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TEPLATOR DEMO: Nuclear Heating for Prague Central Heating Network

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ABSTRACT

A case study focusing on the Teplator DEMO deployment for the existing Prague district heating system is presented. The case study aims at existing natural gas/waste/coal district heating Prague portfolio as well as at the network and existing nuclear licensed sites which are off the city centre and not far from existing heat pipelines. A broad technical and cost study is studied to assess feasibility of nuclear heating source for existing conditions and a similar pathway for other European cities is proposed.

1 INTRODUCTION

Currently, all European countries signed a CO_2 emission reduction agreement; mainly coal plants and heating stations should be replaced by low-carbon-emission technologies. Not only the Czech Republic is trying to find suitable sources of energy that are environmentally friendly, safe for the surrounding population, financially meaningful and stable in terms of energy supply. However, in the long term any replacement of coal power plants and heating stations by natural gas units does not solve the problem of CO_2 emissions. The natural gas is a same fossil fuel as a coal and the CO_2 allowances price increase rapidly, so the heat produced by natural gas will be in future more and more expensive. On the other hand, current studies show that the combustion of natural gas produces about half the CO_2 emissions, but the environment impact is comparable to the coal combustion due to methane leakage during extraction (natural gas contains around 90% of methane) [1].

This issue can be solved by replacing old coal plants with heat generated by nuclear sources. One of the possible nuclear heat sources can be the nuclear heating plant, the TEPLATOR.

2 TEPLATOR DEMO

TEPLATOR is a concept of a heat-only producing reactor developed by a team of researchers from the University of West Bohemia in Pilsen and Czech Technical University in Prague. It is a channel type heavy-water moderated and cooled reactor, which allows using of various types of nuclear fuel with different enrichment, from natural up to spent fuel. The TEPLATOR concept will use already irradiated fuel assemblies from commercial light water reactors, the using of fresh slightly enriched fuel is possible for countries which do not have an irradiated fuel in interim storage. This reactor will produce safe, clean, reliable, and cheap heat energy. Several versions of TEPLATOR with variable capacity and temperature output are proposed, from 50 MWth forTEPLATOR DEMO up to 150 MWth with TEPLATOR FULL. The construction of the reactor core will not be much different between DEMO and FULL versions of TEPLATOR.

TEPLATOR DEMO is the first and smallest demonstration designed unit with 55 VVER-440 fuel assemblies with output capacity 50 MWt, temperature of output coolant is designed to 98 °C. This unit is sufficient for heating a large city with more than 100 000 citizens due to production more than 1 PJ per year. Figure 1 shows the visualisation of the TEPLATOR concept [1] without shielding and other supported technologies.

Figure 1: TEPLATOR design [1]

2.1 Economics

The TEPLATOR design is rather simple, based on known proven technologies that lead to cheap and competitive heat production. The estimated costs for TEPLATOR DEMO construction and operation shows Table 1. Based on these assumptions, the estimated final production price of heat will be 4.68 EUR per GJ for spent nuclear fuel and 6.18 EUR per GJ in case of fresh nuclear fuel [3] . Fresh fuel means slightly enriched, the preliminary study suggested an enrichment around 1%.

Table 1: TEPLATOR DEMO economics [3]

CAPEX [EUR]	30 000 000
Construction costs	15 000 000
Heavy water purchase	15 000 000

OPEX [EUR/YEAR]	1 150 000
Fuelling [EUR/YEAR]	
Spent fuel	0
Fresh fuel	1 500 000
Nuclear account tax (CZ) [CZK/MWht]	1.125
Final heat price [EUR/GJ]	
Spent fuel	**4.68**
Fresh fuel	**6.18**

3 NUCLEAR FACILITIES FOR HEAT PRODUCTION

The use of nuclear energy for heating is not a new idea. This technology can be found in various locations, the source of the heat is almost always an electricity generating NPP, the heat production is just an additional utilization. Using coal power plants for heating is more widespread compared to NPPs. Large conventional coal-based power plants usually deliver heat to the nearest cities. However, there are many nuclear power plants in Europe that generate heat for nearby cities. Table 2 shows the localities currently heated by the existing NPP or by district heating (DH) system connection under construction. More applications are planned or in progress, especially in China.

