INITIAL ASSESSMENT OF TECHNICAL AND ECONOMIC POSSIBILITY OF BACKUP FUEL SYSTEMS AT THE CHP-NORD IN BALTI, MOLDOVA

MOLDOVA ENERGY SECURITY ACTIVITY

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ACRONYMS

BOG	Boil-Off Gas
CAPEX	Capital Expenditure
CHP	Combined Heat and Power or Cogeneration
CNG	Compressed Natural Gas
DF	Diesel Fuel
JSC	Joint-Stock Company
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NPV	Net Present Value
SCADA	Supervisory Control and Data Acquisition

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EXECUTIVE SUMMARY

CHP-Nord is faced with the task of installing a viable backup fuel system and storing backup fuel at its combined heat and power plant (CHP) in the city of Balti, Moldova to ensure reliable heat supply for the city's population. This report, produced under the U.S. Agency for International Development (USAID) Moldova Energy Security Activity, assesses the technical and economic possibility of backup fuel systems at the CHP.

In Phase 1, the team conducted a preliminary technical and economic analysis of the possible backup fueling options at CHP-Nord, identifying an alternative to mazut (fuel oil), for the subsequent more detailed technical and economic analysis. Phase 2 included an initial assessment of the technical and economic possibility of developing and operating an alternative backup fuel facility while restoring and operating the mazut facility at CHP-Nord. The following recommendations are based on the Phase 1 preliminary analysis of backup fuel systems at CHP-Nord (as alternatives to the mazut facility):

- Liquefied natural gas (LNG) cannot currently be recommended as a backup fuel for a number of reasons, primarily due to the very high capital costs of building an LNG storage facility at the CHP and the extremely high capital costs of building a micro liquefaction plant at the CHP.

- Compressed natural gas (CNG) also cannot currently be considered as a backup fuel due to the extremely high cost of building a CNG storage facility.

- Diesel fuel was recommended as one of the backup fuel alternatives to mazut. A preliminary technical and economic analysis was completed to estimate the capital cost of developing a diesel facility and related operating expenses.

- Liquefied petroleum gas (LPG) was recommended as a backup fuel alternative to mazut. A preliminary technical and economic analysis was completed for the capital cost of building the LPG facility and for expected operating expenses.

These preliminary findings were presented to and discussed with CHP-Nord representatives, who selected the LPG option for the Phase 2 analysis. Phase 2 provides a more detailed technical and economic analysis of developing and operating the LPG facility and compares it to restoring and operating the mazut facility. During a site visit, the team inspected the mazut facility, inventoried all equipment, prepared a preliminary specification of the facility's restoration, and made preliminary estimates of the capital costs and expected operating expenses.

The Phase 2 assessment resulted in the following conclusions and recommendations:

- Although the capital cost of restoring the mazut facility is lower than that of the LPG facility and although mazut is cheaper, the following economic benefits of the LPG option are noted, as presented in Table 1:
  - The estimated annual operating expenses of the LPG facility (not including the cost of a ten-day fuel supply, which may not be needed for several years) are about 5 percent of the annual operating expenses of the mazut facility.
  - The estimated net present value (NPV) of developing and operating the LPG facility (including backup fuel costs) is less than that of restoring and operating the mazut facility by 10 percent for a 10-year period and 28 percent for a 20-year period.

TABLE 1. INITIAL ANALYSIS OF COSTS OF RESTORING AND OPERATING THE MAZUT FACILITY VS. DEVELOPING AND OPERATING THE LPG FACILITY (€)

BACKUP FUEL OPTIONS	CAPITAL AND REPAIR COSTS	ANNUAL OPERATING EXPENSES			NET PRESENT VALUE WHEN USING FUEL RESERVES ONCE IN FIVE YEARS	
					EVALUATION PERIOD	
		EXCLUDING TEN-DAY FUEL SUPPLY COST	TEN-DAY FUEL SUPPLY COST	TOTAL	10 YEARS	20 YEARS
Mazut facility	1,106,050	445,965	1,800,878	2,246,843	7,928,983	13,029,857
LPG facility	2,954,850	23,567	2,288,841	2,312,409	7,082,456	10,217,822

- LPG also has the following advantages:
  - Opportunity to maximize the efficiency of fuel systems.
  - Premixed LPG-air has a calorific value close to that of natural gas.
  - There is no need to use more expensive special burners for burning both gaseous and liquid fuels, as would be required when firing mazut or diesel fuel.

- LPG is not subject to a significant increase in viscosity at low temperatures, which is a problem for transporting mazut and diesel fuel from the fuel storage to the CHP's burners.

- Switching from natural gas to LPG takes a maximum of 60 seconds and can be done automatically.

- LPG is considered an alternative clean fuel that pollutes the environment significantly less than either mazut or diesel fuel.

* LPG can be used in the future if CHP-Nord installs gas turbines or a combined-cycle power unit

* LPG has a long history as a fuel for power generation in refinery and power generation systems worldwide.

1. INTRODUCTION

1.1. BACKGROUND

This work, carried out under the U.S. Agency for International Development (USAID) Moldova Energy Security Activity, assesses the technical and economic possibility of backup fuel systems at the combined heat and power plant (CHP) located in the city of Balti, Moldova. The plant is owned by Joint-Stock Company (JSC) CHP-Nord, a company with state capital that is the main producer of electricity and thermal energy and a distributor and supplier of thermal energy in the Balti municipality.

CHP-Nord's mission is to meet customer requirements by providing competitive district heating products and services while constantly improving efficiency and performance and increasing its share of the country's energy mix. It aims to produce reliable thermal and electricity supply while meeting environmental and safety standards. To do so, it must install a backup fuel system at the Balti plant, where backup fuel is currently lacking.

Balti is an industrial city. Its population was 158,800 in 2021, including the village of Elizaveta (3,326 residents) and the village of Sadovoe (1,312 residents), which are not connected to the district heating system. CHP-Nord provides thermal energy (for domestic hot water and space heating) to 121,700 residents as well as municipal, commercial, and industrial customers. In addition, the CHP produces electric power.

The climate in Balti is continental temperate, similar to the rest of the country, with hot summers, short autumns, cold winters, and short springs. The heating season typically starts in October–November and ends in March–April, with an average length of 172 days. The reference temperature for space heating is 18 ˚C for the residential sector and 20 ˚C (or 22 ˚C) for schools and kindergartens. The average temperature of the coldest period is −8 ˚C for 95 days. The average annual temperature is 9 ˚C, the all-time maximum temperature was 39 ˚C, and the all-time minimum was −35 ˚C.

1.2. COMPLETED WORK

Work on this report included two phases:

- Phase 1: Preliminary technical and economic analysis of the possible backup fueling options at CHP-Nord, identifying an alternative to mazut (fuel oil), for the subsequent more detailed technical and economic analysis.

- Phase 2: Initial assessment of the technical and economic possibility of developing and operating an alternative backup fuel facility while restoring and operating the mazut facility at CHP-Nord.

PHASE 1

The team's experts visited CHP-Nord from February 28 to March 2, 2023; met with CHP-Nord management and engineering personnel; inspected equipment; and collected initial information regarding the CHP's condition, fuel consumption, and reliability of fuel supply as well as the condition of the mazut facility, which has barely operated since 2002. In 2009, during the natural gas crisis, there was an attempt to use mazut. For two to three days, CHP-Nord operated on mazut mixed with natural gas and then completely switched back to natural gas. During this visit, multiple discussions were held with CHP-Nord management and other staff regarding alternative backup fuel options.

From March 28 to 29, 2023, the team's expert visited CHP-Nord, studied the technological schematics of the mazut facility, and completed an inventory of equipment with the support of representatives of CHP-Nord.

On May 24, 2023, the local expert team presented to representatives of CHP-Nord the preliminary analysis of reserve fuel options at CHP-Nord, covering the preliminary technical economic analysis of the four options of backup fuel alternatives: liquefied natural gas, compressed natural gas, diesel fuel, and liquefied petroleum gas.

Between these trips, the team's experts continued to work regularly with representatives of CHP-Nord to collect data, better understand equipment performance, and discuss the preliminary results of technical and economic calculations.

As a result of the presentation and discussions with CHP-Nord representatives, the LPG option was selected for more detailed technical and economic analysis.

PHASE 2

The Phase 2 analysis covers the initial assessment of developing and operating an LPG facility and comparing it to restoring and operating the mazut facility.

The results of the Phase 1 and Phase 2 activities are summarized in this technical report.

1.3. REPORT STRUCTURE

Section 2 summarizes the results of the initial technical and economic assessment of CHP-Nord's possible backup fuel systems.

Section 3 provides a preliminary technical and economic analysis of the possible backup fuel system options identified in Phase 1, which are alternatives to mazut for more detailed technical and economic analysis.

Section 4 presents the initial technical and economic assessment, performed in Phase 2, of the technical and economic possibility of developing and operating an LPG facility compared to restoring and operating the mazut facility.

2. RESERVE FUEL OPTIONS CONSIDERED

Because CHP-Nord uses natural gas as its main fuel and, in the past, used mazut as a backup fuel for many years, the team considered the following NG and oil product backup fuel system options:

- Natural gas
  - Liquefied natural gas (LNG)
    - Delivery – storage – regasification – use
    - Liquefaction – storage – regasification – use
  - Compressed natural gas (CNG)
- Oil products
  - Mazut (as baseline)
  - Diesel fuel (DF)
  - Liquefied petroleum gas (LPG).

Figure 2.1.1. CHP-Nord turbine and boiler shop

Fuel prices in Moldova on June 5, 2023, are presented in Table 2.1.1.

TABLE 2.1.1. NATURAL GAS, MAZUT, DIESEL, LPG PRICES

INDICATORS	UNIT	MDL (without VAT)	€[1] (without VAT)	€/kWh
NG[2]	m^3	13,514.00	718.16	0.086
Mazut[3]	ton	15,315.75	813.91	0.085
Diesel[4]	liter	15.94	0.847	0.096
LPG[4]	liter	12.95	0.688	0.109

Notes: [1] Exchange Rate MDL/€, June 5, 2023, oanda.com: 18.817421

[2] Regulated prices, 03.09.2022; CHP-Nord; https://anre.md/tarife-reglementate-de-furnizare-3-269

[3] Termoelectrica S.A.

[4] https://anre.md/

3. PRELIMINARY ANALYSIS OF BACKUP FUEL OPTIONS

3.1. CHP EQUIPMENT AND BACKUP FUEL REQUIREMENTS

3.1.1. MAIN CHP EQUIPMENT

CHP-Nord is a gas-fired CHP with installed electric capacity of 37.416 MW and thermal capacity of 150 Gcal/h. It has six steam boilers: GM-40/39 H2 (1954), GM-40/39 H3 (1957), BK3-75/39 no. 4 (1960), BK3-75/39 no. 5 (1962), BK3-75/39 no. 6 (1968), and E75-3,9-440 ГМА (1990). CHP-Nord also has two steam turbines (GM-40/39 H2, installed in 1995 and 2005) and four gas engines (Jenbacher JMS 620 GS-N.L., installed in 2019) (see Table 3.1.1).

TABLE 3.1.1. CHP-NORD STEAM BOILERS, TURBINES, AND GAS ENGINES

MODEL NAME	INSTALLATION YEAR	INSTALLED CAPACITY		OPERATING HOURS
		ELECTRIC	THERMAL	
Steam boilers				
GM-40/39 H2	1954		26 Gcal/h	205,929
GM-40/39 H3	1957		26 Gcal/h	168,832
BK3-75/39 no. 4	1960		26 Gcal/h	248,975
BK3-75/39 no. 5	1962		26 Gcal/h	244,806
BK3-75/39 no. 6	1968		26 Gcal/h	211,209
E75-3,9-440 ГМА	1990		26 Gcal/h	39,203
Steam Turbines				
ПТ-12/13-3,4/1,0-1	2005	12 MW		61,622
ПТ-12/15-35/10-M	1995	12 MW		107,506
Gas engines				
JMS 620 GS-N.L.	2019	3,354 MWe	3,125 MWt	17,035
JMS 620 GS-N.L.	2019	3,354 MWe	3,125 MWt	16,939
JMS 620 GS-N.L.	2019	3,354 MWe	3,125 MWt	16,905

JMS 620 GS-N.L.	2019	3,354 MWe	3,125 MWt	16,854

Source: JSC CHP-Nord, February 13, 2023

TABLE 3.1.2. MONTHLY CONSUMPTION OF NATURAL GAS, 2020–2022

YEAR / MONTH	AVERAGE OUTDOOR TEMPERATURE	NATURAL GAS CONSUMED	HEAT SUPPLIED TO DISTRICT HEATING	ELECTRICITY PRODUCED		
				STEAM TURBINES	GAS ENGINES	ELECTRICITY SUPPLIED TO
	˚C	000’ Nm^3	Gcal	MWh	MWh	MWh
2020						
January	0.4	7,965.75	38,206	9,928.9	9,704.1	17,352.2
February	3.5	6,388.38	29,994	7,193.8	9,211.9	14,342.7
March	7.0	5,642.90	24,951	5,826.0	9,823.8	13,928.2
April	7.0	2,394.12	7,571	1,627.1	6,347.5	7,192.5
May	13.6	596.36	1,192		2,476.6	2,055.4
June	20.9	579.01	620		2,387.2	2,002.3
July	22.3	602.08	881		2,481.1	2,142.8
August	23.0	598.41	844		2,476.9	2,121.6
September	19.3	581.30	934		2,397.0	2,041.1
October	13.8	1,906.41	7,062	923.4	5,396.9	5,515.1
November	4.3	6,134.69	27,557	6615.9	9,445.6	14,338.9
December	1.7	7,694.30	36,043	9401.4	9,879.2	17,430.3
2021						
January	0.6	8,389.70	39,657	10,089.3	9,812.4	18,067.6
February	-1.5	7,747.31	37,294	9,569.4	8,511.9	16,284.2

