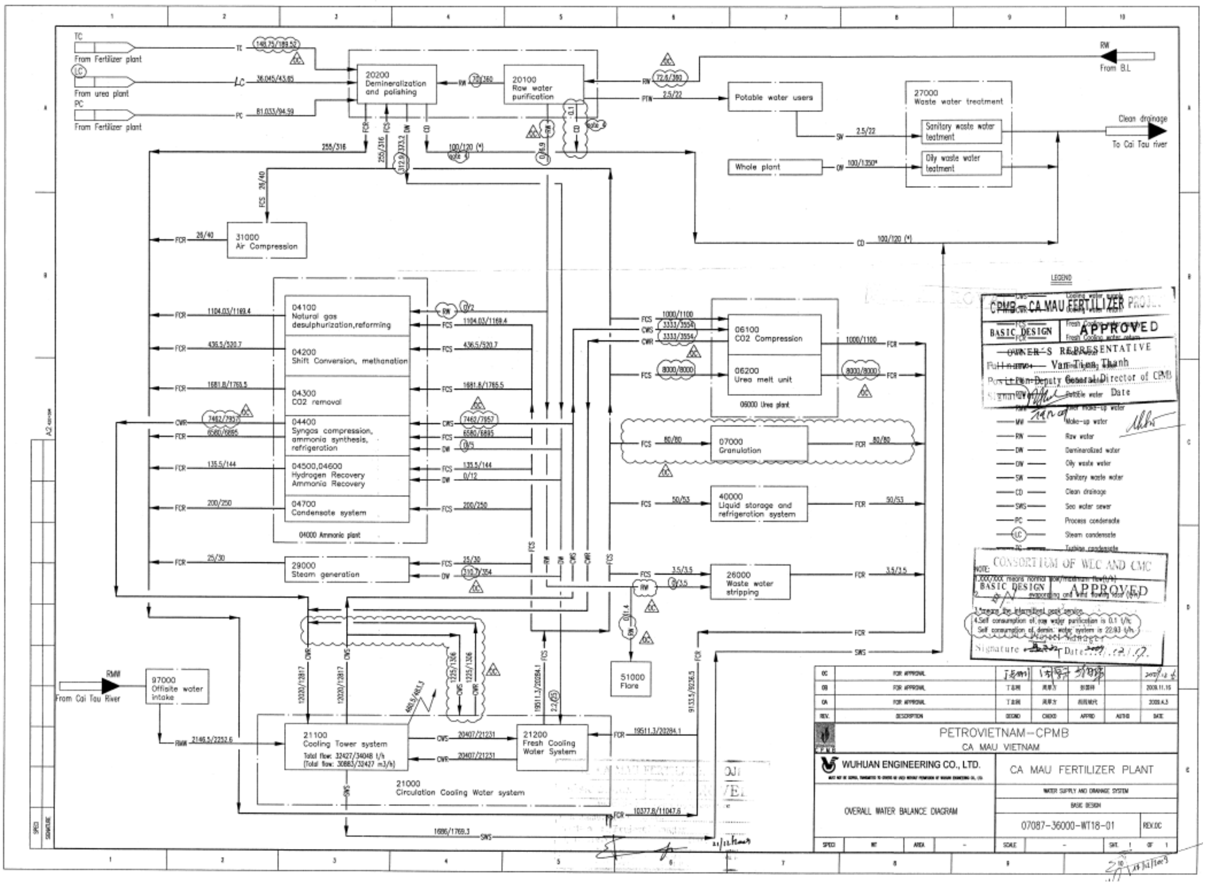


Figure 5.11. Overall cooling water system balance

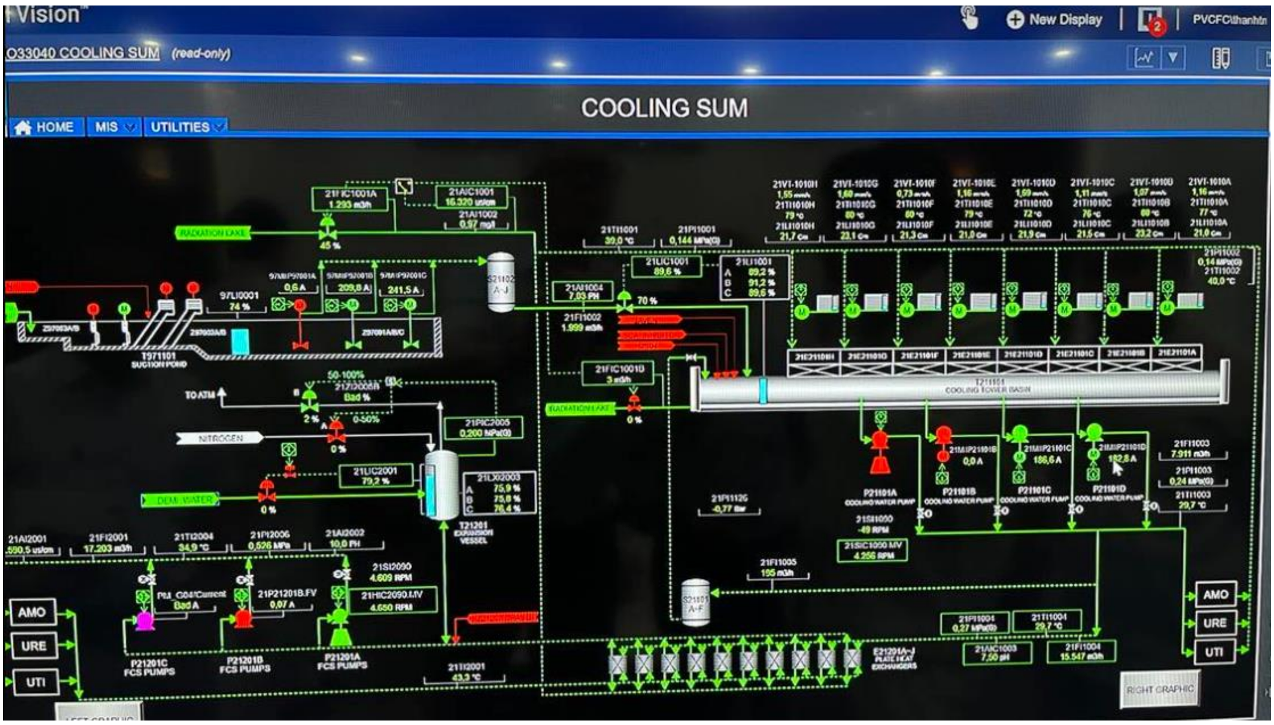


Figure 5.12. Overall cooling water system working data

A delta-T of 5 degrees is relatively high compared to other water-to-water plate heat ex-changers of similar size, where best practice design can be as low as 1 degree. A lower delta-T will improve process cooling all over the facility.

There are opportunities to apply cooling tower water directly for process cooling in some areas in stead of using fresh water cooling. This will make cooling more efficient due to lower feed temperature of cooling tower water and also increase the capacity on E21201H-T (eventually reducing delta-T).

If cooling capacity needs to be increased, it could be considered to use river water directly for certain cooling purposes – this will maybe be cheaper than installing new cooling towers, but any contamina-tion problem and filtration of river water has to be taken into account

PVCFC have already done comprehensive work to optimize cooling tower performance during 2023 and presently operates these close to a theoretical target temperature of the cooling water under the current ambient conditions (temperature and relative humidity).