Table 2: Nuclear power plants for heat production in operation [4]

Country	Plant name	Reactor type	Gross Electric Power (MW_{el})	Heat Output Capacity (MW_{th})
Bulgaria	Kozloduy	2x VVER-1000	2040	20
Czechia	Temelin	2x VVER-1000	2164	100*
Hungary	Paks	4x VVER-440	2000	40
Romania	Cerna Voda	2x CANDU-6	1411	46
Russia	Akademik Lomonosov	2x KLT-40S	70	58*
	Balakovo	4x VVER-1000	4000	920
	Beloyarsk	BN-600	600	280
		BN-800	885	290
	Bilibinoc	4x EGP-6	48/38	78/116
	Kalinin	4x VVER-1000	4000	420
	Kola	4x VVER-440	1660	116
	Kursk	4x RBMK-1000	4000	700
	Leningrad 2	VVER-1200	1187	290
	Novovoronezh	VVER-440, VVER-1000	1417	65
	Novovoronezh 2	2x VVER-1200	2361	190
	Rostov	4x VVER-1000	4030	
	Smolensk	3x RBMK-1000	3000	230
Slovakia	Bohunice V2	2x VVER-440	1010	230
Slovenia	Krsko	PWR	727	70
Switzerland	Beznau	2x WH 2LP PWR	760	75
Ukraine	South Ukraine	3x VVER-1000	3000	40
	Zaporozhye	6x VVER-1000	6000	1400

** DH system under construction.*

In the Czech Republic, Temelin NPP currently supplies heat energy to the nearest city Tyn nad Vltavou and the new interconnection of the NPP Temelin with Ceske Budejovice (nearly 100 000 citizens) DH network is under construction. This pipeline will be 26 km long with a transfer capacity of 100 MWt and the expected amount of heat delivered is 750 TJ per year, which represents 1/3 of the current heat demand. The final construction price is 65 000 000 EUR [5]. There is currently no nuclear heating station in operation in the whole world that produces commercial heat only, and the construction of TEPLATOR may change it.

4 PRAGUE DISTRICT HEATING SYSTEM

The current Prague district heating system is mainly supplied by the Melnik coal power plant (currently converted to natural gas). The Melnik coal power plant is connected to the Treboradice heating station by 40 km long pipelines (diameter 1000mm). The yearly amount of the delivered heat from Melnik is around 9.5 PJ. The rest of the Prague district heating demand is covered by centralized gas sources (3.2 PJ) and an incineration plant (0.8 PJ) [6] located within the city of Prague. The Prague DH network is shown in Figure 2. The total length of the heating system pipeline is around 700 km. A significant part of the city (especially on the left bank of the Vltava River) is not connected to the DH network, and the heat energy in these localities is produced from local sources, mainly fossil fuels-based such as natural gas.

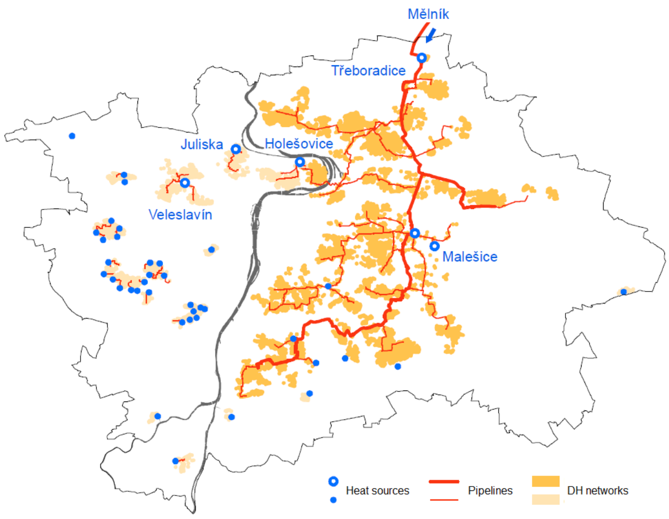

Figure 2: Current Prague district heating system [7]

Finally, nearly 70% of the heat energy delivered is produced from coal combustion, with a substantial environmental impact. Local gas sources and individual fossil fuel-based boilers also negatively affect the Prague environment and produce a significant amount of CO_2 emissions. The possible zero-emission alternative for current sources represents the nuclear concept TEPLATOR.