TABLE 3.1.2. MONTHLY CONSUMPTION OF NATURAL GAS, 2020–2022						
YEAR / MONTH	AVERAGE OUTDOOR TEMPERATURE	NATURAL GAS CONSUMED	HEAT SUPPLIED TO DISTRICT HEATING	ELECTRICITY PRODUCED		
				STEAM TURBINES	GAS ENGINES	ELECTRICITY SUPPLIED TO
	˚C	000' Nm^3	Gcal	MWh	MWh	MWh
March	3.0	6,790.38	31,378	7,596.5	9,860.6	15,606.3
April	7.8	3,319.83	14,096	2,805.3	7,027.7	8,631.5
May	14.6	608.15	1,101		2,473.4	2,093.4
June	19.7	588.94	1,043		2,404.6	2,024.0
July	22.9	609.15	1,076		2,487.3	2,070.9
August	20.4	606.77	1,037		2,478.6	2,082.2
September	14.3	588.30	1,146		2,406.3	2,009.6
October	8.8	1,112.95	3,216		4,558.4	4,015.1
November	5.8	5,310.22	24,782	5,285.2	9,356.4	13,039.4
December	0	7,764.23	37,906	9,954.1	8,308.8	16,493.5
2022						
January	-0.1	8,193.44	39,426	10,016.1	9,773.7	17,977.8
February	2.8	5,835.62	27,112	6,709.2	8,603.2	13,815.5
March	2.8	6,611.99	31,065	7,716.4	9,495.5	15,538.6
April	9.6	430.70	1,404	29.3	1,808.2	1,476.9
May	15.7	345.15	1,084		1,433.7	1,108.0
June	21.3	203.63	622		826.4	683.3
July	22.7	298.92	948		1,265.2	1 076.4
August	23.1	293.13	978		1,219.4	1,038.0

TABLE 3.1.2. MONTHLY CONSUMPTION OF NATURAL GAS, 2020–2022						
YEAR / MONTH	AVERAGE OUTDOOR TEMPERATURE	NATURAL GAS CONSUMED	HEAT SUPPLIED TO DISTRICT HEATING	ELECTRICITY PRODUCED		
				STEAM TURBINES	GAS ENGINES	ELECTRICITY SUPPLIED TO
	˚C	000′ Nm^3	Gcal	MWh	MWh	MWh
September	15.2	356.62	1,118		1,475.4	1,252.8
October	11.4	538.31	1,622		2,194.7	1,891.9
November	5.0	5,271.54	24,880	5,379.4	8,476.9	12,445.5
December	0.6	7,295.22	36,171	9,379	8,177.3	15,801.0
Daily average in January		263.97				
Ten-day supply		2,639.67				

Source: JSC CHP-Nord

3.1.2. BACKUP FUEL RESERVES

The following assumptions were made to determine the base amount of backup fuel required to operate the CHP for ten days during Balti's coldest month:

- The average amount of natural gas consumed by CHP-Nord plants for ten days during the coldest month (January) over the last three years (2020 to 2022) is assumed to be 2.5 million Nm^3.
- When operating with backup fuel, only CHP-Nord's steam equipment (boilers, turbines) operate.
- During the ten days in January, when burning natural gas, CHP-Nord operates with an average efficiency of 90 percent.
- When CHP-Nord's steam boilers use mazut, DF, and LPG, they operate at 86 percent, 88 percent, and 90 percent efficiency, respectively (these efficiencies are commonly used for engineering calculations in European Union countries).

Based on data on actual consumption provided by CHP-Nord (Table 3.1.2), the average daily fuel consumption of natural gas in 2020–2022 was 264,000 Nm^3, and the ten-day supply of natural gas use was 2.64 million m^3. A ten-day natural gas supply requirement of 2.5 million Nm^3 is assumed for this analysis.

Reliable heat supply to consumers must be provided under any conditions; therefore, boiler houses and CHPs must have backup fuel reserves. SNiP II-35-76 Boiler Plants specifies a ten-day fuel supply in the coldest month (January) when designing boiler houses.

From 1971 to 2009, CHP-Nord used mazut as backup fuel. Until 1999, mazut was both the main and backup fuel. From 1999, after switching to natural gas, until 2009, mazut was used as the backup fuel. Since 2009, the Balti CHP has not had an operational backup fuel system (although the mazut backup facility was not dismantled).

Currently, CHP-Nord is faced with the task of installing a viable backup fuel system and storing backup fuel to ensure reliable heat supply for the city's population.

3.1.3. BACKUP FUEL OPTIONS

The following backup fuel options were considered:

- Natural gas
  - LNG options
    - Option 1: Delivery – storage – regasification – use
    - Option 2: Liquefaction – storage – regasification – use
  - CNG
- Oil products
  - Mazut (as baseline)
  - DF
  - LPG-propane-butane

3.2. LIQUEFIED NATURAL GAS (LNG)

3.2.1. LNG BACKUP SYSTEM

LNG is natural gas that has been cooled to –162 °C, changing it from a gas into a liquid that is 1/600th of its original volume.

The following options for the use of LNG at CHP as a backup fuel were considered:

- Option 1: Delivery – storage – regasification – use
- Option 2: Liquefaction – storage – regasification – use

OPTION 1: DELIVERY – STORAGE – REGASIFICATION – USE

The flow chart for this option is presented in Figure 3.2.1.

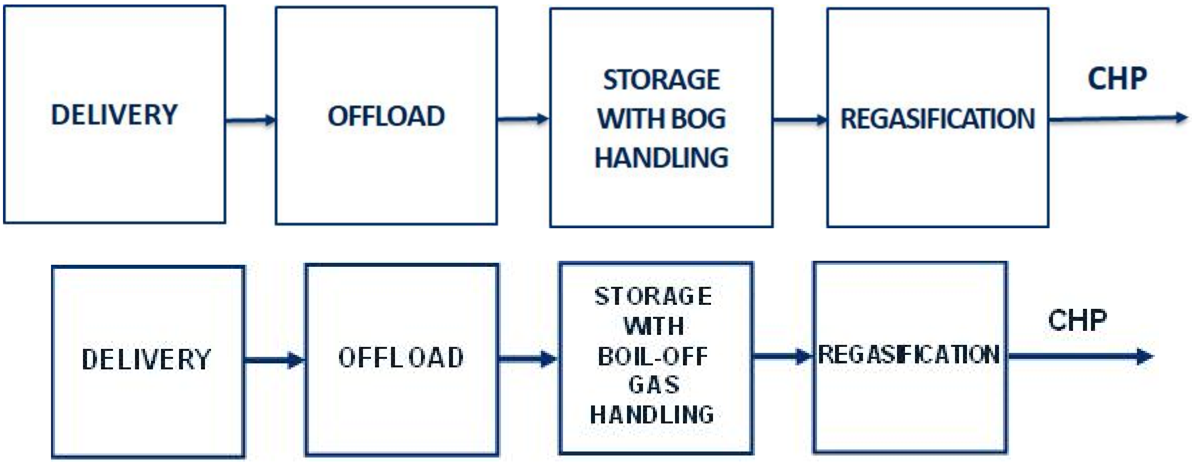


Figure 3.2.1. Flow chart for option 1: LNG delivery – storage – regasification – use

Delivery of LNG to the CHP requires:

- LNG supplies from other exporting countries; and
- In-country availability of transport infrastructure required for LNG delivery.

LNG delivery in Eastern Europe was discussed with the director of Bulmarket Bulgaria in Ruse, Bulgaria, a supplier of LNG and LPG and a member of the LNG-Masterplan project—an international consortium of 33 companies from 17 European Union Member States. These discussions clearly indicated that LNG was not, is not, and is not expected to be available in the region. An LNG terminal, built by Bulmarket Bulgaria on the Danube River in the city of Ruse ($4.5 million investment in 1,000 m^3 of LNG storage), stands empty.

The infrastructure for supplying LNG to consumers in Moldova was discussed during meetings with representatives of TransAutoGas, Achira-Grup, Lukoil, and others, who are engaged in the supply of mazut, DF, and CNG to Moldova. These meetings and discussions found the following:

- There were and are no LNG suppliers in Moldova.

- Thus, there are no transport and storage facilities for LNG.
- Fuel suppliers in Moldova are not considering making the investments needed to develop LNG delivery and storage infrastructure.

LNG storage requires the use of cryogenic terminals to store LNG at −162 °C. Some tank options for vertical and horizontal storage of LNG are presented as examples in Figures 3.2.2 and 3.2.3.

Figure 3.2.2. LNG cylinders built by Bulmarket Ruse, Bulgaria (250 m^3 x 4 = 1,000 m^3)

Figure 3.2.3. LNG cylinders produced by CIMC Enric (150 m^3)

LNG storage is associated with the following problems: boil-off gas (BOG) handling and risk of LNG stratification and potentially explosive “rollover.” Boiling off occurs at any LNG storage, regardless of its thermal insulation. The transfer of heat from the environment into the terminal cryogenic tank is inevitable. This leads some of the LNG to “boil off” into its original gaseous state. During this process, the LNG remains at its boiling temperature (also known as self-cooling), but the pressure inside the tank increases. The resulting BOG must be removed and then used or reliquefied. Reliquefaction and return to the tank require special equipment.

Even if the LNG terminal has the equipment to properly handle the boil-off gas, the quality of the stored LNG still changes over time: it ages. Because LNG is a mixture of liquid components with different molecular weights, the lighter ones (nitrogen and methane) boil off first, changing the composition of the mixture and increasing the density of the LNG.

Additionally, with prolonged storage there is a risk of stratification: gradual separation of LNG components with different molecular weights into distinct layers, with lighter fractions on top and heavier fractions at the bottom. As the boiling-off process occurs at the upper surface, the top layers (originally light) eventually become heavy and cold, while the bottom layers get warmer. This can lead to a rollover: an abrupt reversal of the layers with intense vaporization, which is many times higher than the normal amount of LNG boiling off.

Rollover causes an emergency situation with a real risk of the LNG plant's explosive destruction (and the destruction of surrounding areas).

LNG regasification is the process of converting LNG back into its gaseous state as a result of the heating process, which requires the installation of specialized regasification equipment. Regasification consumes a significant amount of heat, which can be a low-grade heat. LNG terminals in ports use sea water as an unlimited source of such heat. It is also possible to use atmospheric air-based LNG evaporators, but they are large, require significant area, and are expensive to manufacture, build, and install.

Preliminary estimates of the capital expenditure (CAPEX) required to construct an appropriate LNG storage facility are included in Table 3.2.1.

TABLE 3.2.1. PRELIMINARY ESTIMATES OF CAPEX FOR LNG STORAGE CONSTRUCTION

INDICATOR	UNIT	VALUE
Ten-day LNG supply	m^3	4,078
CAPEX for constructing a 1,000 m^3 LNG terminal (250 m^3 x 4) on the Danube River in Ruse, Bulgaria[1]	€	4,500,000
Preliminary estimate of CAPEX for a 4,078 m^3 LNG storage facility based on CAPEX data for the LNG terminal in Ruse[1]	€	16,000,000 – 18,000,000
Preliminary estimate of CAPEX for 4,078 m^3 LNG storage facility[2]	€	8,000,000 – 11,000,000

[1] Source: Bulmarket Bulgaria

[2] Source: CIMC Enric Financial Proposal for Supply of LNG tanks of 150 m^3

OPTION 2: LIQUEFACTION – STORAGE – REGASIFICATION – USE

Option 2 has the same final storage and regasification stages as Option 1, but instead of obtaining LNG from third-party suppliers, it involves on-site liquefaction of the natural gas delivered by the existing pipeline.

Liquefaction of natural gas requires the construction of a micro-factory for producing LNG at CHP-Nord. The micro-factory cools the natural gas to –162 °C, thereby turning it from gas to liquid.

The flow chart for Option 2 is shown in Figure 3.2.4.

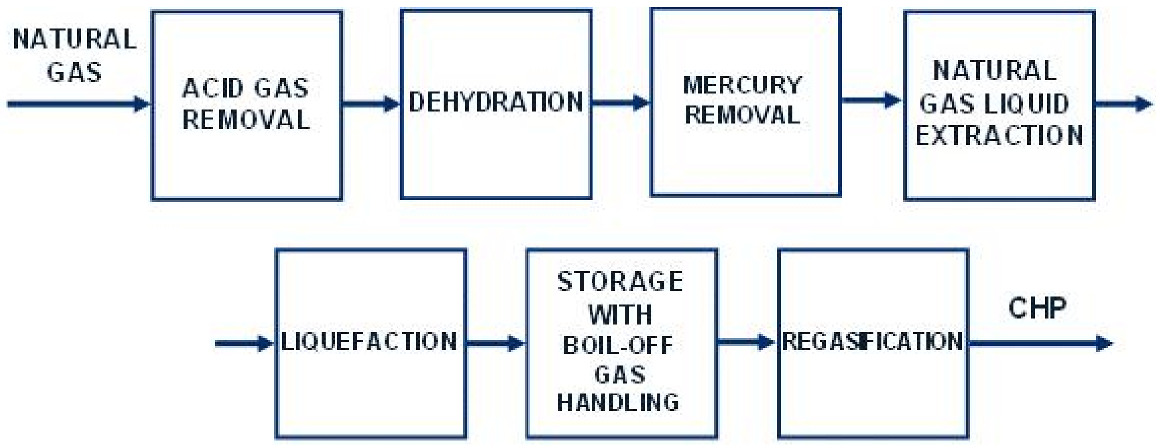


Figure 3.2.4. Option 2: liquefaction – storage – regasification

To obtain indicative estimates of the capital costs for the construction of a micro-factory for liquifying natural gas, data were collected and analyzed for nine state-of-the-art LNG plant projects in the United States and Canada. The experts also reviewed the "Techno-Economic Assessment of the Liquefied Natural Gas (LNG) Production Facilities in Western Canada"[1], which summarizes data from 22 LNG plants in Canada and many other countries, such as Angola, Argentina, Brunei, Egypt, Indonesia, Oman, Peru, Qatar, Russia, Yemen, and others.

Of the 31 LNG plants reviewed, 28 have an annual capacity of more than 200,000 tons of LNG. For comparison, operating CHP-Nord for ten days in January under full load would require 1,724 tons of LNG—less than 0.9 percent of the capacity of those 28 plants (Table 3.2.1). Capital expenditures for the reviewed plants range from $1.5 billion to $30 billion, and capital expenditures based on 1 ton of LNG production are as follows:

- From $1,000/ton at huge U.S. LNG plants (55,000–75,000 tons per day) with total CAPEX of $20–30 billion; and

- Up to $5,500/ton at the micro-plant in Australia (50 tons per day), which required a total CAPEX of $100 million.

The data from the reviewed plants shows that a reduction in plant throughput often results in an increase in estimated CAPEX per ton of LNG.