During the site visit, the following readings were made:

- Ambient conditions during the site visit :
  - Relative Humidity 65.94%
  - Wet bulb temperature : 25.55 deg. C
  - Dry bulb temperature 31.58 deg. C
- Cooling tower temperature
  - Inlet Temperature : 40 deg. C
  - Outlet cold water temperature : 29.7 deg. C
- Range : 10.3 deg. C
- Approach : 4.15 (about 1-1.5 deg. C gap from best possible approach)
- Effectiveness : 71.3 %

As such it appears that the cooling water temperature is fine (can be optimized further), but that the efficiency of the cooling towers are not high enough due to a complicated mix of flows and cooling loads. This can be investigated further.

The actual operating temperatures of the cooling water system during the visit with an ambient temperature of approx. 27°C and a relative humidity of 70%, the cooling towers deliver a feedwater temperature of 29.7C, which is very close to the theoretical limit.

The theoretical limit was during the mission assessed to be 1-1½°C lower than 29.7°C. Such an improvement might be relatively expensive to achieve, and the other options considered in this report might be investigated first.

5.5.2 Cooling System Mapping

River water system (Cooling tower water)

Riverwater (Riverwater Cooling System) is directly used in all turbine condensers (E04401 26%, E06140 10% and E21102 4%, 40% in total) of the. Additionally, it is employed to cool the freshwater cooling system through plate heat exchangers E21201A~J (60%).

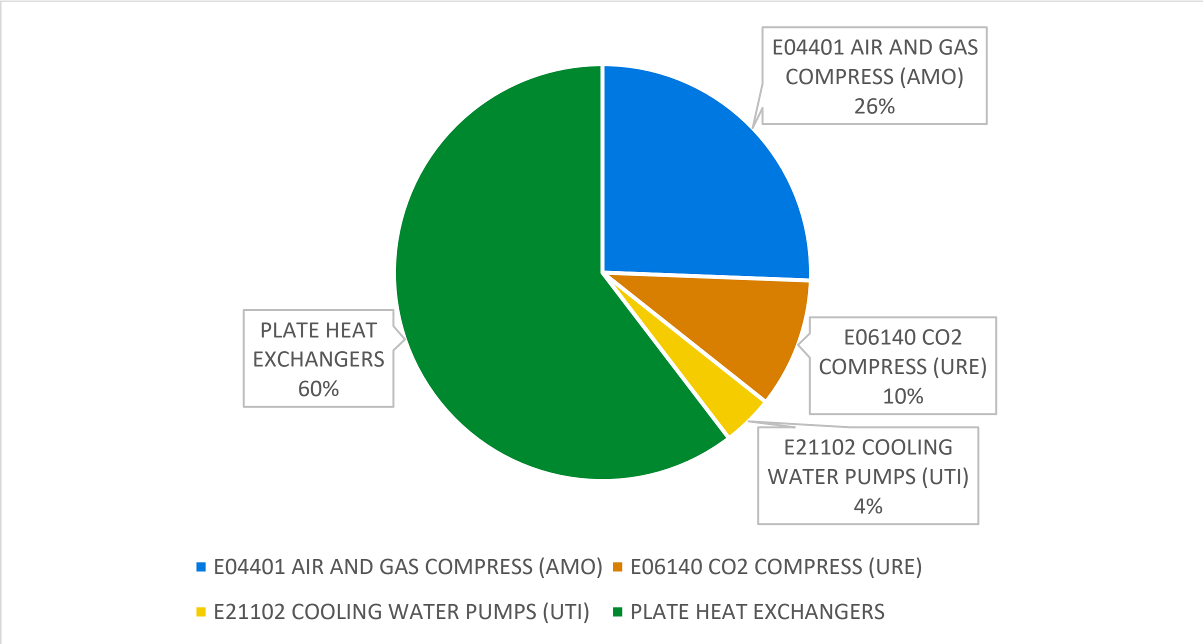


Figure 5.13. River cooling water mapping

Fresh water system

Freshwater is directly used in condensers and heat exchangers, except for turbine condensers in the plant, to reduce the temperature of process streams. It is then cooled down by Riverwater through Riverwater-freshwater plate heat exchangers E21201A~J.