5 TEPLATOR POTENTIAL

The TEPLATOR locality must meet the legislative requirements for the nuclear facility in accordance with the Atomic Act. In the nuclear favourable year 1970, two different sites for NPP construction were proposed inside Prague – site Holesovice and Modrany. These two NPPs were proposed to supply both electricity and heat for the whole of Prague. Currently, two localities exist with nuclear facilities in operation within Prague reach: Czech Technical University in Holesovice, which operates the VR-1 training reactor, and the Research Center

Rez with two experimental reactors LR-0 and LVR-15 [8]. Holesovice is in the centre of the Prague city, Rez locality is 10 km from the current pipeline from Melnik to Prague and less than 10 km from the Prague centre. Based on that, the Rez site could be proposed for the TEPLATOR DEMO concept facility, easily connected to the existing Melnik-Prague heatline.

The TEPLATOR DEMO 50 MWth facility will produce approximately 1 PJ of heat energy per year. Prague heat demand is sufficient for several TEPLATOR units considering the diversification of the heat source mix. There could be placed more units with higher power compared to DEMO unit. Replacement of current fossil fuel-based sources could save a significant amount of air pollutants and CO_2 emissions and provide a stable and clean source of energy.

5.1 Economics

Connection of the TEPLATOR unit located in Rez to the DH network will require approximately 15 km of the new pipeline. The estimated price of this construction based on the current Temelin NPP – Ceske Budejovice connection project is around 22 500 000 EUR. The final price of produced heat, including this investment, will increase to 7.06 EUR/GJ for the spent fuel and 8.55 EUR/GJ for the fresh fuel, see Table 3.

Table 3: Final heat price including Prague DH network connection [3]

Type of the fuel	Final heat price with pipeline price [EUR/GJ]
Spent fuel use	**7.06**
Fresh fuel use	**8.55**

The average heat consumer price in Prague locality is 25 EUR per GJ including VAT [9]. For coal-based heat production, the costs of fuel and emissions allowances are 6 EUR/GJ on average for the Czech Republic DH network in 2019. For other types of fuel, the costs are significantly higher and the price of emissions allowances is also rapidly increasing. The presented numbers do not include any operating and maintenance costs for conventional heating plants [10]. For all these reasons mentioned before, the price of heat produced by TEPLATOR is fully competitive for the Prague district heating system and could be a profitable and clean source of heat energy.

5.2 Scale up potential

Choosing an already licensed nuclear location (Rez) reduces the legal effort to approve the site in the Prague case. A similar approach can be applied to large cities with a nearby nuclear research reactor sites in Europe where DH network is already built (e.g. Budapest, Munich, Ljublana, Dresden…).

As the TEPLATOR DEMO can be started with fresh fuel assemblies and later updated to TEPLATOR FULL, it can provide a stepwise approach to replacing the current fossil heating portfolio when the old sources will be gradually replaced. Moreover, as the used fuel assemblies can be used in both the DEMO and FULL version, utilisation of possible irradiated assemblies can be considered if a country has a stick pile of irradiated fuel (which is the case for e.g. Czech Republic, Slovakia, Slovenia, Hungary, Germany, Bulgaria).

6 CONCLUSIONS

This work focuses on a case study of placing a TEPLATOR unit for heating the Prague. This idea arose in response to the rising price of CO_2 allowances and due to the efforts to reach net zero greenhouse gases emissions before 2050. Using the heat produced by nuclear chain reaction for heating is not a new idea and several sites in Europe can be found that have used it, and Prague started thinking about this solution in 1970. TEPLATOR could be a revival of this idea.

In this article, the possible locations of the TEPLATOR unit were evaluated and a locality was chosen near Prague with existing nuclear facilities, Rez locality. Based on this assumption, the possibility of connecting the TEPLATOR output to the DH Prague grid was calculated. The final price of produced heat is slightly dependent on the fuel used for TEPLATOR, but if we consider the most expensive modification, the price of heat produced by TEPLATOR is fully competitive to other fossil sources like natural gas or coal. The main advantages of the TEPLATOR system are: 1/ the heat produced is free of any greenhouse emissions, which means that this solution is fully climate friendly, 2/ TEPLATOR system can upcycle irradiated fuel assemblies that are currently considered a substantial liability for all NPPs.

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