TABLE 3.2.2. PRELIMINARY EXPERT ESTIMATES OF CAPEX IN LPG PRODUCTION FACILITY BASED ON CAPEX IN EXISTING LNG PLANTS

[1] Elsevier BV, Sustainable Energy Technologies and Assessments 18, December 2016, https://www.researchgate.net/publication/ 309707225.

INDICATOR	UNIT	VALUE	VALUE	VALUE
Ten-day LNG supply	ton	1,724	1,724	1,724
Daily LNG production to fill storage in 90 days	ton/year	6,992	6,992	6,992
Project name		BOC LNG Plant Tasmania	Driftwood LNG	Plaquemines LNG
Location		Westbury, Tasmania, Australia	Lake Charles, LA, United States	Port of New Orleans, LA, United States
Total CAPEX	$	100,000,000	30,000,000,000	21,000,000,000
Annual production	ton	18,250	27,600,000	20,000,000
Daily production	ton/day	50	75,616.44	55,556
CAPEX per ton per annum	$/ton	5,479	1,087	1,050
	€/ton	5,026	997	963
Preliminary estimates of CAPEX for production of 1,724 т СПГ in 90 Days	€	34,000,000	7,000,000	6,500,000
Preliminary estimates of CAPEX for LNG production and storage facility	€	42,000,000–52,000,000	15,000,000–25,000,000	14,500,000–24,500,000

The analysis of the LNG industry identified only two micro-LNG production facilities, both of which were implemented by Dresser-Rand (Siemens):

- Modular natural gas liquefaction plants in Pennsylvania, United States, built in 2016
- Dresser-Rand's modular LNG plant in Dawson Creek, British Columbia, Canada, built in 2018.

The cost of these installations was not found in the public domain. Moreover, the contacts listed in the Siemens and Dresser-Rand brochures for these plants in 2017–2018 are not available, and links to Dresser-Rand are redirected to the Siemens-Energy homepage.

Despite several requests for specifications and prices for a micro-LNG production plant at CHP-Nord, the team received no information from Siemens-Energy.

Based on data analyzed from 31 LPG plants, the capital cost of building a micro-plant for 1,724 tons of LPG per year can be very preliminarily estimated at between €14.5 million and €52 million.

3.2.2. RECOMMENDATIONS

An analysis of the LPG market in the region, infrastructure in Moldova, and CAPEX for LPG production, storage, and regasification finds the following:

- Lack of an LNG market in Moldova and neighboring countries, as well as lack of LNG transport and storage infrastructure in Moldova.
- Very high capital costs for LNG terminals. This is based on current data from a potential LNG supplier in Bulgaria and Romania and a quotation from China's largest LNG cryogenic tank manufacturer.
- Estimated very high capital costs for the construction of a cryogenic LNG plant. This is based on the cost and performance analysis of more than 30 LNG plants in the United States, Canada, and many other countries.
- Great difficulty in building not only LNG plants, but also LNG storage facilities due to the complexity of the storage process.
- Great difficulties not only in LPG production plant operation, but also in LNG storage, including the removal or return of boil-off gas and the prevention of stratification rollover and its associated explosion risks.
- A lack of estimates for a cryogenic storage facility's operating expenses. They are expected to be very high (according to some sources, comparable to the costs of liquefaction).

These factors do not currently allow LNG to be offered as an alternative backup fuel for CHP-Nord.

3.3. COMPRESSED NATURAL GAS (CNG)

3.3.1. CNG BACKUP SYSTEM

CNG is natural gas compressed by a compressor unit to a pressure of 200–250 bar. Its advantages as a backup fuel include:

- No need to change the CHP’s boilers or gas reciprocating engines and no corresponding changes to the CHP’s performance indicators.
- Simple CNG production process.
- Many years of practical experience using natural gas compression technology up to 250 bar (CNG is used as a road transport fuel in Moldova and other countries). The experience of using CNG in vehicles has been studied in several countries, including Moldova, Bulgaria, and the United States:
  - Moldova: TransAutoGas S.R.L., leader in the CNG market in Moldova since 1985
  - Bulgaria: Remix Bulgaria Ltd, a company engaged in the design, manufacture, and sale of cylinders, trailers, and semi-trailers for the storage and transportation of CNG and the construction and maintenance of CNG filling stations
  - United States: “Analysis of Cost Associated with Compressed Natural Vehicle Fueling Infrastructure,” published by the U.S. Department of Energy.

Types of steel tanks for CNG are shown in Figures 3.3.1–3.3.3.

Figure 3.3.1. CNG sphere, 48-inch (1.219 meter) ID (NOV Inc, United States)

Figure 3.3.2. CNG cylinders, diameter 3.56 m, length 1.775 m, 78-cylinder platform (Remix Bulgaria Ltd.)

Figure 3.3.3. CNG cylinders, length 40 ft (12.192 m), 8-cylinder skid (CIMC Enric, China)

For a preliminary estimate of the capital costs for CNG storage, financial proposals were requested and received for 250 bar pressure storage tanks located at CHP-Nord with a ten-day natural gas supply (2.5 million Nm^3). Quotes were received from CIMC Enric (China), Remix (Bulgaria), and NOV Inc. (United States). The quote providers' specifications and a summary of their financial proposals are presented in Table 3.3.1.

TABLE 3.3.1. PRELIMINARY ESTIMATES OF CAPEX FOR CNG STORAGE FACILITY AT CHP-NORD

INDICATOR	UNIT	PROPOSAL 1	PROPOSAL 2	PROPOSAL 3
Company name		NOV Inc.	ReLtd.	CIMC Enric
Location		Huston, Texas, United States	Sofia, Bulgaria	Shenzhen, China
Model		48 in ID sphere	150 L cylinder	8-cylinder 40 ft CP18020
Tank size		48 in (1.219 m) diameter	1.78 m length	40 ft (12.19 m) length
Pressure	Bar	250	250	250
Type of tank/platform/skid		Single sphere	78-cylinder platform	8-cylinder skid
Tank volume or skid volume	nm^3	273	3,363	5,574
Unit cost	€/nm3	145	18	14
Number of tanks or skids		9,165	743	448

TABLE 3.3.1. PRELIMINARY ESTIMATES OF CAPEX FOR CNG STORAGE FACILITY AT CHP-NORD				
Ten-day supply of fuel at CHP	nm^3	2,500,000	2,500,000	2,500,000
Total CNG storage facility CAPEX for 2,500,000 nm^3 natural gas	€	361,000,000	41,000,000	32,000,000

According to these financial proposals, the capital cost of CNG storage for a ten-day natural gas supply ranges from €32 million to €361 million.

3.3.2. RECOMMENDATIONS

CNG cannot be recommended as an alternative backup fuel given the extremely high capital cost of CHP CNG storage facilities, ranging from €32 million to €361 million for a ten-day CNG supply. This cost is estimated based on bids received for this project from:

- NOV Inc., one of the largest manufacturers of CNG tanks in the United States;
- Remix, Bulgarian supplier of CNG cylinders from manufacturers from Italy and other countries; and
- CIMC Enric, one of the largest manufacturers in China of all types of large storage tanks for CNG, LNG, and LPG, supplied to Germany, Canada, and many other countries.

3.4. MAZUT

According to the 1971–1973 evaluation report "Technical Condition of the Equipment and Fuel Oil at JSC CHP-Nord"[2], the following mazut facility equipment was installed:

- An oil pumping station with a capacity of 36 m^3/h
- Two concrete underground fuel oil storage facilities with a capacity of 1,000 tons each
- Railway fuel oil discharge for eight 50-ton tanks
- Mazut heaters
- Pumping station.

The CHP's equipment was designed to burn mazut grade M 100.

[2] JSC CHP-Nord, Balti, August 2022.

In 1990–1993, a new mazut pumping station was installed with four main pumps, each with a capacity of 50 m^3/h, and a new receiving tank of 400 m^3/h with transfer pumps (three units of 150 m^3/h), circulation pumps (two units of 105 m^3/h), and five metal ground tanks, each with a volume of 5,000 m^3. The length of the fuel oil pipeline is 1,040 m, and the steam pipelines are 520 m long. The pumping station's estimated service life is 20 years.

In September 2019, HORUS Energy LLC, Chisinau, Moldova, examined the condition of the mazut facility, the results of which are summarized in the "Preliminary Report on the Assessment of the Current Situation of Fuel Oil at JSC CHP-Nord." The report included:

- Assessment of the state of the mazut facility and the associated railway tracks;
- Recommendations for additional special technical diagnostics to determine the condition of the five mazut tanks and other equipment; and
- Proposals for the repair and replacement of recovery equipment.

The HORUS Energy LLC report, provided by CHP-Nord, did not include specifications or estimates of capital costs and repair costs for the mazut facility's rehabilitation.

In August 2022, CHP-Nord (with the participation of representatives of Termoelectrica S.A.) prepared the "Evaluation Report on Technical Condition of the Equipment and Fuel Oil at JSC CHP-Nord," which included conclusions regarding the technical condition of the mazut facility's equipment and recommended necessary steps to prepare CHP-Nord to use mazut.

In Phase 1, a preliminary engineering assessment was completed to determine the costs and benefits of restoring and operating the mazut facility and to compare that with alternative options (i.e., developing and operating the DF facility and the LPG facility) The Phase 1 assessment included:

- Conducting an inventory of the mazut facility
- Examining the conditions of the mazut facility's equipment
- Preliminarily specifying the mazut facility restoration
- Estimating the capital cost of restoring the mazut facility
- Estimating the operating expense of the mazut facility

- Summarizing the advantages and disadvantages of using mazut as a backup fuel compared to DF and LPG.

During Phase 2, additional engineering analysis clarified and detailed the capital cost and operating expenses of the restoration and operation of the mazut facility (and the advantages and disadvantages of mazut as a backup fuel compared to LPG, selected by CHP-Nord as an alternative backup fuel).

Section 4.1 of this report presents the results of the Phase 1 and Phase 2 assessments of restoring and operating the mazut facility. The assessment covers:

- Full inventory of equipment and assessment of the technical condition of the mazut facility
- Initial engineering proposals for the rehabilitation of the mazut facility, including the repair and replacement of existing equipment
- Initial specifications
- Initial estimates of capital cost and cost of repair works
- Initial estimate of operating expenses
- Advantages and disadvantages of using the mazut facility.

3.5. DIESEL FUEL

3.5.1. DIESEL FUEL FACILITY DEVELOPMENT

DF has a long and successful history of producing electricity and heat in power plants and boiler houses as a backup fuel. In several countries, including, Bulgaria, thermal power plants and CHP plants have switched from using fuel oil as a backup fuel to DF.

Considering this successful experience, in Phase 1, a preliminary engineering analysis included:

- Preliminarily specifying the CHP-Nord DF facility
- Estimating the capital cost of developing the DF facility
- Estimating the operating expense of the DF facility

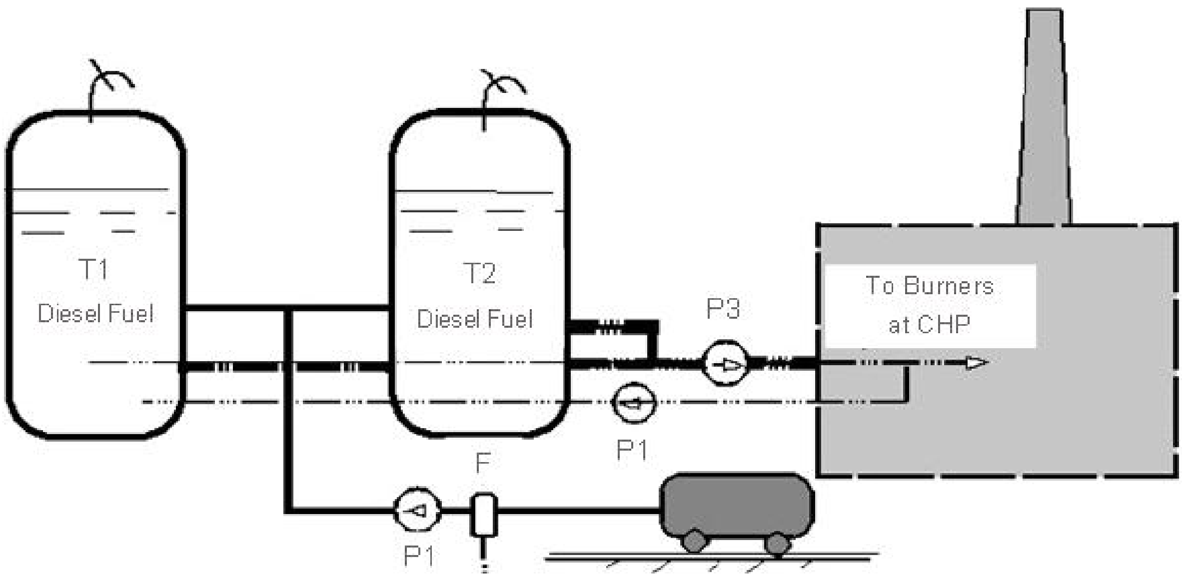
- Summarizing advantages and disadvantages of using DF as a backup fuel compared to mazut and LPG.

SPECIFICATION AND ESTIMATED COSTS

As a result of the initial engineering analysis, it is assumed that the location of the diesel storage tank farm is within the existing mazut facility or nearby. This results in cost savings because the following existing equipment and facilities can be used:

- Railcar diesel tank unloading dock
- Bund retaining wall surrounding mazut tanks
- Pumping station building
- Aerial pipeline trestles
- Electrical cable trays, electrical circuit boards, etc.
- Fire protection systems.

One existing 5,000 m^3 tank may need to be completely dismantled to make room for two new tanks. A schematic diagram of the storage and use of a DF facility is shown in Figure 3.5.1.