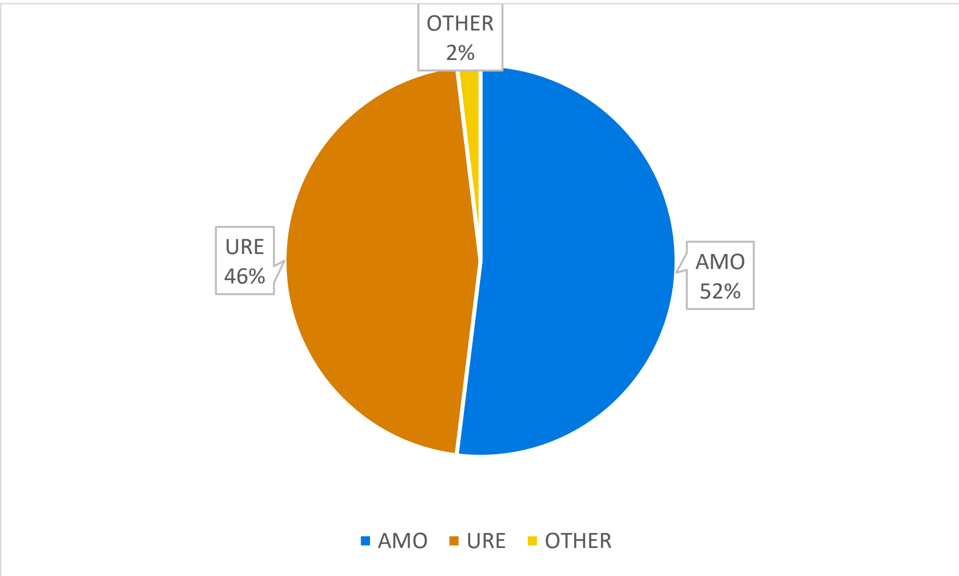


Figure 5.14. Fresh cooling water overall mapping

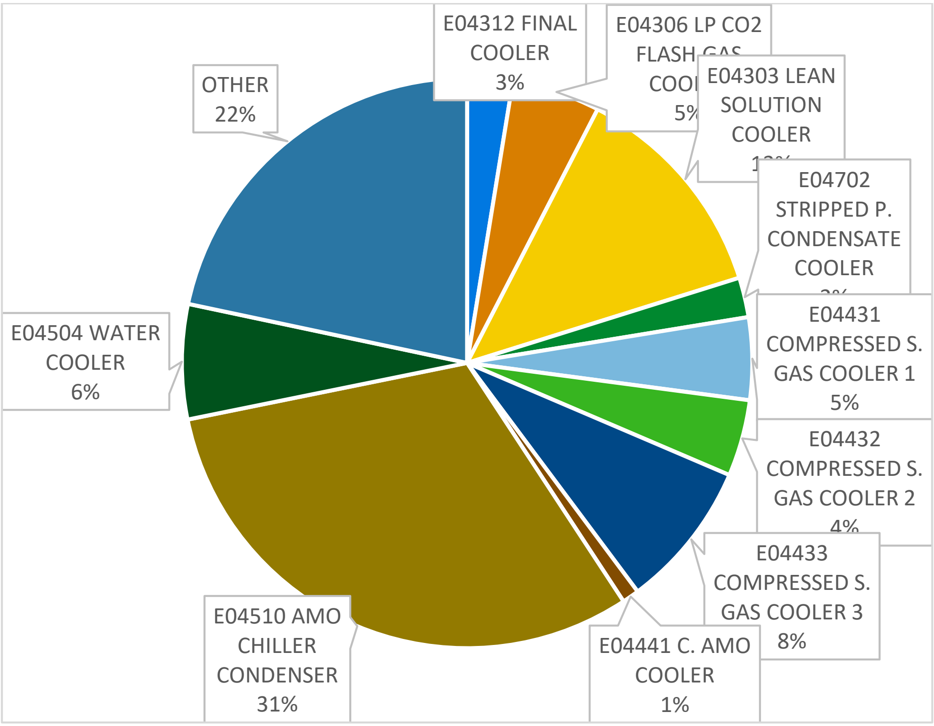


Figure 5.15. Fresh cooling water mapping for AMO section

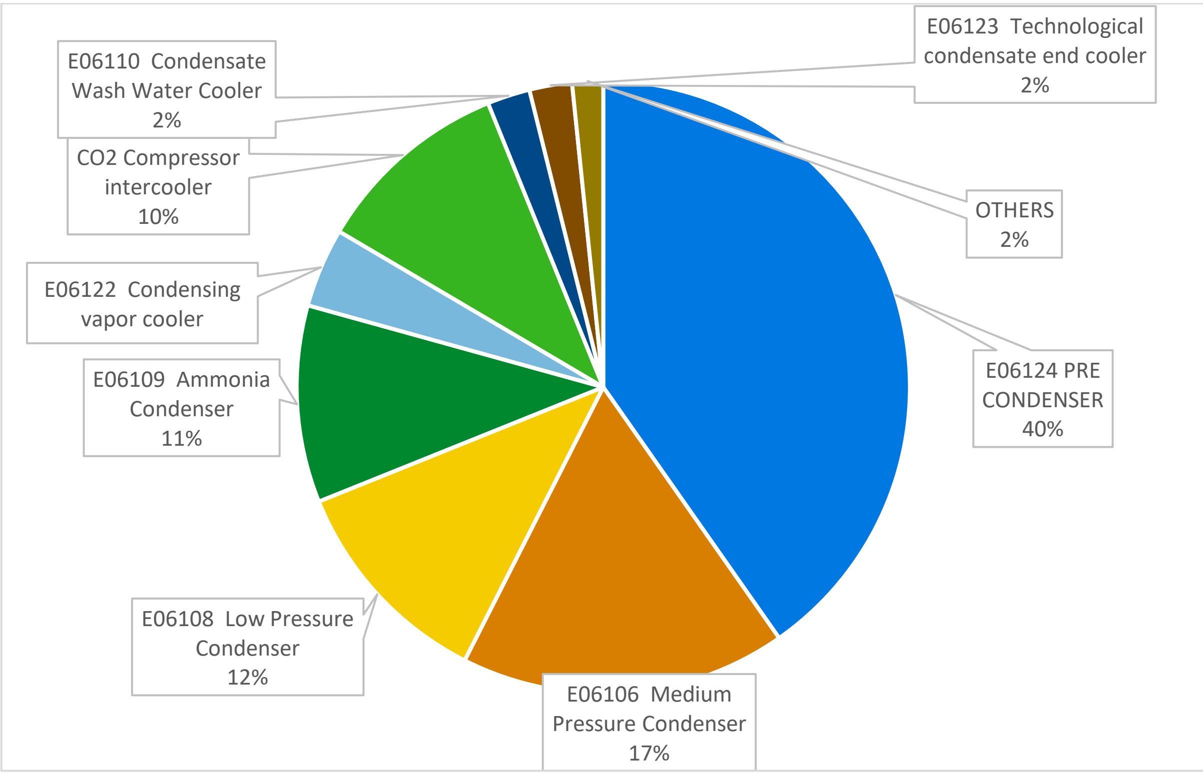


Figure 5.16. Fresh cooling water mapping for URE section

The amonia chilller condensor E04510 accounts for most of the cooling water demand of the AMO section. The condensor can be replaced with an Evaporative Condenser. This will improve the amonia chiller performance and significantly reduce the fresh cooling water demand.

As mentioned, there are opportunities for heat recovery from cooling system up to 28% of the total fresh water cooling load:

- E04510 AMO Chiller Condenser: Capacity: 28,650 kW; Operating Temperature: 102.4°C
- E04433 Compressed S. Gas Cooler 3: Capacity: 7,719 kW; Operating Temperature: 157.6°C
- E04221-E04224 C. Air Cooler: Operating Temperature: 124.8°C
- E06119 CO_2 compressor first intercooler: Capacity 3,217 kW, temperature in 170.2 ^oC
- E06120 CO_2 compressor second intercooler: Capacity 3,669 kW, temperature in 220.8 ^oC
- E06121 CO_2 compressor third intercooler: Capacity 2,722 kW, temperature in 177 ^oC.

6 Financial - technical obligations

6.1 Basic financial constraints

- Prices and basic costs are as of 2023.
- Prices and costs are based on the exchange rate between Vietnam Dong and USD: 1 USD = 25,642 VND (Average interbank exchange rate 03/2024).

6.2 Energy and standards

- Fuel costs and usage are collected from energy bills and documents.
- The CO_2 emission factor of Vietnam's power grid is 0.7221 tons of CO_2/MWh (according to Official Dispatch No. 1278/BĐKH-TTBVTOD of the Ministry of Natural Resources and Environment - Department of Climate Change issued on December 31, 2022).

Table 6.1. Major energy constraints and standards

No	Fuel type and standard	Unit	TOE/unit	Calorific value/unit (MJ/unit)	CO2 emission factor	
					Kg CO2/MJ	tons of CO2/unit
1	Electricity	1000 kWh	0.1543	-	-	0.8041
2	Coke	ton	0.7 – 0.75	29,309 – 31,402.5	0.0946	2.77 – 2.97
3	Coal dust type 1,2	ton	0.7	29,309	0.0983	2.88
4	Coal dust type 3,4	ton	0.6	25,122	0.0983	2.47
5	Coal dust type 5,6	ton	0.5	20,935	0.0983	2.06
6	DO (DO Oil)	ton	1.02	42,707.40	0.0741	3,165
		1000 liters	0.88	36,845.60		2.73
7	FO (FO Oil)	ton	0.99	41,451.30	0.0774	3,208
		1000 liters	0.94	39,357.80		3,046
8	CNG	ton	1.09	45,638.30	0.0631	2.88
9	Natural Gas (NG)	1000 m3	0.9	37,683.00	0.0561	2,114
10	Gasoline for cars and motorbikes	ton	1.05	43,963.50	0.0693	3,047
		1000 liters	0.83	34,752.10	-	2,408
11	Jet fuel	ton	1.05	43,963.50	0.0715	3,143
12	Rice husk/Other solid biomass	ton	-	16,100	0.1	-

- TOE coefficients are referenced by Official Dispatch No. 3505/BCT-KHCN, April 19, 2011.
- The energy conversion factor is calculated based on the conversion value of 1TOE = 41.868 MJ
- Calorific value coefficient (MJ/unit), CO_2 emission system for energy types are for reference only.

6.3 How to convert energy used to TOE units

Energy of fuels (direct conversion according to formula):

TOE = L x M x 41,868

In there:

- L – Specific heat energy (GJ/ton)
- M – Mass (tons)
- Conversion factor: 41.868 (GJ/TOE)

Electricity:

1kWh = 1.543 x 10-4 TOE

6.4 Evaluate energy saving measures

Basically the following values are determined to evaluate energy saving measures:

- Energy savings in thermal or electrical units (kJ or kWh)
- Energy savings by unit of mass, volume (ton, liter, m^3)
- Annual energy cost savings (VND/year)
- Capital costs to implement energy saving measures (VND, million VND)
- Payback period (months, years)

The formula for calculating payback period is as follows:

Payback period = (Initial investment cost [thousand VND])/(annual cost savings [thousand VND/year]); (years).

7 Energy saving solutions

7.1 Level B projects (screening list)

During the energy audit, a wide range of observations regarding potential energy savings were noted. Given the volume of these observations, it was not feasible to perform a detailed analysis on each one. Instead, all observations have been initially categorized as level B projects. Following in-depth discussions with facility staff, the most promising opportunities were identified and selected for further development into level A projects.

Level A projects represent the subset of initiatives that have been sufficiently refined and prioritized to justify the next step—a decision on whether to conduct a comprehensive pre-feasibility study. These projects have undergone a preliminary evaluation to assess their technical and economic viability, ensuring that only the most impactful and feasible opportunities advance to more detailed analysis.

A full presentation of the level A projects, including their expected benefits and implementation considerations, is provided in Section 7.2.

Table 7.1. Level B projects (screening list)

No.	Solutions	Detail
1	Rehabilitation of cooling systems	There are opportunities to apply cooling tower water directly for process cooling in some areas in stead of using fresh water cooling (5°C higher temperature) - This will make cooling more efficient due to lower feed temperature of cooling tower water - This will also increase the capacity on E21201H-T (eventually reducing delta-T) Promissing locations are: - Syn Gas compressor intercooler E04431, E04432, E04433 (16,629 kW). - Air compressor intercooler E04221, E04222, E04223, E04224 (9,738 kW) - CO2 compressor intercooler E06119, E06120, E06121 (11,040 kW)
2	Optimization of Plate Heat exchangers E21201H-T	A delta-T of 5 degrees for E21201H-T is relatively high compared to other water-to-water plate heat ex-changers of similar size. The current construction of the heat exchanger E21201H-T leaves a place for extra plates to increase size minimizing delta-T. Fresh cooling water temperature can ben reduced by about 1.1 oC after increasing E21201H-T size by 50%.
3	Use of VSDs to control the capacity of large fans and pumps	It has been observed that large manual valves are installed in multiple locations within the utility systems to regulate flow capacity. Specifically, the following dampers are partially closed: B07602 and B07603 (70%), B07605 (60%), and B07601 (50%). The plant has

		already planned to install a Variable Speed Drive (VSD) for B07602 to reduce energy consumption. It is recommended that VSDs also be considered for B07602, B07603 and B07605 to enhance energy efficiency.
4	Delta-T-hunting and improved heat recovery	E04503 (~195 GJ/h) has high delta-T that can be improved to recover heat and reduce cooling load at E04504.
5	Increased power production with ORC	After a comprehensive mapping of the heat exchangers and cooling system, the following waste heat sources have been identified as candidates for power production using an Organic Rankine Cycle (ORC) or for chilled water production using an absorption chiller: - E04510 AMO Chiller Condenser: Capacity: 28,650 kW; Operating Temperature: 102.4°C - E04433 Compressed S. Gas Cooler 3: Capacity: 7,719 kW; Operating Temperature: 157.6°C - E04221-E04224 C. Air Cooler: Operating Temperature: 124.8°C - E06119 CO2 compressor first intercooler: Capacity 3,217 kW, temperature in 170.2 ^{o}C - E06120 CO2 compressor second intercooler: Capacity 3,669 kW, temperature in 220.8 ^{o}C - E06121 CO2 compressor third intercooler: Capacity 2,722 kW, temperature in 177 ^{o}C.
6	Rehabilitation of boiler feedwater preheating system	Increase E04205 feedwater preheater size to recover more heat from pre-reformer furnace exhaust gas (160^{o}C).
7	Rehabilitation of condensers in ammonia chiller system to improve COP	Replacing the water-cooled condenser E04510 with an Evaporative Condenser. The condensing temperature can be reduced from 40.6oC to 33oC (temperature difference of 6.4oC), which can potentially increase the cooling capacity by 6.4%.
8	Optimization of compressed air systems operation	Including 1 or 2 compressors with VSD-drive to avoid frequent in-efficient load/un-load-operations
9	Assessment of potentials for use of biomass, CO2-capture and green hydrogen	There is potential to use biomass for the auxiliary boiler as a replacement for natural gas (NG). However, this option could impact plant operations and require further research. Therefore, it is not a priority at this time.
10	Waste heat recovery from AMO for drying NPK products	Excess heat from AMO section (E04433 Compressed S. Gas Cooler 3: Capacity: 7,719 kW; Operating Temperature: 157.6°C; E04221-E04224 C. Air Cooler: Operating Temperature: 124.8°C) can be transferred via high-pressure hot water to the NPK workshop, where there is a relatively high demand for heat to dry products at approximately 100°C. To implement this, additional heat exchangers and pipelines will be required to transport the waste heat to the consumption site.

11	Waste heat recovery from CO2 compressor intercooler	Utilize wates heat from CO2 compressor intercooler (E06119, E06120, E06121) for the Vacuum Evaporator (E06114) to reduce the low-pressure steam consumption.

7.2 Level A projects

7.2.1 Optimization of Plate Heat exchangers E21201H-T

Project information		
Project:	**Project no.**	**Date:**
Enterprise:	**Auditing company:**	**Auditor:**

Project description

Current situation

The fresh cooling water is cooled down by river water through 10 river water-fresh water heat plate exchangers E21201A~J with total duty of 214,225 kW.

Current working status:

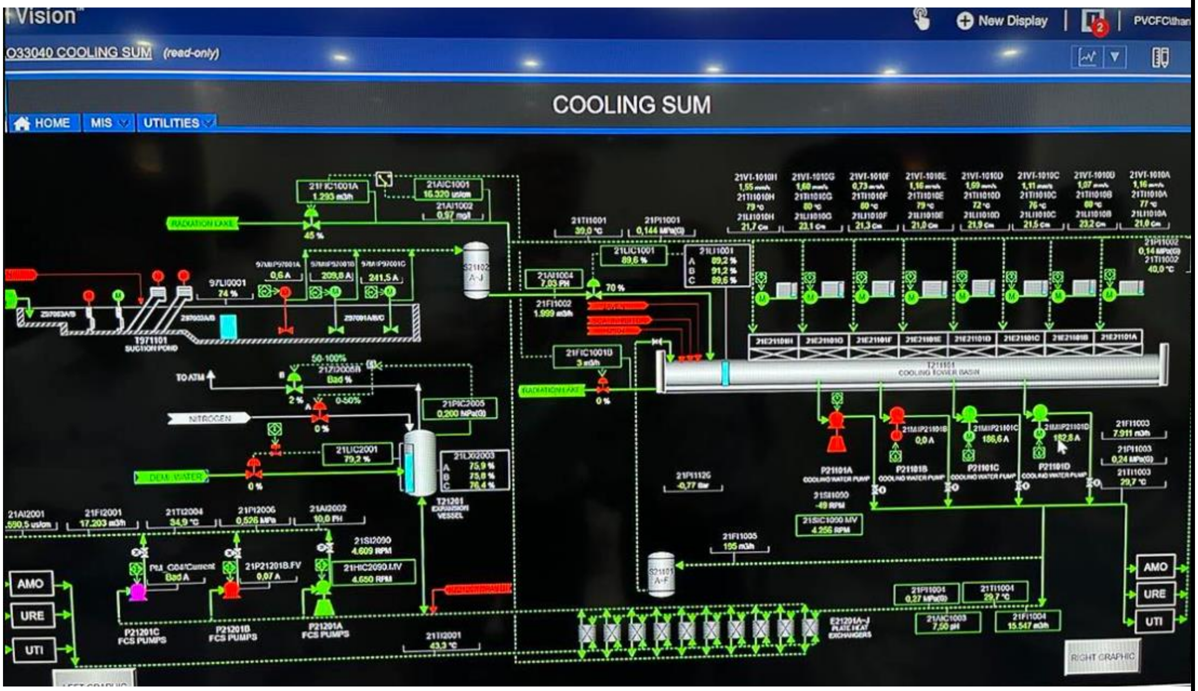


Figure 7.1. Current working status of water cooling system

Table 7.2. Current working status of river – fresh water plate heat exchangers

Flow configuration	Counter flow	
Medium	Hot: Water	Cold: Water
Flow (m3/h)	17,203	15,547
T In (oC)	43.3	29.7
T out (oC)	34.9	39
Delta T (K)	8.5	9.3
Heat flow rate Q (kW)	167,064	
Pinch point Delta T-pinch (K)	4.3	

Heat Transfer effective kA (kW/K)	35,360
Efficiency	0.68

A delta-T pinch of 4.3 degrees is relatively high compared to other water-to-water plate heat exchangers of similar size, where the best practice design can be as low as 1 degree. However, it is mainly because the current flow both primary and secondary has been reduced by cutting of 01 pumps on each side. The current construction of the heat exchanger system leaves a place for extra plates to minimize delta-T, see photo below.

Figure 7.2. River – Fresh water plate heat exchangers

Proposed project

Increase size of PHEs by 50%.

Table 7.3. Working status of river – fresh water plate heat exchangers after size increases

Flow configuration	Counter flow	
Medium	Hot: Water	Cold: Water
Flow (m3/h)	17,203	15,547
T In (oC)	43.3	29.7
T out (oC)	33.8	40.17
Delta T (K)	9.5	10.47
Heat flow rate Q (kW)	188,023	
Pinch point Delta T-pinch (K)	3.133	
Heat Transfer effective kA (kW/K)	52,332	
Efficiency	0.77	

Fresh cooling water temperature reduces by about 1.1 oC after increasing PHEs size by 50%.

- Reduced ~0.33% energy consumption for compressors (4 stage synth. Gas 16,629 kW, 5 stage air compressors 9,738 kW, and CO2 compressor 11,040 kW) ~ 125 kW
- Reduced ~3% energy consumption for the ammonia chiller 6,176 kW ~ 185 kW

Project illustration (PFD)

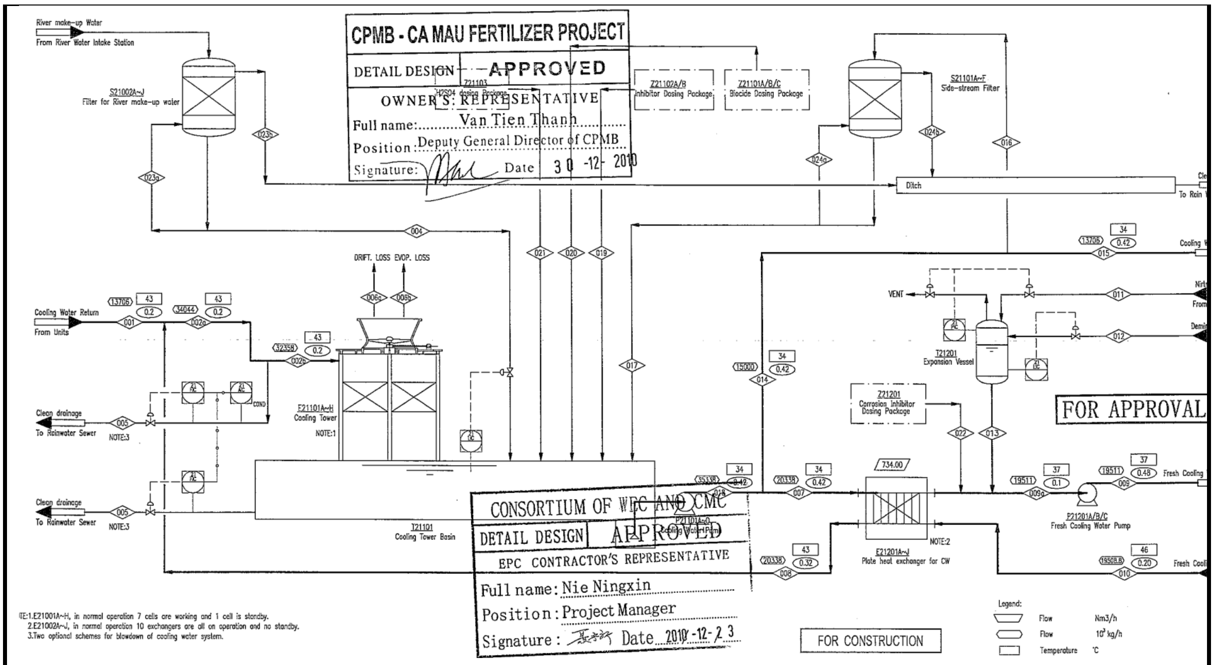


Figure7.1. River water-fresh water heat plate exchangers E21201A~J

Project Budget

Element	**Units**	**Unit costs**	**Costs**
Extra plate for plate heat exchanger	10	14,000	140,000
Installation	10	1,000	10,000
Total	**150,000**		

TIME SCHEDULE

Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Pre-feasibility												
Feasibility studies												
Final Investment Decisions					**X**							

Saving

Energy(annual): 9,811 GJ	**Financial (annual): 98,112 USD**
Co2 (annual): 550 tons	**Simple Payback (years): 1.5**

Risk Analysis

Risk	**Likelihood**	**Impact**	**Mitigation Measures**
Installation delays	Medium	Medium	Develop a detailed timeline and contingency plan. Ensure contractor availability and supply chain readiness.
Cost overrun	Low-Medium	High	Include a buffer in the budget (~10–15%). Use fixed-price contracts with suppliers and contractors.
Underperformance of PHEs	Low	High	Conduct detailed performance modeling and use high-quality materials. Perform rigorous testing post-installation.

Operational disruption	Medium	Medium	Schedule installation during low-demand periods or planned maintenance shutdowns.
Unexpected technical issues	Medium	Medium-High	Perform pre-installation system audits. Include expertise from experienced vendors/engineers.
Inaccurate energy savings estimation	Low	Medium	Use validated models for predictions and monitor performance post-implementation.
Environmental concerns	Low	Low	Ensure compliance with local environmental regulations during installation.
Stakeholder resistance	Low	Medium	Communicate the project's benefits clearly, including cost savings and sustainability impacts.

Non Energy benefits

- Increased production capacity via higher product flows and/or better performance of unit operations
- Support future capacity expansions

7.2.2 Replacement of Ammonia Refrigeration Condenser by Evaporative Condenser

Project information		
Project:	**Project no.**	**Date:**
Enterprise:	**Auditing company:**	**Auditor:**

Project description

Current situation

The current refrigeration system uses a water-cooled condenser to condense the refrigerant (NH3). The cooling water circulates in a closed water loop (Clean Water) and is cooled by the cooling tower's circulating water (River Water). Due to indirect heat exchange through 2-loops (figure below)., the condensing temperature of the refrigerant is high (~34.5oC), resulting in increased power consumption of the ammonia compressor.