T1 – Tank, T2 – Tank, F – Filter, P1 – Unloading pump, P2 – Recirculation pump, P3 – Feed pump

Figure 3.5.1. Schematic diagram of diesel fuel unloading, storage, and delivery to CHP

The following equipment was included in the DF facility's capital cost estimate:

- Two new tanks of 1,500 m^3
- Pipe fittings—density class A
  - Gate valves, check valves, valves for instrumentation and instrumentation, drainage
- Pipelines
  - Steel pipes (possibly flexible discharge) of different diameters depending on their purpose, approximately from DN25 to DN125
  - About 1,500 m to be laid for DF transportation
- Pumps
  - For supplying DF from tanks to steam boilers, as well as for pumping from railway tanks, the following equipment is required:
    - Main pumps: two to three for supplying DF from tanks when boilers are firing DF
    - Recirculation pumps: two to ensure the circulation of DF from tanks to boilers and vice versa, and to maintain the working circuit in constant readiness for CHP operation
    - Drain pumps: two for draining DF from railway tanks into storage tanks and vice versa
    - Water ring vacuum pumps: two to create a vacuum in tanks when pumping DF into tanks by these pumps to fill empty tanks
    - Drainage pump for pumping DF from the drainage pit to the drain pipeline to the tanks
- Boiler firing DF requires:
  - Modifying the CHP's boilers to work with DF, including installing diesel nozzles and adding new boiler piping to combine the operation of the automatic control system that regulates the supply of DF with the existing gas distribution system.
- External fire water conduit requires:

- Installing a fire-fighting conduit around the DF facility, which includes fire hydrants for connecting fire trucks, sectional valves, drain valves for emptying the conduit, and a branch to the DF pumping station and through it to irrigate tanks with shut-off valves.

- Fire extinguishing systems, including automatic fire extinguishing systems
  - On all pressure and suction pipelines of the DF facility, emergency ("fire") valves with an electric drive are required. These valves are sealed in the open position (emergency valves are closed during a fire through a fire alarm system and can be controlled locally).
  - To detect and eliminate fires in the pumping room, the drain platform, and tanks, high-expansion foam fire-extinguishing equipment must be installed.
  - In the pump room and in other rooms, as specified in safety regulations, the necessary ventilation equipment is required, as are light and sound alarms.
- Technological control over the parameters and operation of the DF facility (control and control panel)
  - Control of important parameters of the entire system (e.g., flow, pressure, level, temperature)
  - Automatic and manual controls of the DF facility's operation.

The initial specification and estimated capital costs for developing DF facility are presented in Table 3.5.1.

TABLE 3.5.1. SPECIFICATION AND ESTIMATED COSTS OF DF FACILITY DEVELOPMENT

#	EQUIPMENT	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)	NOTE
	Capital costs and repair costs				
	Technological equipment				
1	Design		24,000	24,000	Expert estimate
2	Tank 1,500 m^3	2	320,000	640,000	Without insulation
3	Buffer tank 20 m^3	1	35,000	35,000	Without insulation

TABLE 3.5.1. SPECIFICATION AND ESTIMATED COSTS OF DF FACILITY DEVELOPMENT					
#	EQUIPMENT	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)	NOTE
4	Unloading platform and receiving and draining device	1	9,000	9,000	
5	Pipes DN25–DN125 with installation, m	1,500	70	105,000	Diameter (DN) no more than 125 mm
6	Fittings DN25-DN125, Ru16 (gate valves, check valves, gates)	75	105	7,875	Class A
7	Deluge fire protection system	1	7,800	7,800	
8	Filters	2	2,900	5,800	
9	Burners	6	24,000	144,000	
10	Heater up to 20 m^3/h (network water is used)	1	14,000	14,000	Or heating tapes (optional), may not be included in the investment
11	Electrical heating tapes (trace cables) for extreme temperatures, m	250	22	5,500	Or heaters (optional)
12	Installation of new cables and electrical panels	1	85,000	85,000	
13	Unloading pumps—drain	2	1,400	2,800	Pumps of 7–11 kW
14	Operating and standby pumps for supply from tanks to boilers	3	1,800	5,400	Pumps of 7–11 kW
15	Recirculation pumps—from tanks to boilers and back	2	1,080	2,160	Pumps of about 7 kW
16	Liquid ring vacuum pumps for vacuum in tanks	2	990	1,980	Pumps of about 7 kW
17	Drainage pump type Ш-40	2	580	1,160	Pumps of about 5 kW
18	Other equipment	1	10,000	10,000	

TABLE 3.5.1. SPECIFICATION AND ESTIMATED COSTS OF DF FACILITY DEVELOPMENT					
#	EQUIPMENT	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)	NOTE
	Total technological equipment			1,106,475	
	Devices and automation				
19	Instrumentation and automation, sensors	45	150	6,750	
20	Sensors with transmitters	12	350	4,200	
21	Level sensors with transmitters	3	2,400	7,200	
22	Level controller and pumps	2	2,300	4,600	
23	Burner control regulator (controller and sensors)	4	11,500	46,000	
24	Monitoring and control system—SCADA	1	70,000	70,000	
25	Other equipment			6,000	
	Total devices and automation			144,750	
		Repair and restoration of equipment			
26	Repair and restoration of the railway	1	130,000	130,000	Expert estimate based on inspection
27	Dismantling of one 5,000 m^3 tank and site preparation for installation of two 1,500 m^3 tanks	1	44,000	44,000	
28	Fire extinguishing system (repair and restoration), including automatic fire extinguishing system	1	42,000	42,000	
29	Repair existing structures	1	35,000	35,000	Expert estimate
30	New burner nozzles	18	175	3,150	Not all for all boilers

TABLE 3.5.1. SPECIFICATION AND ESTIMATED COSTS OF DF FACILITY DEVELOPMENT					
#	EQUIPMENT	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)	NOTE
31	Adjustment of burners for DF	1	3,500	3,500	
32	Other equipment	1	8,000	8,000	
	Total repair and restoration of equipment			265,650	
	Total capital costs and repair costs			1,516,875	

OPERATING EXPENSES

The DF Facility's estimated annual operating expenses are presented in Table 3.5.2. These estimates assume that a ten-day supply of backup fuel supply is completely used once every five years (during a natural gas supply outage).

TABLE 3.5.2. ESTIMATED ANNUAL OPERATING EXPENSES OF THE DF FACILITY					
#	EXPENSES	UNITS	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)
	Annual operating expenses				
1	Electricity cost for unloading and feeding boilers for ten days	kWh	8,000	0.24	1,892
2	Salary for four employees at 500 €/month for six months	Month	6	2,000	12,000
3	Other expenses			2,000	2,000
	Total annual operating expenses without DF cost for ten days				15,892
	DF cost for ten days				
4	DF cost, excluding DF for ten days of heat production	m^3	2,370	847	2,007,925
5	DF cost for heat production for ten days (2 Gcal in total)	m^3	0.23	847	196
	Total DF cost for ten days				2,008,121
	Total annual operating expenses				2,024,013

3.5.2. ECONOMIC ANALYSIS

The DF facility's cost, operating expenses, and net present value (NPV) at a discount rate of 3 percent are presented in Table 3.5.3.

TABLE 3.5.3. ESTIMATED PROJECT COST, OPERATING EXPENSES, AND NPV OF THE DF FACILITY (€)	
Project cost	1,516,875
Annual operating expenses	
Operating expenses without ten-day fuel supply cost	15,892
Ten-day fuel supply cost	2,008,121
Total annual operating expenses	2,024,013
NPV for 10-Year period	5,129,940
NPV for 20-Year period	7,851,274

3.5.3. ADVANTAGES AND DISADVANTAGES

The key advantages of using DF compared to mazut (the estimated economic indicators of the mazut facility are presented in Section 4.1) as a backup fuel are:

- The estimated annual operating expenses of the DF facility (not including the cost of a ten-day fuel supply) is only 3.6 percent of the annual operating expenses of the mazut facility.
- Estimated NPVs of developing and operating (including backup fuel costs) the DF Facility within 10 and 20 years are less than the corresponding NPVs of restoring and operating the mazut facility.
- The DF facility is easier to operate and maintain than the mazut facility.
- In some countries, contracts for the near-term delivery of large volumes of DF, in case of interruptions in natural gas supply, can be signed with DF suppliers to decrease the amount of backup fuel that has to be stored onsite.

At the same time, a few shortcomings of the DF facility are noted:

- DF pollutes the environment less than mazut, but more than LPG.

- DF cannot be used (like mazut) for the gas engines JMS 620 GS-N.L. installed at CHP-Nord.
- DF cannot be used for gas turbines or a combined-cycle unit if CHP-Nord installs such equipment in the future.

3.6. LIQUEFIED PETROLEUM GAS (LPG)

LPG is a mixture of propane and butane in various proportions. It has a long history of use as a fuel for power generation in refineries and power generation systems around the world. In countries such as Japan, Korea, China, the United States, Canada, and others, LPG is used as a backup fuel for thermal power plants. Despite its advantages over traditional alternative sources of reserve fuel (mazut, DF), LPG is not as widely used in Europe. On the other hand, the new Evonik CHP built in 2022 in Marl, Germany (90 MWe and 220 MWth, Siemens SGT-800 gas turbine and SST-400 steam turbine) fires as its main fuels natural gas (60 percent) and LPG (40 percent).

Considering the promising and growing experience of using LPG for power generation, Phase 1 included a preliminary engineering assessment of developing and operating an LPG facility to compare with mazut and DF facility and select a priority alternative backup fuel for the Phase 2 analysis:

- Preliminarily specifying the CHP-Nord LPG facility
- Estimating the capital cost of developing the LPG facility
- Estimating the operating expense of the LPG facility
- Summarizing advantages and disadvantages of using LPG as a backup fuel compared with mazut and DF.

All Phase 1 results were included in a presentation for and discussion with CHP-Nord. The findings were compared with those for the mazut facility and the DF facility.

Section 4.2 presents the results of the Phase 1 and Phase 2 assessments of developing and operating the LPG facility. The assessment includes:

- Initial project specifications
- Initial estimates of capital costs, considering its location and including input from CHP-Nord's staff

- Initial estimates of operating expenses
- Description of key operating systems of the LPG facility
- Advantages and disadvantages of LPG as a backup fuel
- Comparative analysis of developing and operating the LPG facility versus restoring and operating the mazut facility, considering all clarifications and additions made during Phase 2.

3.7. COMMENTS AND RECOMMENDATIONS

Based on the preliminary analysis of LNG, CNG, DF, and LPG as alternatives to mazut as a backup fuel, the following recommendations can be drawn:

- LNG is not recommended for several reasons, primarily because of the high capital costs of building the LNG storage facility and the extremely high capital costs of the micro liquefaction plant.
- CNG is not recommended as a potential backup fuel option because of the extremely high cost of building a CNG storage facility.
- Restoring the mazut facility has the following key advantages and disadvantages:
  - Advantages:
    - Lowest capital cost compared to both the DF facility and the LPG facility.
    - Lowest fuel cost in Moldova (to date).
    - CHP-Nord has many years of experience operating the mazut facility (until 2009).
  - Disadvantages:
    - Highest operating expenses of the three possibilities (not including the cost of a ten-day fuel supply).
    - Estimated NPVs of restoring and operating the mazut facility (including backup fuel costs), when considering 10- and 20-year time horizons, are higher than the corresponding NPVs for developing and operating the DF and LPG facilities.

  - Mazut has more serious environmental pollutant emissions, especially compared to LPG.

  - Mazut cannot be fired in the JMS 620 GS-N.L. gas engines installed at CHP-Nord.

  - Mazut cannot be used for gas turbines or a combined-cycle unit if CHP-Nord installs such equipment in the future.

- DF is recommended as a potential backup fuel option.

  – Advantages:

    - The estimated annual operating expenses of the DF facility (not including the cost of a ten-day fuel supply) is 3.6 percent of the expenses of the Mazut facility.

    - Estimated NPVs of developing and operating the DF facility (including backup fuel costs) are less than the corresponding NPVs for restoring and operating the mazut facility.

    - The DF facility is easier to operate and maintain than the mazut facility.

  – Disadvantages:

    - DF pollutes the environment less than mazut but more than LPG.

    - DF cannot be used by the JMS 620 GS-N.L. gas engines currently installed at CHP-Nord.

    - DF cannot be used if CHP-Nord installs gas turbines or a combined-cycle unit in the future.

- LPG is recommended as a backup fuel alternative.

  – Advantages:

    - The estimated annual operating expenses of the LPG facility (not including the cost of a ten-day fuel supply) is less than 6 percent of the operating expenses of the mazut facility.

- Estimated NPVs for developing and operating the LPG facility (including the backup fuel costs) are less than the corresponding NPVs of restoring and operating the mazut facility.
- The premixed LPG-air has a calorific value close to that of natural gas.
- There is no need to install expensive burners for burning both gaseous and liquid fuels, as would be the case when using mazut or DF as the backup fuel.
- The viscosity of LPG does not increase at low temperatures, which negatively affects the transportation of mazut and DF from fuel storage tanks to burners.
- Switching from natural gas to LPG takes up to 60 seconds and can be done automatically.
- LPG is considered an alternative clean fuel that pollutes the environment less than mazut or DF.
- LPG can be used if CHP-Nord installs gas turbines or a combined-cycle power plant in the future.

– Disadvantages:

- The capital cost of developing the LPG facility is higher than the capital costs of restoring the mazut facility or developing the DF facility.
- The 9JMS 620 GS-N.L. gas engine cannot operate on both natural gas and LPG without the company retrofitting it with the appropriate equipment and using the more expensive HD5 class LPG.

In summary, although the capital cost of developing the LPG facility is higher than the capital cost of restoring the mazut facility or developing the DF facility, LPG was selected for further analysis considering LPG construction and operation's lower NPVs and the fuel's other advantages.

These findings were presented to representatives of CHP-Nord in May 2023. As a result of the presentation and discussions with representatives of CHP-Nord, the LPG option was selected for Phase 2 assessment.

4. INITIAL ASSESSMENT OF POSSIBLE BACKUP FUEL SYSTEMS

4.1. MAZUT BACKUP FUEL SYSTEM REHABILITATION

4.1.1. CURRENT CONDITIONS

From March 28 to 29, 2023, a team expert visited CHP-Nord. The expert met with CHP-Nord management, studied the technological process of the fuel and transportation shop, inspected the mazut facility's equipment, and produced a complete equipment inventory. The expert was supported by the head of the fuel and transportation shop. The preliminary results of the inspection and inventory were discussed with representatives of CHP-Nord.

The technological scheme of the mazut facility is presented in Figure 4.1.1.