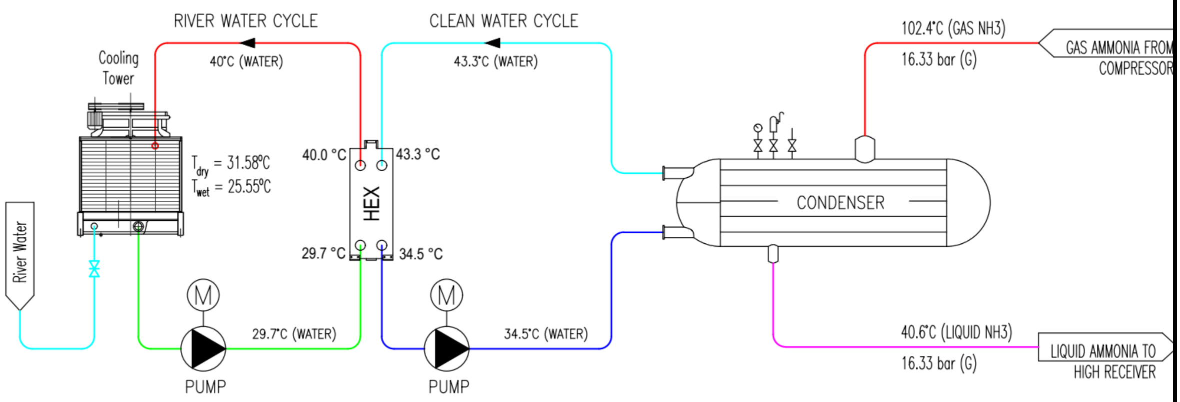


Figure 7.3. Current situation of the ammonia chiller condenser

Proposed project

In the ammonia refrigeration, if condensing temperature increase 1°C means approx.: 1% lower cooling capacity, 3% lower COP, and 3.1% higher power consumption. Therefore, to improve the energy efficiency of the refrigeration system, the condensing temperature of the refrigerant needs to be reduced. This can be achieved by replacing the water-cooled condenser with an Evaporative Condenser. The condensing temperature can be reduced from 40.6oC to 33oC (temperature difference of 6.4oC), which can potentially increase the cooling capacity by 6.4%, 19.2% higher COP and reduce the 20% power consumption. Reduced ~20% energy consumption for the ammonia chiller 6,176 kW ~ 1,232 kW.

Project illustration (PFD)

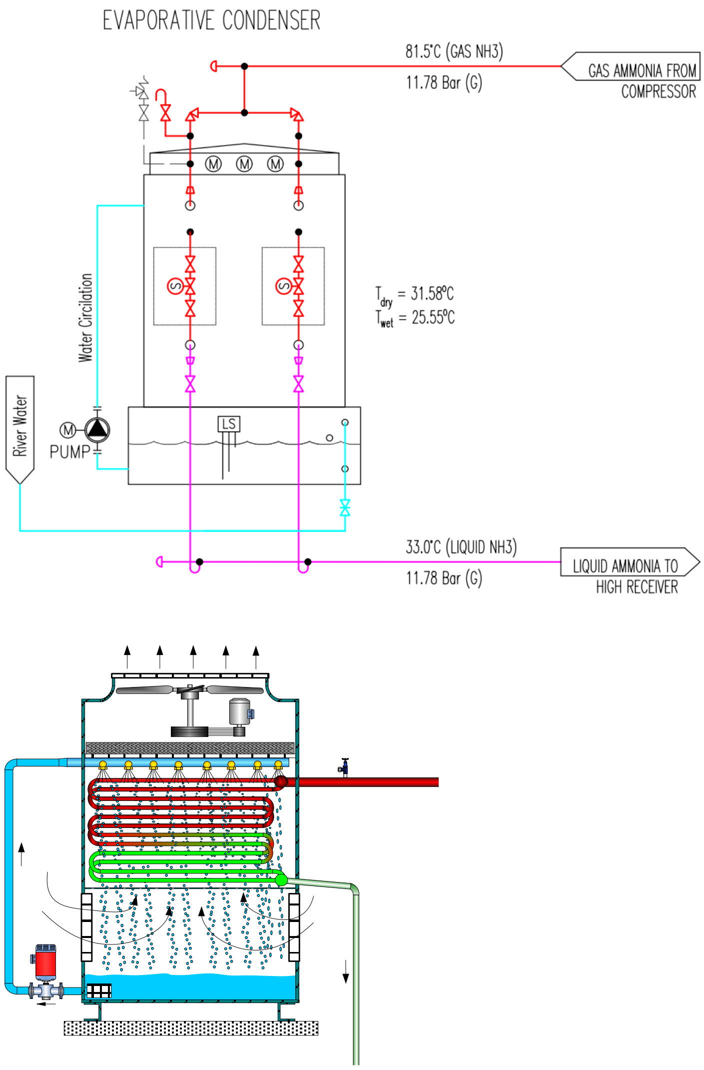


Figure 7.4. Ammonia chiller evaporative condenser

Project Budget

Element	Units	Unit costs	Costs
Evaporative condenser			
Old condenser removed			
Installation			
Total	**300,000**		

TIME SCHEDULE

Activity	1	2	3	4	5	6	7	8	9	10	11	12
Pre-feasibility	■											
Feasibility studies		■	■	■								
Final Investment Decisions				■	X							

Saving

Energy(annual): 38,806 GJ	Financial (annual): 388,000 USD/year

Co2 (annual): 2,134 tons	Simple Payback (years): 0.77

Risk Analysis

Risk	Likelihood	Impact	Mitigation Measures
Installation delays	Medium	Medium	Develop a detailed timeline and contingency plan. Coordinate with experienced contractors.
Cost overrun	Low-Medium	High	Include a 10–15% contingency buffer in the budget. Use fixed-price contracts.
Operational disruption	Medium	Medium	Schedule installation during planned shutdown periods.
Underperformance of evaporative condenser	Low	High	Ensure proper design and selection of evaporative condenser. Perform thorough commissioning tests.
Scaling or maintenance issues	Medium	Medium	Establish a regular maintenance plan to manage scaling and fouling risks.
Environmental compliance	Low	Low	Ensure the system adheres to local environmental and safety standards.

Non Energy benefits

- When the refrigeration system does not use clean water for cooling, the clean water circulation flow can be reduced by approx. 2,750 m3/h (~16% of total fresh cooling water flow). The reduced clean water flow will increase the heat exchange efficiency of the HEX and will reduce the temperature of the clean water, before it is supplied to other processes.
- Support future capacity expansions

7.2.3 Increase E04503 capacity to reduce energy loss at E04504.

Project information		
Project:	**Project no.**	**Date:**
Enterprise:	**Auditing company:**	**Auditor:**

Project description

Current situation

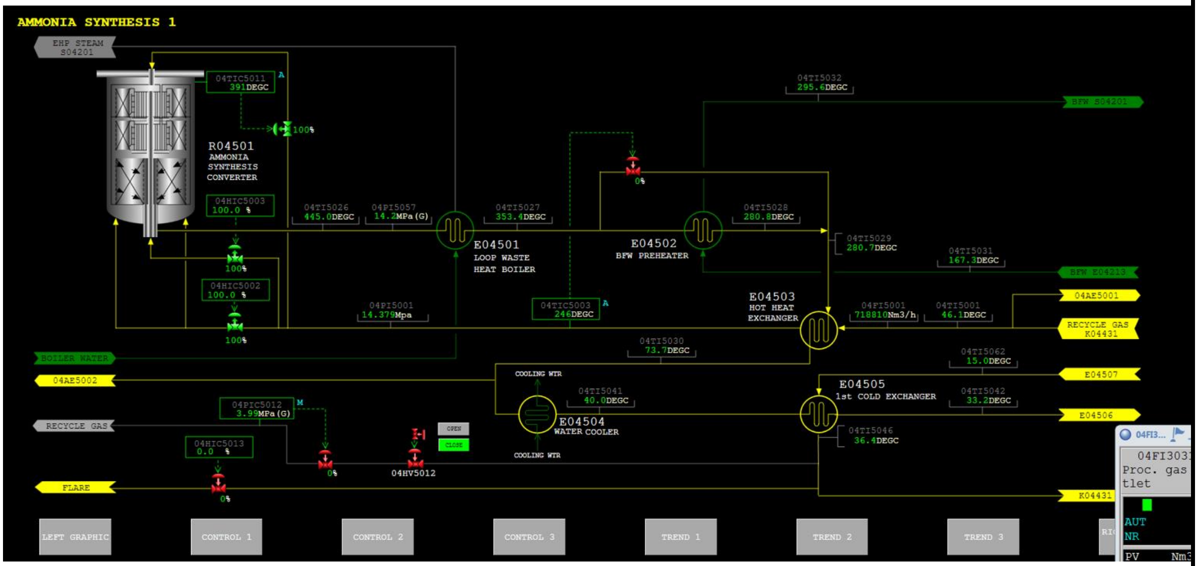


Figure 7.5. E04503 hot heat exchanger

The gas leaving the synthesis tower R04501 is cooled step by step, before being discharged in the waste heat boiler E04501 from a temperature of about 441oC to 340oC. Next, the gas is cooled to about 280-290oC in the boiler feed water heater E04502 and in the hot heat exchanger E04503, where the synthesis gas is cooled to 65oC by heating the synthesis tower inlet gas. The synthesis gas is then cooled to 41oC in the water chiller E04504 and further down, to 34-35oC in the heat exchanger E04505, which is used to heat the synthesis inlet gas.

E04503 (~195 GJ/h) has high delta-T that can be improved to recover heat and reduce cooling load at E04504.

Proposed project

Increase E04503 capacity by 12% to 234 GJ/h to recover heat and reduce cooling load at E04504. Heat recovery by heating inlet gas from 46.1OC to ~ 270 OC.

Project illustration (PFD)

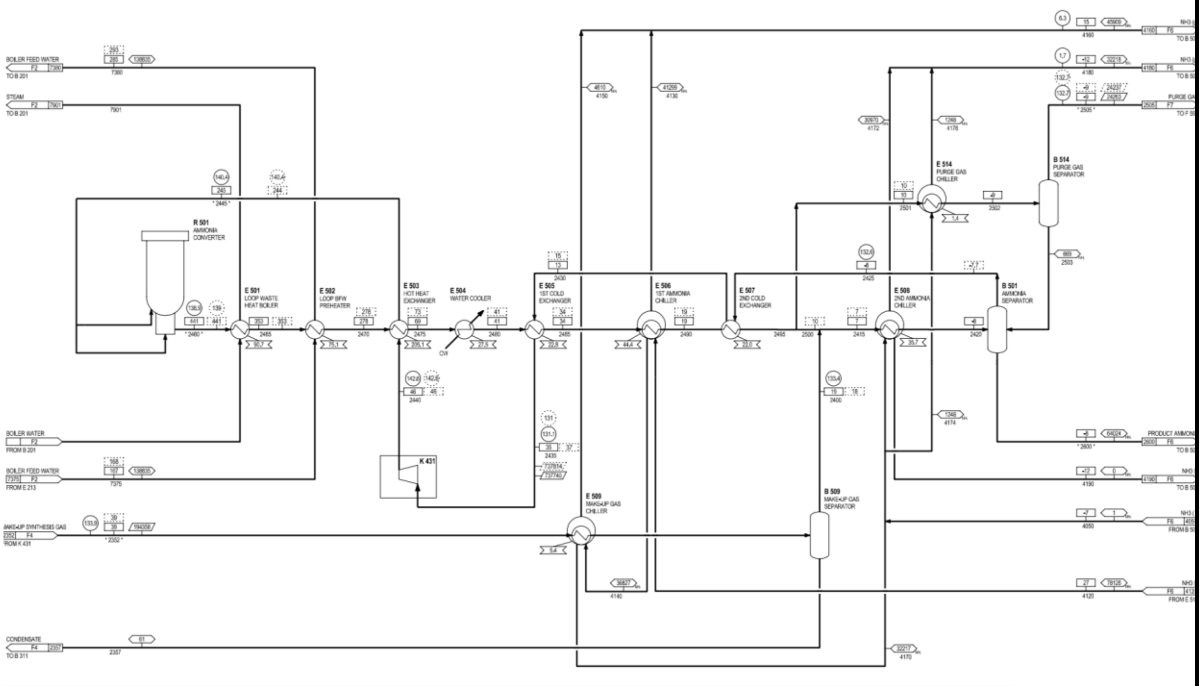


Figure7.2. E04503 hot heat exchanger

Project Budget

Element	Units	Unit costs	Costs
Total	**2,000,000 USD**		

TIME SCHEDULE

Activity	1	2	3	4	5	6	7	8	9	10	11	12
Pre-feasibility												
Feasibility studies												
Final Investment Decisions					X							

Saving

Energy(annual): 131,400 GJ	**Financial (annual): 1,314,000 USD/year**
Co2 (annual): 7,227 tons	**Simple Payback (years): 1.52 years**

Risk Analysis

Risk	Likelihood	Impact	Mitigation Measures
Design or sizing errors in E04503	Low	High	Use advanced modeling and experienced engineering consultants. Perform detailed design reviews.
Cost overrun	Medium	Medium	Include a contingency budget of ~10–15%. Negotiate fixed-price contracts with suppliers.
Installation disruptions	Medium	Medium	Schedule work during planned maintenance shutdowns to avoid unplanned downtime.

Underperformance of E04503	Low	High	Conduct thorough performance testing during commissioning. Choose a proven, high-quality design.
Scaling and fouling issues	Medium	Medium	Regularly monitor and maintain the heat exchanger to prevent performance degradation.

Non Energy benefits

- Reduce cooling load at E04504 by reducing input temperature to ~ 50 OC thus reducing fresh cooling water flow.
- Support future capacity expansions

7.2.4 Direct use of cooling tower water for intercooler of compressors

Project information

Project:	Project no.	Date:
Enterprise:	Auditing company:	Auditor:

Project description

Current situation

Freshwater is directly used in condensers and heat exchangers, except for turbine condensers in the plant, to reduce the temperature of process streams. It is then cooled down by Riverwater through Riverwater-freshwater heat exchangers E21201A~J. The temperature of fresh cooling water is higher than the temperature of river cooling water by 5oC.