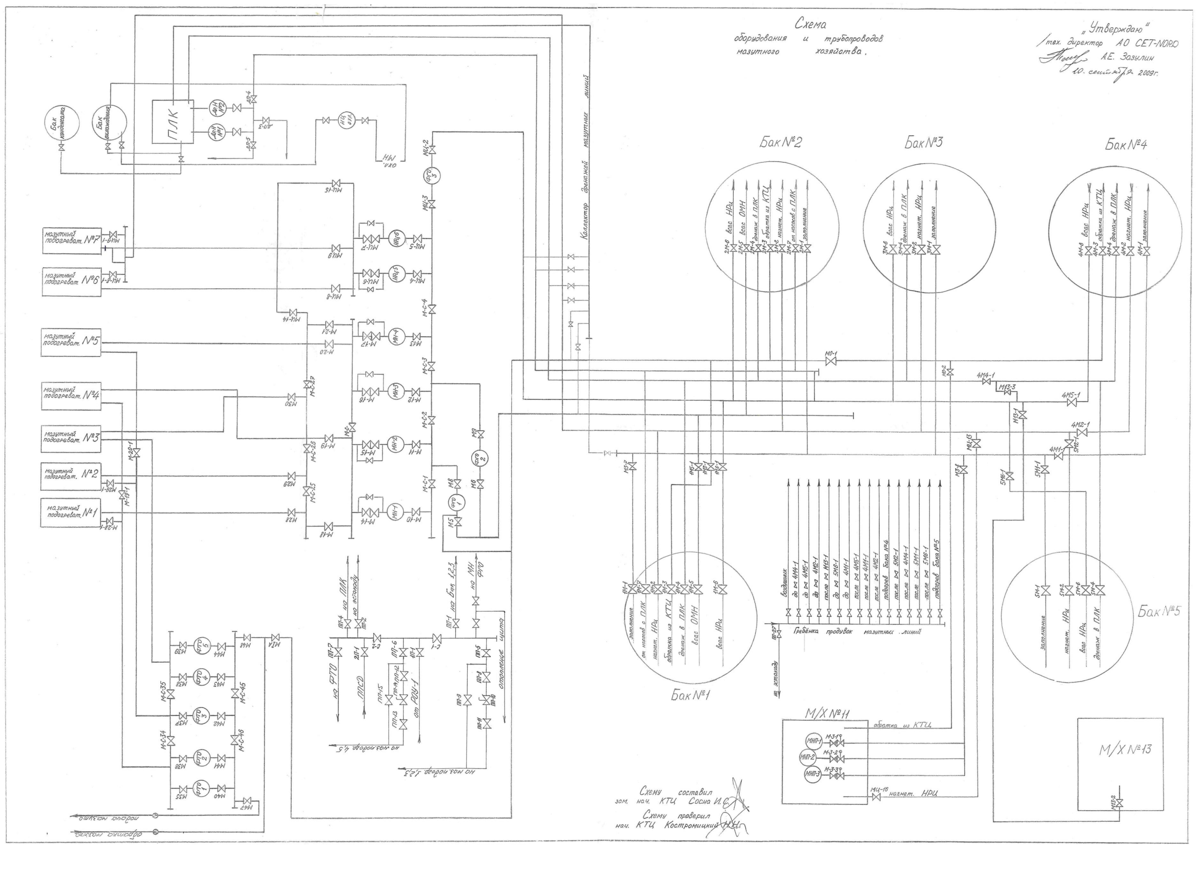


Figure 4.1.1. Technological scheme of the mazut facility

The results are summarized below. Equipment photographs taken during the visit are also provided below.

- Railway sidings used to access the mazut facility are in poor condition. Sleepers and semi-hulls are completely rotten and require 100 percent replacement.

Figure 4.1.2. Railway access roads (detail)

- The unloading platform is rusty, but after full maintenance and repair, it would be in full working order.
- Receiving pits (mazut receiving and draining device) look satisfactory. However, the condition of the steam heating lines and steam extinguishing system is unknown. One pit had its heaters replaced in 2009.

Figure 4.1.3. Mazut receiving and draining device/pits

- The hydraulic seal and its mesh filter require full maintenance, and the meshes need to be replaced.

Figure 4.1.4. Hydraulic seal with filter mesh

- The concrete mazut drain channel between the hydraulic seal and the receiving reservoir X-11 (length 42.5 m) requires major repairs.

Figure 4.1.5. Concrete mazut drain channel

- Receiving reservoir MX-11 (volume 400 m^3) requires an inspection to identify possible issues and the complete replacement (or perhaps overhaul) of the heating coil.

- Transfer pumps МНП 1, 2, 3 (model 12НА-22, Q = 150 m^3/h, H = 54 m, В140М4 engine, N = 30 kW) require complete testing, maintenance, and repair. They are thought to be in working condition.

Figure 4.1.6. Transfer pumps МНП 1, 2, 3

- Equipment for adding additives to the mazut consists of two vertical tanks (volume unknown) and two pumps. No one at CHP-Nord was able to explain why this equipment is needed. It is not in working condition. The pumps are dismantled and disconnected from the mazut pipelines.

Figure 4.1.7. Installation for additives

- Mazut tank МБ-1 (volume 5,000 m^3) has been cleaned of mazut. Because 35 percent of the thermal insulation fell off, the remaining insulation was removed. Per requirements, all the welds of the walls and bottom of the tank will have to be examined. The condition of the steam heater is unknown. Respiratory valves were not audited, so their condition is unknown.

- Mazut tank МБ-2 (volume 5,000 m^3) has been cleaned of mazut and mazut residues. Per requirements, all the welds of the walls and bottom of the tank will have to be examined. The tank's foundation must be inspected and repaired. The condition of the steam heater is unknown. Respiratory valves were not audited, so their condition is unknown.

Figure 4.1.8. Mazut tank МБ-2

- Mazut tanks МБ-3, 4, 5 (volume 5,000 m^3 each) have not been cleaned of mazut residues. Per requirements, all the welds of the walls and bottom of the tank will have to be examined. The tank has foundation problems, so inspection is needed. There is a suspicion of groundwater undermining the foundation. The condition of the steam heater is unknown. Respiratory valves were not audited, so their condition is unknown.

Figure 4.1.9. Mazut tanks МБ-3 and МБ-3

- Mazut coarse filters of model ФМ-1,2,3 (ФМ-40-30-40, Q = 30 m^3/h) are in working order.

- The condition of mazut pumps (model 5Н-5х4, Q = 50 m^3/h, H = 280 m, engine ВА02-280S-2, N = 132 kW) is unknown. They have not been tested for more than 14 years.

- Mazut recirculation pumps НРц-1, 2 (model 6 НК -9х1, Q = 105 m^3/h, H = 60 m, non-native engine, N = 40 kW) did not provide the required output during their last operation. Representatives of the fuel and transportation shop consider the pumps faulty.

- Condensate pumps НК-1, 2 (model КС 20-50, Q = 20 m^3/h, H = 50 m, motor ВАО-42-2, N = 7.5 kW) have not been used for more than 25 years. Their condition is unknown.

Figure 4.1.10. Condensate pumps

- The condensate collection tank (capacity 40 m^3) is in working condition but has a lot of rust.

- Cooling pumps НО -1, 2, 3 were intended for cooling the bearings and mechanical seals of the mazut pumps МН -1, 2, 3, 4; oil recirculation pumps НРц -1, 2; and condensate pumps НК-1, 2. Pump НО-2 was dismantled at the time of the inspection, and pumps НО-1, 3 require full maintenance and repair.

- The coolant collection tank (capacity 40 m^3) is in working condition but has a lot of rust.

- The storm sewer pit needs inspection and repair.
- Drainage pumps ДрН-1.2 (model ГНОМ 10-10, Q = 10 m^3/h, H = 10 m, H = 1.1 kW) are in working condition.
- Mazut heaters МП-1, 2, 3, 4 (model ПНР-64-60, Q = 60 m^3/h) were repaired by plugging internal tubes. Information about the share of plugged tubes was not available.
- Mazut heaters (model ПНР-64-60, Q = 60 m^3/h) are plugged and completely out of order.
- Recycled mazut heaters (model ПНР -13-120, Q = 120 m^3/h) are completely out of order.
- Fine filters ФТО-1, 2, 3, 4, 5 (model ФМ-40-30-40, Q = 30 m^3/h) are in working condition.
- Mazut pipelines 1 and 2, which run between the mazut pumping station and the turbine and boiler shop, are not in working order. They have many leaks and need to be replaced.
- The mazut recirculation pipeline is partially dismantled and out of order. The mazut recirculation scheme was changed, and mazut pipeline 2 was used for recirculation.

Figure 4.1.11. Cooling pumps

Figure 4.1.12. Fine filters

- Peak mazut heaters ПМП-1, 2 were dismantled more than 30 years ago, as they were not subject to restoration.
- Mazut supply equipment at boiler units KA-2, 3 was completely dismantled.
- Mazut supply equipment for boiler units KA-4, 5, 6 are installed, but their condition is unknown.

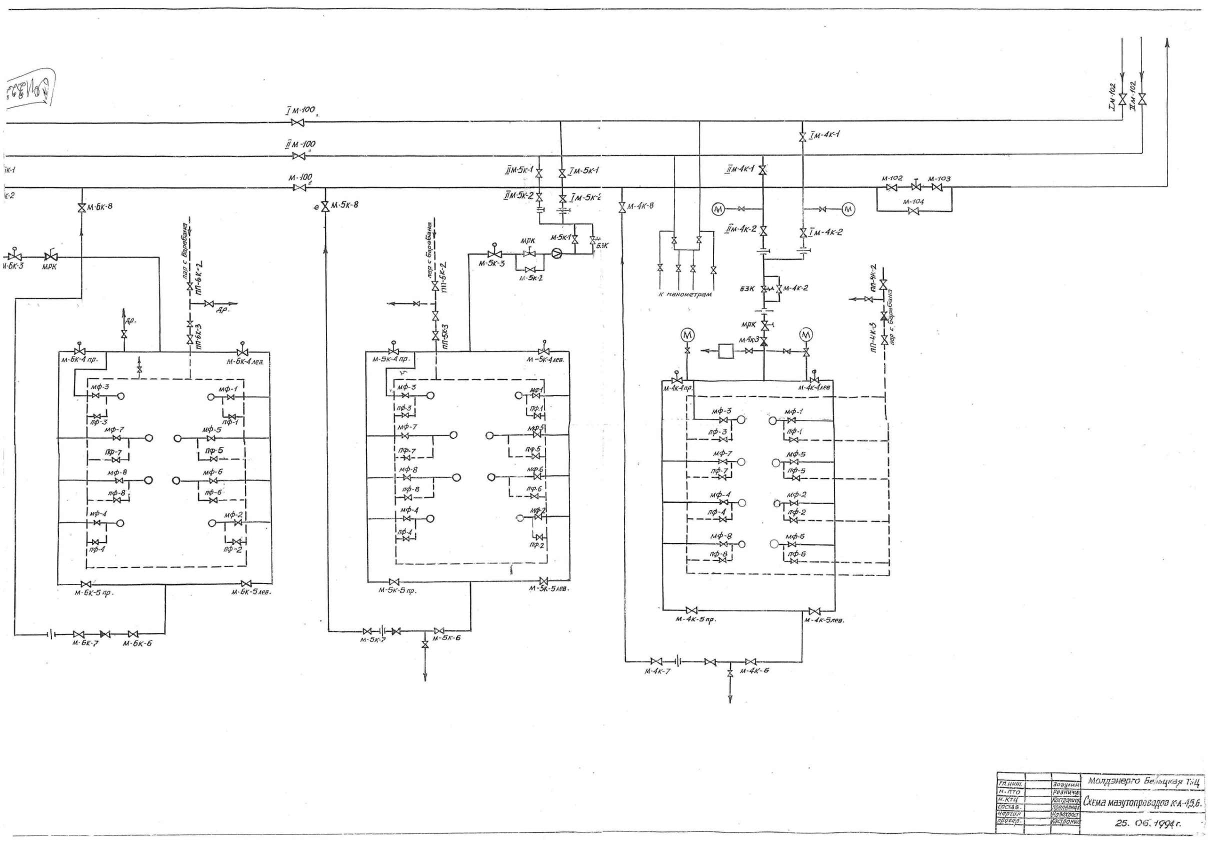


Figure 4.1.13. Scheme of mazut supply to boilers KA-4, KA-5, KA-6

Figure 4.1.14. Mazut pipelines in boiler and turbine shop (boiler KA-4)

Figure 4.1.15. Mazut supply pipelines to burners and mazut injectors

- Mazut supply equipment for boiler KA-7 is installed, but its condition is unknown. This boiler has not been in working order for a long time.

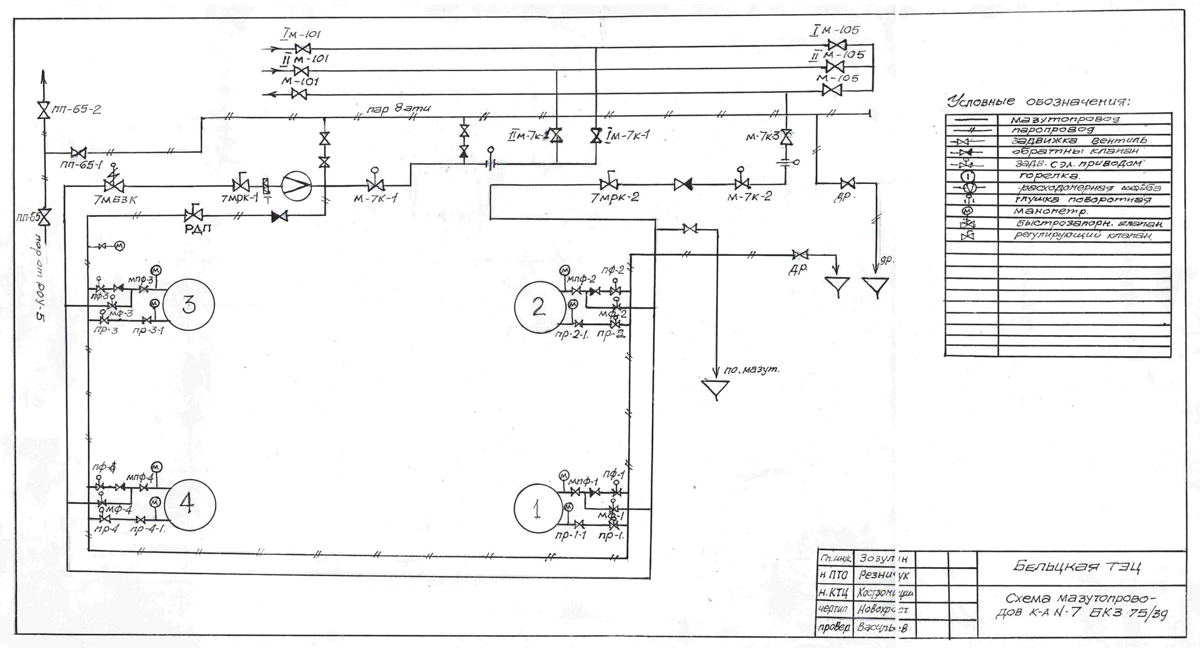


Figure 4.1.16. Technological scheme of mazut supply to boiler KA-7

Figure 4.1.17. Mazut pipelines in boiler and turbine shop (boiler KA-7)

- Water tanks ПБ-1, 2, 3 of the fire extinguishing system require complete reconstruction. They currently have a lot of welded backfills and replaced heater coils. The tanks are currently empty.