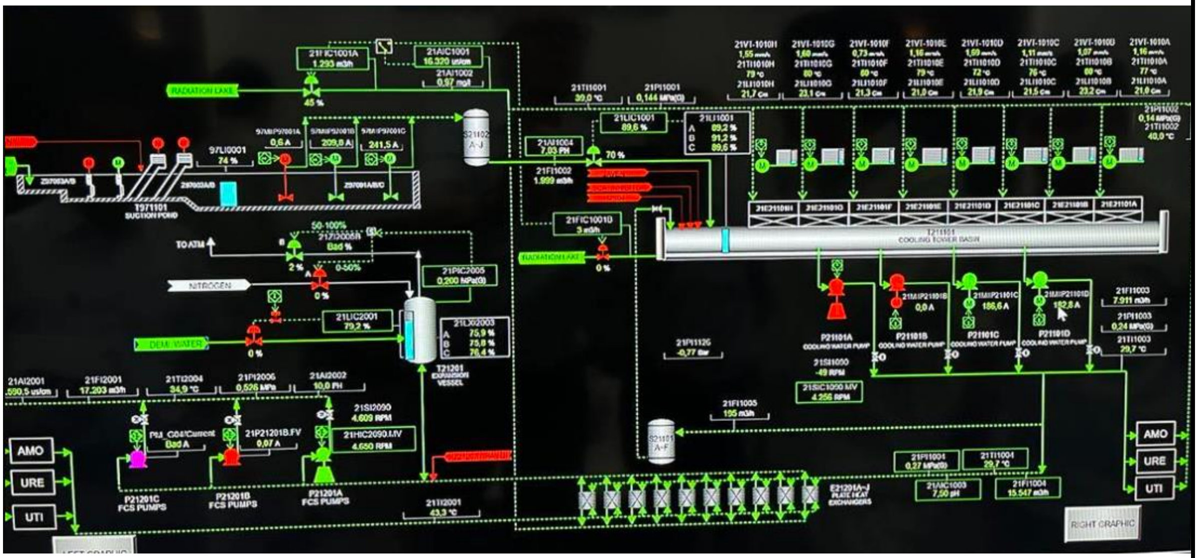


Figure7.3Water cooling system

Proposed project

There are opportunities to apply cooling tower water directly for process cooling in some areas in stead of using fresh water cooling,

- This will make cooling more efficient due to lower feed temperature of cooling tower water
- This will also increase the capacity on E21201H-T (eventually reducing delta-T)

Promissing locations are:

- Syn Gas compressor intercooler E04431, E04432, E04433 (16,629 kW).
- Air compressor intercooler E04221, E04222, E04223, E04224 (9,738 kW)
- CO2 compressor intercooler E06119, E06120, E06121 (11,040 kW)

By reducing cooling water temperature 5oC, the energy consumption for compressors can reduce ~ 1.65%.

Project illustration (PFD)

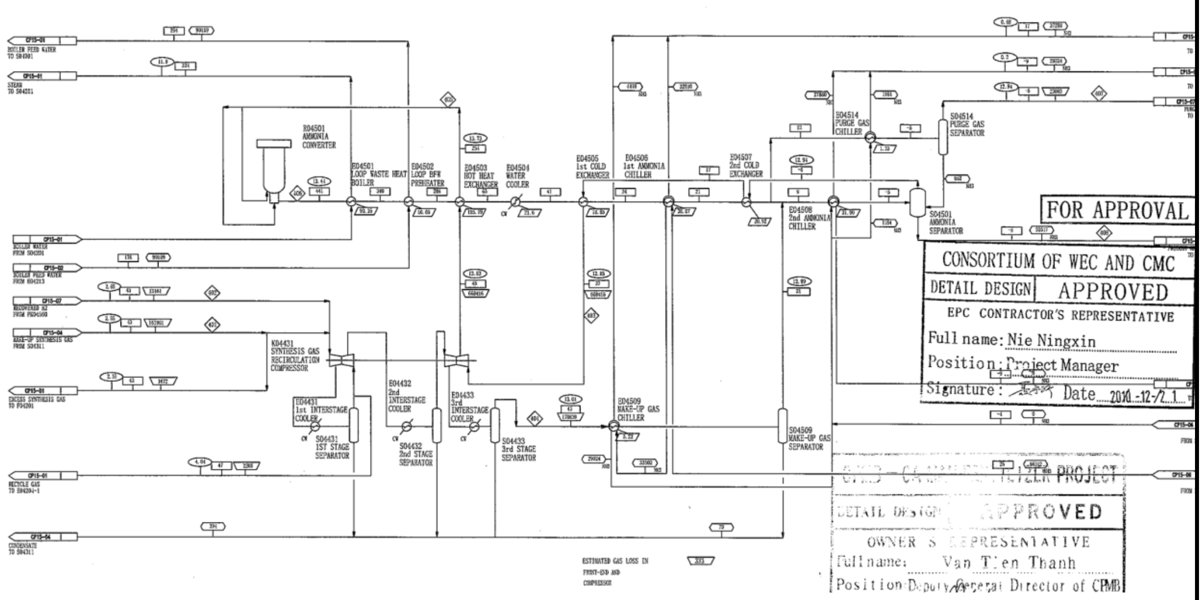


Figure 7.6. Intercooler of synthesis gas compressors

Project Budget

Element	Units	Unit costs	Costs
Piping and Valves	Lot	150,000	150,000
Instrumentation & Control		50,000	50,000
Water Treatment System Upgrade		100,000	100,000
Engineering & Design		50,000	50,000
Installation & Commissioning		100,000	100,000
Contingency		50,000	50,000
Total	**500,000 USD**		

TIME SCHEDULE

Activity	1	2	3	4	5	6	7	8	9	10	11	12
Pre-feasibility												
Feasibility studies												
Final Investment Decisions					X							

Saving

Energy(annual): 49,055 GJ	**Financial (annual): 490,560 USD/year**
Co2 (annual): 2,750 tons	**Simple Payback (years): 1.02 year**

Risk Analysis

Risk Description	Likelihood	Impact	Mitigation Strategy
Inadequate Cooling Tower Water Treatment leading to corrosion/scaling/fouling	2-Medium	3-High	Implement a robust water treatment program with appropriate corrosion inhibitors, biocides, and regular monitoring. Conduct regular inspections of intercoolers.
Incompatibility of materials with cooling tower water	1-Low	3-High	Thorough material compatibility assessment during the design phase. Confirm material specifications with vendors.

Unexpected impact on cooling tower performance	2-Medium	2-Medium	Detailed hydraulic calculations and modeling during the design phase. Monitor cooling tower performance after implementation.
Insufficient cooling capacity from the cooling tower	1-Low	3-High	Verify cooling tower capacity against required cooling load during the design phase.
Increased maintenance requirements for intercoolers	2-Medium	2-Medium	Implement a preventive maintenance program for the intercoolers. Monitor intercooler performance and schedule regular inspections.
Unplanned shutdowns due to cooling system issues	1-Low	3-High	Implement redundancy in the cooling system where feasible. Develop emergency procedures for cooling system failures.

Non Energy benefits

- Reduced Freshwater Consumption. By switching to cooling tower water, the project directly reduces the demand for freshwater resources. This is particularly important in regions with water scarcity or where freshwater treatment is energy-intensive. This aligns with sustainability goals and can improve the plant's environmental footprint.
- Increased Heat Exchanger Capacity/Efficiency. As highlighted in the project description, using colder cooling tower water can increase the capacity and efficiency of existing heat exchangers (E21201H-T).
- Increased Production Capacity/Revenue. If applicable, quantify the potential increase in production output or product quality resulting from improved cooling.