- The automatic foaming and foam supply system does not work in the fire pump station.

- Automation of the fire pump station does not work.

- The deluge fire protection system and foam extinguishing system pipelines are in unknown condition.

- Foam generators have been serviced, but their condition is unknown.

- Underground water pipes from the fire pump station were partially replaced.

Due to the mazut facility being unused/shut down, maintenance/operating personnel did not maintain process equipment (except for shutoff valves) and did not pressure test equipment and pipelines (for operating and test pressures). The equipment's condition is largely unknown. This costly equipment is required for the mazut facility's operation.

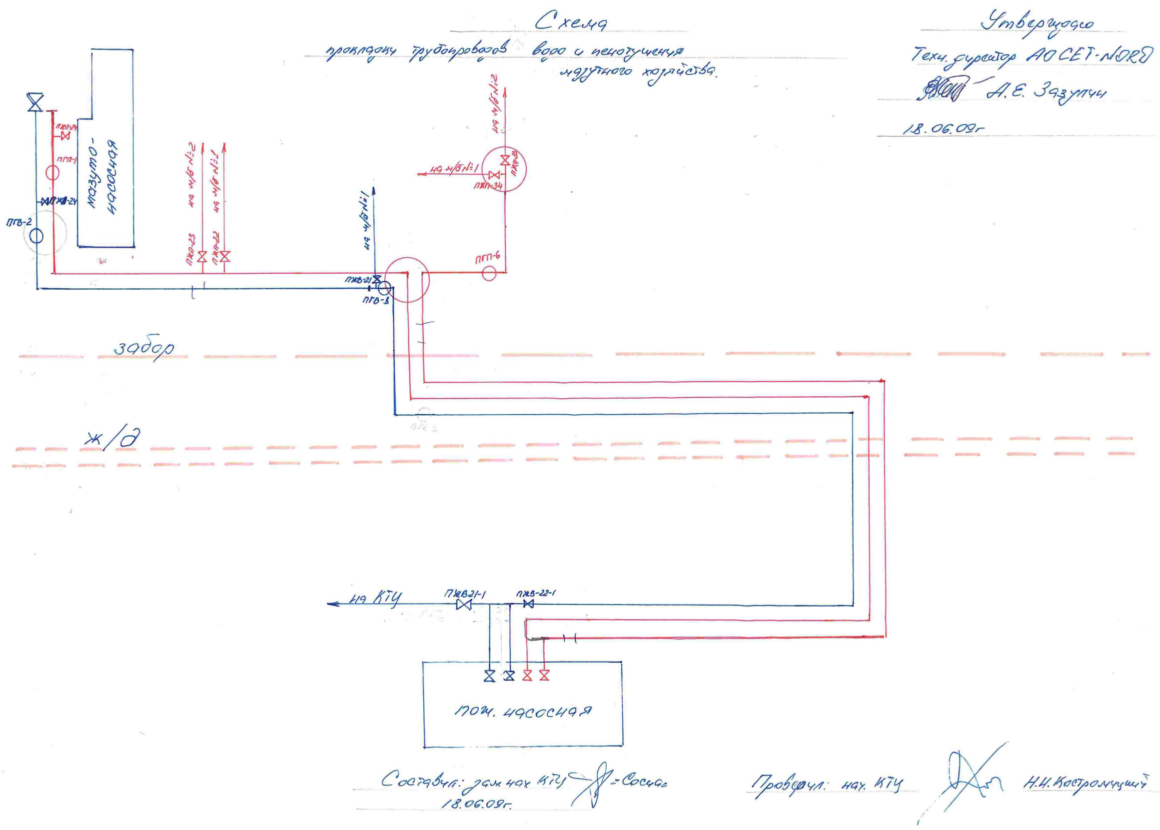


Figure 4.1.18. Technological scheme of the mazut facility's fire extinguishing system

4.1.2. MAZUT FACILITY RESTORATION

SPECIFICATION AND ESTIMATED COSTS

Based on the inventory of the mazut facility and discussions with CHP-Nord representatives, the facility's equipment was classified using the following general categories:

- Requiring replacement
- Requiring repair/restoration/maintenance
- Unnecessary/not needed
- In operating condition

- Condition to be determined by further inspection or testing.

This classification scheme was used when developing the capital cost estimate, and the mazut facility's equipment was classified as follows:

- Railway sidings: restoration (the estimated cost of CHP-Nord's contribution is included in the capital cost estimate)
  - Sleepers: replacement by the railway company
- Unloading platform: full maintenance and repair
- Receiving and draining device, water trap, and concrete channel for draining mazut between the water trap and receiving tank: restoration
  - Steam pipelines: inspection
  - Steam heaters: replacement
  - Concrete mazut drain channel: repair
- Receiving tank МХ-11 (volume 400 m^3): restoration
  - Heating tube coil for steam heating: replacement
- Transfer pumps МНП 1, 2, 3
  - Two new transfer pumps with lower pumping flow: replacement
  - Two existing pumps as backup: maintenance
- Mazut tanks (two must be used)
  - Two tanks of 5,000 m^3 each (for example, МБ-1 and МБ-2): restoration/clean
    - Full maintenance and repair to approximately each tank's average fuel level
  - Heaters, breathing valves, fittings, foam and deluge fire protection systems, and other elements of tank equipment: repair
- Mazut pumps МН-1, 2, 3, 4
  - Two pumps: replacement with new pumps with lower pumping flow

  - One pump as a backup: maintenance and repair
- Condensate pumps НК-1, 2
  - One condensate pump: replacement with new pump with lower pumping flow
  - One backup condensate pump: maintenance and repair
- Mazut recirculation pumps НРц-1, 2
  - One pump: replacement with a new pump of reduced capacity
  - One backup pump: repair
- Fine filters ФТО-1, 2, 3, 4, 5
  - Two fine filters: repair
  - Two other fine filters: operational and can be used as backups
- Mazut pipelines 1 and 2 between mazut pump station and turbine and boiler shop, other mazut pipelines of different diameters and lengths, including fittings
  - Pipelines 1 and 2: replacement with pipelines with reduced diameter
  - Pipeline sections: repair and replacement (including fittings)
- Mazut recirculation pipeline
  - Pipelines supplying Mazut to four boilers: complete restoration
  - Insulated pipelines: replacement
- Mazut supply equipment at the boilers (burners, nozzles)
  - Mazut supply equipment: inspection—elements are missing or of unknown condition
  - Four boilers: restoration, including new equipment
- Fire extinguishing system
  - Water tanks, foam generators, water pipes: inspection and repair
  - Fire pump station automation: replacement

- Monitoring of important mazut facility parameters and video surveillance: replacement
- Steam heating system for mazut pipelines
  - Steam heating system: inspection, state unknown
  - Electrical heating tapes (trace cables): in operating condition
- Steam pipelines, fittings: replacement (20–40 percent) at a reduced diameter.

The initial specification for restoring the mazut facility is presented in Table 4.1.1. The specification includes the estimated costs for the purchase, delivery, installation, and commissioning of new equipment to replace some old equipment as well as the expenses for reconditioning the rest.

TABLE 4.1.1. SPECIFICATION AND ESTIMATED COSTS OF MAZUT FACILITY'S RESTORATION

#	EQUIPMENT	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)	NOTE
	Capital costs and repair expenses				
	Technological equipment				
1	Mazut fittings Ду 25-Ду 150, Ру16 – 64	90	95	8,550	Partial replacement
2	Steam fittings Ду 25-Ду 150, Ру16 – 64	80	95	7,600	Partial replacement
3	Pumps	6	1,550	9,300	Primary only (not backup)
4	Burners	6	22,000	132,000	Not all for all boilers
5	Other equipment	1	28,000	28,000	
	Total technological equipment			185,450	
	Devices and automation				
6	Pressure and Temperature sensors with transmitters	12	330	3,960	
7	Level sensors with transmitters	3	2,800	8,400	

TABLE 4.1.1. SPECIFICATION AND ESTIMATED COSTS OF MAZUT FACILITY'S RESTORATION					
#	EQUIPMENT	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)	NOTE
8	Level and pump controller	3	3,200	9,600	
9	Burner controller	4	11,000	44,000	
10	Control and management system—SCADA	1	68,000	68,000	
11	Installation of new cables and electrical panels	1	60,000	60,000	
	Total devices and automation			193,960	
	Repair and restoration of equipment				
12	Mazut fittings Ду 25-Ду 150, Ру16	90	60	5,400	Partial replacement
13	Steam fittings Ду 25-Ду 150, Ру16	65	60	3,900	Partial replacement
14	Tank: cleaning, repair (new shell up to 1,500–2,000 м^3)	2	150,000	300,000	
15	Repair/restoration of the railway	1	130,000	130,000	Expert estimate based on inspection
16	Repair railway unloading installation (unloading platform, receiving and draining device, hydraulic seal, concrete mazut drain channel)	1	12,000	12,000	Expert estimate based on inspection
17	Repair receiving reservoir 400 м^3	1	5,200	5,200	Expert estimate based on inspection
18	Replace sections of mazut pipelines Ду25-Ду150 with installation, €/m	950	95	90,250	Expert estimate based on inspection
19	Replace sections of steam pipelines Ду25-Ду150 with installation and insulation, €/m	700	95	66,500	
20	Replace some of the steam heating system for mazut pipelines with electrical heating tapes (trace	700	40	28,000	Expert estimate based on inspection

TABLE 4.1.1. SPECIFICATION AND ESTIMATED COSTS OF MAZUT FACILITY'S RESTORATION					
#	EQUIPMENT	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)	NOTE
	cables), €/m				
21	Repair pumps	8	180	1,440	Partial replacement
22	Repair filters	2	350	700	Primary only (not backup)
23	Repair mazut heaters	3	650	1,950	Primary only (not backup)
24	Replace instrumentation	30	90	2,700	
25	Repair various structures	1	40,000	40,000	
26	Replace nozzle and repair of burner	18	200	3,600	
27	Repair fire extinguishing system	1	35,000	35,000	
	Total repair and restoration of equipment			726,640	
	Total capital costs and repair expenses			1,106,050	

OPERATING AND MAINTENANCE COSTS

The mazut facility's estimated annual operating expenses are presented in Table 4.1.2. The estimates are based on the following assumptions: a ten-day supply of backup fuel supply is completely used once every five years during a natural gas supply outage, and 20 percent of mazut will be replaced every year to support the required mazut quality.

TABLE 4.1.2. ESTIMATED ANNUAL OPERATING EXPENSES OF THE MAZUT FACILITY					
#	EXPENSES	UNITS	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)
	Annual operating expenses				
1	Electricity costs for pumps to unload one-fifth of the mazut volume per year	kWh	220	€0.24	€52
2	Electricity costs for mazut circulation pumps, 150 days	kWh	36,877	€0.24	€8,721

TABLE 4.1.2. ESTIMATED ANNUAL OPERATING EXPENSES OF THE MAZUT FACILITY					
#	EXPENSES	UNITS	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)
3	Thermal energy (steam) cost needed to support the readiness of the mazut facility for five months per year	Gcal	410	€100.04	€41,017
4	Salary (four people at €500/month for six months)	Month	6	2,000	12,000
5	Mazut replacement (20 percent per year)	ton/Year	443	814	360,176
6	Other expenses	€	1	24,000	24,000
	Total annual operating expenses without mazut cost for ten days				€445,965
	Mazut cost for ten days				
7	Mazut cost, excluding mazut for heat production for mazut facility operation for ten days	ton	2,196	814	1,787,555
8	Mazut cost for heat production (156 Gcal) for mazut facility operation for ten days	ton	16	814	13,323
	Total mazut cost for ten days	ton	2,213	814	1,800,878
	Total annual operating expenses				2,246,843

4.1.3. ECONOMIC ANALYSIS

The mazut facility's cost, operating expenses, and NPV at a discount rate of 3 percent are presented in Table 4.1.3.

TABLE 4.1.3. ESTIMATED PROJECT COST, OPERATING EXPENSES, AND NPV OF THE MAZUT FACILITY	
INDICATOR	€
Project cost	1,106,050
Annual operating expenses	

TABLE 4.1.3. ESTIMATED PROJECT COST, OPERATING EXPENSES, AND NPV OF THE MAZUT FACILITY	
INDICATOR	€
Operating expenses without ten-day fuel supply cost	445,965
Ten-day fuel supply cost	1,800,878
Total annual operating expenses	2,246,843
Net present value for 10-year period	7,928,983
Net present value for 20-year period	13,029,857

4.1.4. ADVANTAGES AND DISADVANTAGES

The key advantages of using mazut compared to LPG (the estimated economic indicators of the LPG facility are presented in Section 4.2) as a backup fuel are:

- Availability of mazut infrastructure at CHP-Nord
- Many years of experience using mazut at CHP-Nord
- The cost of Mazut, which is lower than competing backup fuels (although backup fuel may only be needed every few years for several days)

The main disadvantages of mazut as a backup fuel include:

- The mazut facility's very high operating expenses (€445,965 per year), which is 28 times higher than those of DF and 19 times higher than those of LPG
- Estimated NPVs of restoring and operating the mazut facility (including backup fuel costs) are higher than the NPVs for developing and operating the DF or LPG facilities
- Significantly higher air emissions than LPG
- Cannot be used for the JMS 620 GS-N.L. gas engines that are installed at CHP-Nord
- Cannot be used for gas turbines or a combined-cycle unit if CHP-Nord installs such equipment in the future.

4.2. LPG BACKUP FUEL SYSTEM

4.2.1. LPG FACILITY DEVELOPMENT

Based on the preliminary engineering analysis performed in Phase 1, LPG was selected by CHP-Nord as the preferred backup fuel. The results of the engineering analysis presented in this subsection include the findings of both Phase 1 and Phase 2.

The LPG facility, including uploading, storage, and preparation of LPG for combustion, requires the following main equipment:

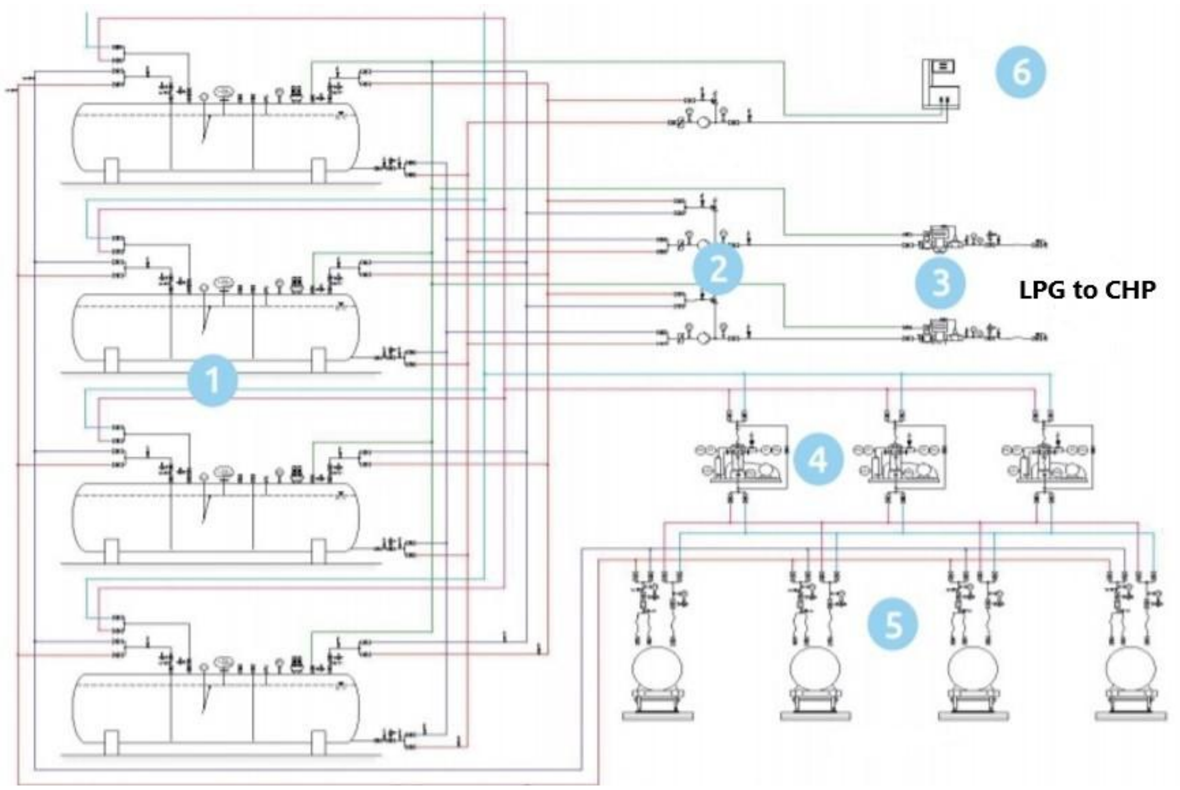
- Fuel storage tanks located below or above ground level, with single or double walls
- Pipelines and fittings
- Pumps for unloading the LPG
- Pumps for supplying LPG to the vaporizer
- Vaporization system for converting LPG from the liquid phase to the gas phase before the gas is fed into the inlet of the air mixing system
- Air mixing system for mixing LPG with air (low- or high-pressure mixer)
- Compressor for high-pressure mixing equipment.

In addition, the LPG facility must have fire protection, alarm, automation, and monitoring systems. An example of an LPG rail tank is shown in Figure 4.2.1. A horizontal LPG tank (cylinder) is shown in Figure 4.2.2.

Figure 4.2.1. LPG rail tank

Figure 4.2.2. Horizontal LPG tank

A schematic diagram of CHP-Nord's LPG unloading, storage, and delivery facility is presented in Figure 4.2.3.



1. Reservoirs. 2. Pump station. 3. Metering and drain unit. 4. Compressors.
5. Unloading system for railcars or truck tanks.

Figure 4.2.3. Schematic diagram of the CHP'S LPG unloading, storage, and delivery facility

USE OF LPG FOR BOILER OPERATION

LPG is delivered and drained into the fuel storage in its liquid state, while liquefied gas enters the boiler in a gaseous state. A natural transition from a liquid to a gaseous state is not always possible. Therefore, the facility must have a vaporization system. The vaporization system has a special container in which the LPG is heated to its vaporization temperature, transforming the liquid propane into gaseous propane at the appropriate pressure.

LPG VAPORIZERS

LPG vaporizers are classified according to the type of LPG heating:

- Dry electric vaporizers use electric heaters to heat the vaporizer's container.
- Liquid vaporizers use heat exchangers (of different designs) and a heat transfer fluid to heat the vaporizer. The transfer fluid's heat source can be steam or water produced by boilers, the heating network, electric heaters, or a heat exchanger (heated by a gas-fired burner).
- Open-flame vaporizers use an open flame (direct combustion) to heat the LPG vaporizer.

The technical conditions for connecting the vaporizer to the LPG facility usually determine the type of vaporizer. If it is possible to connect electricity, electric vaporizers can be used, and if it is possible to use water from heating networks, then a liquid vaporizer can be used.

Another parameter to consider is the speed at which the vaporizer reaches its operating mode. This is important when designing an uninterrupted reserve fuel supply system, as in this case. Liquid vaporizers with internal heating of the coolant are more inertial (i.e., take more time to warm up) than electric and open-flame vaporizers.

This analysis assumes that liquid vaporizers will be used and that they will use for their heat source a heating network, which retains sufficient heat energy potential for long periods of time. The amount of LPG required to heat the vaporizer is included in the ten-day fuel supply calculations. One advantage of liquid vaporizers is that water can be heated by an electric heater and/or burner, giving them a redundant/backup heat source.

MIXING LPG WITH AIR

To use the same CHP equipment as is used for burning natural gas, LPG is premixed with air (in proportions dependent on the ratio of propane and butane). Gas mixers (LPG/air mixing system) are recommended to both achieve the calorific value of natural gas and to eliminate the risk of condensation in gas pipelines.

Modern, efficient automated systems are used for these mixing systems. Depending on the load, a programmable controller regulates the heating and mixing processes and maintains the constant pressure of the gas-air mixture in the receiving tank (hereafter referred to as the receiver). The receiver has a safety valve, a drain valve, a pressure gauge, and inlet and outlet valves for the gas-air mixture.

In practice, low-pressure (less than 5 kPa), medium-pressure (from 5 kPa to less than 0.3 MPa), and high-pressure (from 0.3 to 1.2 MPa) mixing systems are used.

In low-pressure systems, gas mixing typically uses Venturi tubes, or special mechanical or electrical valves. The high-pressure LPG vapor enters through a nozzle or a mixing valve, and atmospheric air enters through an air strainer. In the valve's diffuser, or mixing chamber, partial mixing of air and the LPG vapor phase takes place. Then the resulting mixture enters the receiver-separator through the outlet pipe, where the final mixing of air with LPG occurs.

In a high-pressure mixing system, air and gas are supplied to the vaporization system, each through its own inlet pipe; pass through the air and gas pressure regulators, respectively; and enter the mixing chamber. For the mixing system to operate normally, it is very important to have equal and constant air and gas pressure after the regulators. Only in these conditions will the mixture have a constant composition. The pressure of gas and air, after the regulators, can vary between 1.0 and 1.7 MPa.

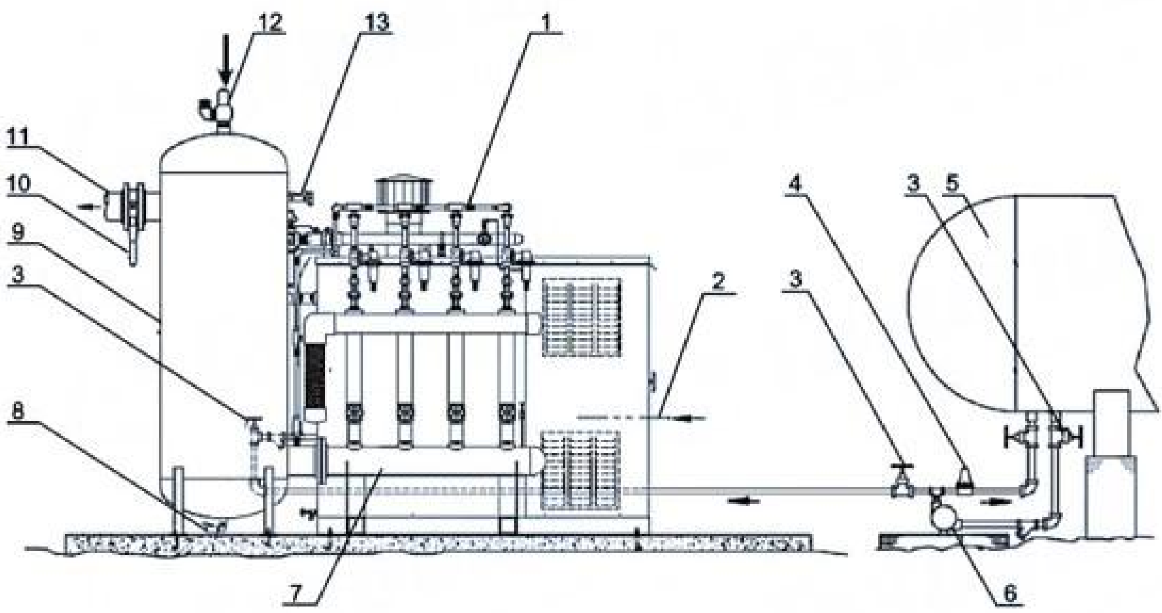
Monoblock (combined) evaporative-mixing plants include an LPG vaporizer, which includes both the mixing system and the receiver. The workflow is automated. To start the system, one must simply open the valve that supplies the LPG liquid phase and press the start button. It takes less than a minute for the evaporator to reach its operating temperature from a cold start. A pump may be required to provide sufficient gas pressure for the mixing process. A liquid phase pump is required if there is insufficient pressure in the tank under the existing temperature conditions.

The range of gas-air mixture preparation systems is extensive, in terms of both characteristics and operating principles, design, automated control systems, safety systems, etc. Most manufacturers offer options that combine the functions of an LPG vaporizer and mixing unit ("vaporizer-mixer"). These systems are typically compact, modular, highly efficient, reliable, and easy to use, with ample room for improvement and customization.

Regarding comparing the type and price of mixing systems and vaporizer systems or monoblock type: it is better not to compare individual systems, but rather to compare the entire solution, including compliance with the CHP's requirements and the CHP's specific technical conditions. The selection of various equipment and systems mainly depends on the required amount of gas, the range and rate of change in the gas flow rate, the degree of process automation, and several other factors that are specified in the design assignment, including regulatory requirements.

For this report's initial calculations, the use of two monoblock vaporizing-mixing units is assumed. Several modern solutions and full gas treatment processes automation for boilers are available.

The schematic diagram of the proposed LPG vaporizing-mixing system is shown in Figure 4.2.4.



1. Modular mixing and vaporization system. 2. Electricity connection. 3. Shut-off valve with hydrostatic valve. 4. Pump pressure bypass valve. 5. LPG storage tank. 6. Pump. 7. Liquid filter on the pipeline. 8. Drain valve. 9. Storage tank. 10. Ball valve. 11. Outlet of the gas-air mixture. 12. Safety relief valve. 13. Pressure gauge.

Figure 4.2.4. Schematic diagram of the LPG vaporizing-mixing system

OTHER LPG FEATURES

LPG viscosity does not significantly increase at low temperatures. By contrast, viscosity adversely affects the transportation of mazut and DF from external storage to burners. For mazut to maintain its readiness for five months a year, 400 Gcal of thermal energy (i.e., steam) is used, and another 156 Gcal of steam is used for the ten-day periods each year when reserve fuel is fired in the CHP (per the analysis's assumptions).

The CHP's steam boilers and steam turbines, when fired using the LPG backup system, will generate the required amount of heat and electricity. Combustion of LPG, premixed with air, in CHP-Nord's current boilers is technically possible without complex repairs, equipment replacement, or operating mode problems. There is no need to use more expensive combined burners for burning both gaseous and liquid fuels (as in the case of mazut or DF). The LPG-air mixture has a calorific value close to that of natural gas.

Switching the combustion fuel from natural gas to LPG at the CHP will take 60 seconds.

Modern systems for storing, preparing, and burning LPG are fully automated, including monitoring and all necessary security measures.

USE OF LPG FOR JMS 620 GS-N.L. GAS PISTON ENGINES

The conditions for using LPG in the four JMS 620 GS-N.L. gas piston engines were discussed with representatives of the gas piston engine manufacturer Jenbacher INNIO. As a result of these discussions, the following information was received from Jenbacher INNIO and Vipropat Ltd:

- The JMS 620 GS-N.L. engines installed at CHP-Nord are designed to work on natural gas.
- These engines can operate on both natural gas and LPG, but the following circumstances must be considered:
  - JMS 620 GS-N.L. engines need to be retrofitted by ordering and installing the appropriate equipment.
  - Gas piston engines, produced by Jenbacher INNIO, can only use HD5-class LPG with a propane content of more than 90 percent. Regular LPG (propane content is 36–46 percent in Moldova) cannot be used by Jenbacher INNE engines due to the high amount of butane.
  - According to preliminary data received from Achira-Grup, the price of LPG with propane content above 90 percent could be 1.5 times higher (MDL 23 per liter) than the regular LPG sold in Moldova.

- Even when using HD5-class LPG with greater than 90 percent propane, the power of the JMS 620 GS-N.L. will be a maximum of 50 percent of the rated power when operating on natural gas.

- After four to five years of operation (the JMS 620 GS-N.L. engines were installed at CHP-Nord in 2019), it is not recommended that they be modified for firing LPG.

SPECIFICATION AND ESTIMATED COSTS

The following equipment was included in the capital cost estimate:

- LPG uploading system: an unloading platform for two rail tanks
- LPG storage tanks: 327 m^3 each
- Piping system
- Shutoff and control valves: tank safety valves, and check valves on pumps and pipelines
- Compressors for creating a pressure drop in tanks for transferring gas from railway tanks to storage tanks
- LPG pumping units for LPG supply to the system
- Vaporizer and gas-air mixer: receiver—mixing tank
- Automation: measurement and signaling systems (instrumentation with installation and commissioning)
- Monitoring and control system: SCADA
- Wiring and other electrical equipment
- Fire safety systems: monitoring, sprinklers, protection, detection, and alarms as appropriate for gas leaks, gas levels in each tank, LPG levels (85 percent alarms), high temperature, high pressure, and flames; and audio and video monitoring.

The initial specifications and estimated capital costs for developing the LPG facility are presented in Table 4.2.1.

TABLE 4.2.1. SPECIFICATION AND ESTIMATED COSTS OF LPG FACILITY DEVELOPMENT

#	EQUIPMENT	QUANTITY	COST PER	TOTAL	NOTE

TABLE 4.2.1. SPECIFICATION AND ESTIMATED COSTS OF LPG FACILITY DEVELOPMENT					
			UNIT (€)	COST (€)	
	Technological equipment				
1	Design	1	33,000	33,000	Expert estimate
2	Unloading platform for two rail tanks	1	80,000	80,000	Expert estimate
3	Repair/restoration of the railway	1	130,000	130,000	Expert's estimate based on inspection
4	LPG tanks (cylinders), 327 m^3 each	12	67,000	804,000	Other options are possible
5	Compressors for creating differential pressure in tanks for overflowing gas from rail tanks into LPG tanks	3	48,000	144,000	Estimated price from manufacturer
6	LPG vapor-phase compressors	2	20,000	40,000	Estimated price from manufacturer
7	Pumps for supplying LPG to CHP-Nord	2	45,000	90,000	Estimated price from manufacturer
8	Piping system, uninsulated (m)	550	46	25,300	Estimated price from manufacturer
9	Piping system, insulated, after vaporization of LPG to boilers (m)	850	78	66,300	Estimated price from manufacturer
10	Shutoff and control valves including filling and drain valves, pressure equalization valves, safety valves on tanks, and check valves on pumps and pipelines	85	250	21,250	Expert estimate
11	Electrical wiring and other electrical equipment	1	55,000	55,000	Estimated price from manufacturer
12	Vaporizer and LPG-air mixer	2	88,000	176,000	Estimated price from

TABLE 4.2.1. SPECIFICATION AND ESTIMATED COSTS OF LPG FACILITY DEVELOPMENT					
	(receiver—mixing tank)				manufacturer
13	Additional ventilation system (tenfold air exchange—two-thirds of the air intake must be provided from the lower zone of the room)	1	38,000	38,000	Expert estimate
14	Safety systems	1	190,000	190,000	Expert estimate
15	Setup and commissioning	1	12,000	12,000	
16	Other costs	1	20,000	20,000	Expert estimate
	Total technological equipment			1,924,850	
	Dismantling of mazut facility equipment and site preparation				
17	Dismantling of tanks, mazut pipelines, steam pipelines, and structures	1	230,000	230,000	Expert estimate
18	Site preparation: development of pits, construction of foundations, etc.	1	155,000	155,000	Expert estimate
	Total dismantling of mazut facility equipment and site preparation			385,000	
	Devices and automation				
19	Automation, measurement, and alarm system	1	550,000	550,000	Estimated price from manufacturer
20	Control and management system—SCADA	1	95,000	95,000	Expert estimate
	Total devices and automation			645,000	
	Total capital costs			2,954,850	

When developing a new LPG facility, there will be several alternative technical solutions/options. Final decisions on all technical issues and options must be made after a full feasibility study is completed by a local engineering company in accordance with the requirements of Moldovan legislation.

OPERATING EXPENSES

The LPG facility's estimated annual operating expenses are presented in Table 4.2.2. These estimates assume that a ten-day supply of backup fuel supply is completely used once every five years (during a natural gas supply outage).

TABLE 4.2.2. ESTIMATED ANNUAL OPERATING EXPENSES OF THE LPG FACILITY

#	EXPENSES	UNITS	QUANTITY	COST PER UNIT (€)	TOTAL COST (€)
1	Electricity for unloading and feeding boilers for ten days	kWh	32,000	0.24	7,567
2	Consumables		1	2,500	2,500
3	Salary expenses (four people at €500/month for six months)	Month	12	1,000	12,000
4	Other expenses	€	1	1,500	1,500
	Total annual operating expenses without LPG Cost for ten days				€23,567
5	LPG cost, excluding LPG for ten days of heat production for the vaporizer	m^3	3,300	688	2,270,901
6	LPG cost for ten days of heat production for the vaporizer (26 Gcal, totally)	m^3	26	688	17,940
	Total LPG cost for ten days	m^3	3,326	688	2,288,841
	Total annual operating expenses				2,312,409

4.2.2. ECONOMIC ANALYSIS

The LPG facility's cost, operating expenses, and NPV at a discount rate of 3 percent are presented in Table 4.2.3.

TABLE 4.2.3. ESTIMATED PROJECT COSTS, OPERATIONS AND MAINTENANCE COST, AND NPV OF THE LPG FACILITY (€)

Project cost	2,954,850

TABLE 4.2.3. ESTIMATED PROJECT COSTS, OPERATIONS AND MAINTENANCE COST, AND NPV OF THE LPG FACILITY (€)	
Annual operating expenses	
Operations and maintenance cost without fuel cost	23,567
Fuel cost	2,288,841
Total annual operating expenses	2,312,409
Net present value for 10-year period	7,082,456
Net present value for 20-year period	10,217,822

4.2.3. ADVANTAGES AND DISADVANTAGES

The key advantages of using LPG, compared to mazut, as a backup fuel in steam boilers are as follows:

- The estimated annual operating expenses (not including the purchase of a ten-day fuel supply, which is expected to be needed once every five years) are less than 6 percent of the annual operating expenses of the mazut facility.
- Estimated NPVs of developing and operating the LNG facility (including backup fuel costs), when considering 10 and 20-year time horizons, are less than the corresponding NPVs of restoring and operating the mazut facility by 12 percent and 28 percent, respectively.
- Premixed LPG-air has a calorific value close to that of natural gas.
- There is no need to use more expensive special burners for burning both gaseous and liquid fuels (as is the case when using mazut or DF as the backup fuel).
- The viscosity of LPG does not increase with low temperatures; by contrast, viscosity negatively affects the transportation of mazut and DF from the fuel storage to burners.
- Switching combustion systems from natural gas to LPG takes 60 seconds.
- If the mazut backup fuel were replaced with LPG, according to a preliminary initial estimate, emissions into the atmosphere would be reduced as follows: sulfur dioxide (SO_2) 99.6 percent, nitrogen oxides (NOx) 89.2 percent, carbon monoxide (CO) 93.4 percent, soot 99.8 percent, and carbon dioxide (CO_2) 22.1 percent.

- LPG can be used for gas turbines or a combined-cycle unit if CHP-Nord installs such equipment in the future.

The disadvantages of using LPG are:

- The estimated capital cost of developing the LPG facility is 2.7 times the capital cost of restoring the mazut facility.
- The need to comply with safety requirements caused by the properties of LPG adds to this cost.
- There is a lack of experience developing LPG storage facilities of this size in Moldova.
- Although the JMS 620 GS-N.L engines (installed in 2019) can operate on both natural gas and LPG, they would need to be retrofitted with the appropriate equipment; have to fire the more expensive HD5-class LPG; and operate at a maximum of 50 percent of their rated power when operating on natural gas. Furthermore, after operating for four to five years, it is not recommended that the JMS 620 GS-N.L engines be modified for firing LPG.

4.3. COMPARATIVE ANALYSIS OF MAZUT AND LPG BACKUP FUEL SYSTEMS

The initial technical and economic assessment of restoring and operating the mazut facility compared to developing and operating the LPG facility finds that the estimated total capital cost required to restore the mazut facility is significantly lower than the estimated total capital cost of developing the LPG facility. However, LPG has a number of other important economic, technical, and environmental advantages over mazut. Thus, using LPG as the backup fuel system is recommended for further consideration.

Although the capital cost of restoring the mazut facility is lower than the capital cost of the LPG facility, the following economic benefits of the LPG option are noted, as presented in Table 4.3.1:

- The estimated annual operating expenses of the LPG facility (not including the cost of a ten-day fuel supply, which may not be needed for a number of years) are less than 6 percent of the operating expenses of the mazut facility.
- The NPVs of developing and operating the LPG facility (including backup fuel costs) are less than the corresponding NPVs of restoring and operating the mazut facility by 10 percent and 26 percent for periods of 10 and 20 years, respectively.

TABLE 4.3.1. INITIAL ANALYSIS OF THE COST OF RESTORING AND OPERATING THE MAZUT FACILITY

VERSUS DEVELOPING AND OPERATING THE LPG FACILITY (€)						
BACKUP FUEL OPTION	CAPITAL AND/OR REPAIR COSTS	ANNUAL OPERATING EXPENSES			NPV WHEN USING FUEL RESERVES ONCE IN FIVE YEARS	
		EXCLUDING TEN-DAY FUEL SUPPLY COST	TEN-DAY FUEL SUPPLY COST	TOTAL	EVALUATION PERIOD	
					10 YEARS	20 YEARS
Mazut facility	1,106,050	445,965	1,800,878	2,246,843	7,928,983	13,029,857
LPG facility	2,954,850	23,567	2,288,841	2,312,409	7,082,456	10,217,822

Firing LPG at power plants pollutes the environment to a much lesser degree than firing mazut and DF. If Mazut is replaced with LPG, according to initial calculations, emissions into the atmosphere would be reduced as follows: sulfur dioxide (SO_2) by 99.6 percent, nitrogen oxides (NOx) by 89.2 percent, carbon monoxide (CO) by 93.4 percent, soot by 99.8 percent, and carbon dioxide (CO_2) by 22.1 percent.

The key advantages and disadvantages of these two backup fuel systems are presented in Table 4.3.2.

TABLE 4.3.2. ADVANTAGES AND DISADVANTAGES OF MAZUT AND LPG BACKUP FUEL SYSTEMS

BACKUP FUEL SYSTEM	ADVANTAGES	DISADVANTAGES
Mazut facility	• The capital cost of the restoring the facility is 37 percent of the capital cost of developing the LPG facility • Lowest fuel price in Moldova (currently) • Many years of experience operating the mazut facility (closed in 2009)	• Very high estimated annual operating expenses: €445,965 (19 times higher than the cost of operating the LPG facility, not including the purchase of a ten-day supply of fuel) • Estimated NPVs of restoring and operating (including backup fuel cost) are higher than the corresponding NPVs of developing and operating the LPG facility • More serious environmental pollutants compared to LPG • Cannot be used for the JMS 620 GS-

TABLE 4.3.2. ADVANTAGES AND DISADVANTAGES OF MAZUT AND LPG BACKUP FUEL SYSTEMS		
BACKUP FUEL SYSTEM	ADVANTAGES	DISADVANTAGES
		N.L. gas engines that are installed at CHP-Nord • Cannot be used for gas turbines or combined-cycle units if CHP-Nord installs such equipment in the future
LPG facility	• Estimated annual operating expenses of the LPG facility (not including the cost of a ten-day fuel supply) are less than 6 percent of the operating expenses of the mazut facility • Estimated NPVs of developing and operating (including backup fuel cost) are less than the corresponding NPVs for restoring and operating the mazut facility by 12 percent and 28 percent for 10- and 20-year time horizons, respectively • The premixed LPG-air has a calorific value close to that of natural gas • There is no need to install expensive burners for burning both gaseous and liquid fuels (as is the case when using mazut) • The viscosity of LPG does not increase at low temperatures; by contrast, viscosity negatively affects the transportation of mazut from the fuel storage to burners • Switching from natural gas to LPG CHP firing takes up to 60 seconds	• The estimated capital cost of developing the LPG facility is 2.7 times that of the capital cost of restoring the mazut facility • The LPG facility will need to comply with special safety requirements caused by the properties of LPG • There is a lack of experience developing and operating LPG storage facilities of this size in Moldova • Although the JMS 620 GS-N.L. engines can operate on both natural gas and LPG, they need to be retrofitted with the appropriate equipment; must fire more expensive HD5-class LPG; and can operate at a maximum of 50 percent of their rated power when operating on natural gas. After they have been operating for four to five years, it is not recommended that these engines be modified for firing LPG

TABLE 4.3.2. ADVANTAGES AND DISADVANTAGES OF MAZUT AND LPG BACKUP FUEL SYSTEMS		
BACKUP FUEL SYSTEM	ADVANTAGES	DISADVANTAGES
	and is automated • LPG pollutes the environment much less than mazut, significantly reducing atmospheric pollutant emissions • If, in the future, CHP-Nord installs gas turbines or a combined-cycle power unit, they can use LPG	

4.4. CONCLUSION AND RECOMMENDATIONS

The initial technical and economic Phase 2 assessment resulted in the following conclusions and recommendations:

- Although the capital cost of restoring the mazut facility is lower than that of building the LPG facility is cheaper, the following economic benefits of the LPG option are noted, as presented in Table 4.3.1:
  - The estimated annual operating expenses of the LPG facility (not including the cost of a ten-day fuel supply, which may not be needed for several years) are less than 6 percent of the annual operating expenses of the mazut facility.
  - Estimated NPVs of developing and operating the LPG facility (including backup fuel costs) are less than the corresponding NPVs of restoring and operating the mazut facility by 10 percent and 28 percent for periods of 10 and 20 years, respectively.
- LPG also has the following advantages:
  - It presents an opportunity to maximize the efficiency of fuel systems.
  - Premixed LPG-air has a calorific value close to that of natural gas.
  - There is no need to use more expensive special burners for burning both gaseous and liquid fuels, as would be required when firing mazut or DF.

- LPG is not subject to a significant increase in viscosity at low temperatures; by contrast, viscosity negatively affects the transportation of mazut and DF from the fuel storage to the CHP's burners.

- Switching from natural gas to LPG takes a maximum of 60 seconds and can be done automatically.

- LPG is considered an alternative clean fuel that pollutes the environment significantly less than either mazut or DF.

- LPG can be used in the future if CHP-Nord installs gas turbines or a combined-cycle power unit.

• LPG has a long history as a fuel for power generation in refinery and power generation systems worldwide.