Motivations and Challenges in Utilization of Combined Heat and Power Cycle for the Nuclear Power Plants in Korea

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ABSTRACT: To promote carbon-neutrality in the future, leaning on power generation mostly from renewables will likely not be enough. To support carbon-free power generation, nuclear power must find a way to increase its utilization as stable carbon-free energy source. The combined heat and power application of nuclear energy (also known as cogeneration) may allow its coexistence with renewable energy. However, utilizing district heating or desalination systems as low-temperature CHP applications to any nuclear plants in Korea may need to overcome issues in economics, regulations, and even public acceptances of having CHP applications. More advanced CHP applications with higher-temperature steam extractions may have technological limitations to be applied to the current nuclear power plants, with its maximum steam temperature around 300°C and the temperature of actual extractable steam even lower. Nonetheless, development of small modular reactors and advanced reactors along with CHP systems may allow utilization of higher-temperature steam for the CHP applications of the nuclear power plants in the future

1. Introduction

- **Korea's 2050 Carbon-Neutrality Strategy expects the costs of renewables to keep decreasing, ultimately expecting the market-induced widespread of the renewable energy as well as other related technologies such as fuel cell, carbon-free hydrogen, and energy storage systems**
- **Korean government expects advancements in above technologies will allow moving away from traditional power sources (such as coal and nuclear)**
- **However, electricity is closely intertwined with national security and economy, and thus power demand and supply should be predicted in a conservative manner for the future**
- **According to *The 9th Basic Plan of Long-Term Electricity Supply and Demand*, even the *8th Basic Plan* from 2017 underpredicted the maximum electrical power demand during the winter of 2017 and summer of 2018 by 3.0 GW and 6.4 GW, respectively, showing difficulties in predicting the power demand even just couple of years ahead**
- **Thus, the government and the power industry should also develop technologies to utilize other existing carbon-free sources such as nuclear energy**
- **Through application of combined heat and power (CHP) cycle, also known as cogeneration, nuclear can become more sustainable carbon-free source of electricity if it can overcome technical, economical, and political limitations**

2. Combined Heat and Power Cycle

- **Combined Heat and Power (CHP) cycle is the concurrent production of electricity and useful thermal energy from a single prime mover (i.e. source of energy) by taking advantage of the waste heat, ultimately increasing its overall efficiency**
- **However, electrical power generation efficiency may be decreased**
- **Types of prime movers for CHP installations include gas turbine (including combined cycle with heat recovery steam generator, HRSG), boiler/steam turbine, reciprocating engines, microturbines, and even fuel cells**
- **Majority of current CHP installations are from fossil fuels (Figure 1), with capacity mostly from steam turbines and gas turbines including combined cycle (Figure 2)**

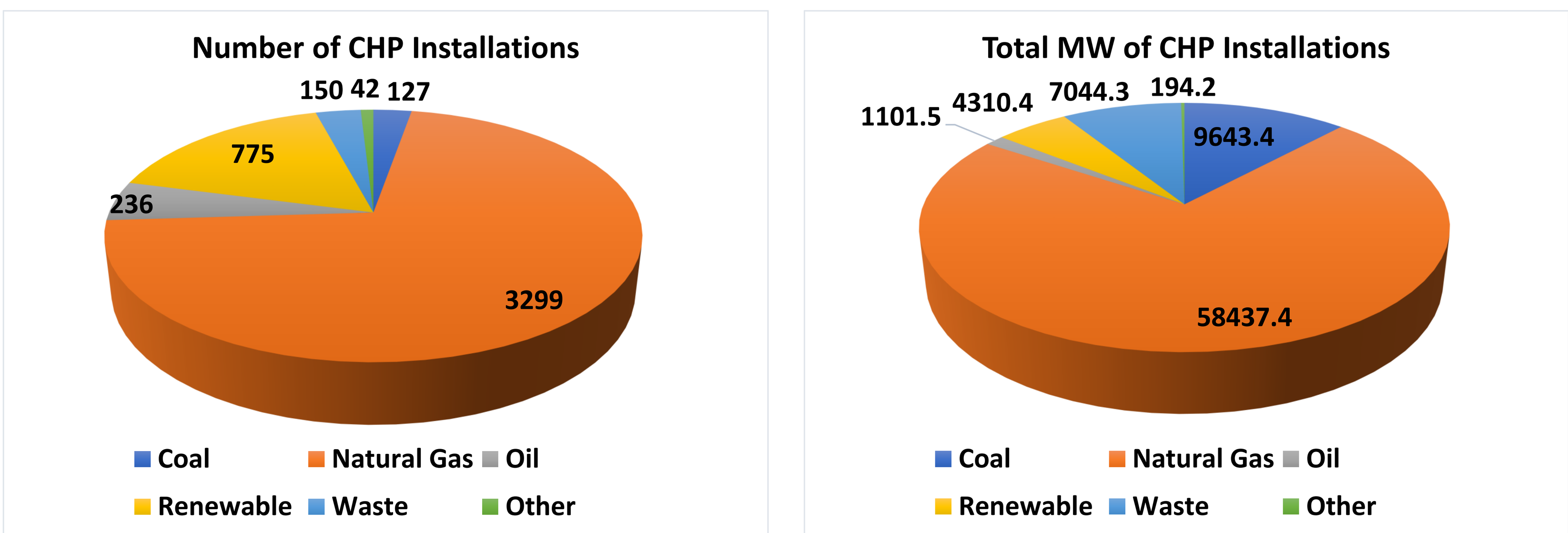

Figure 1. Number and Total Capacity of Combined Heat and Power Installations in the U.S.

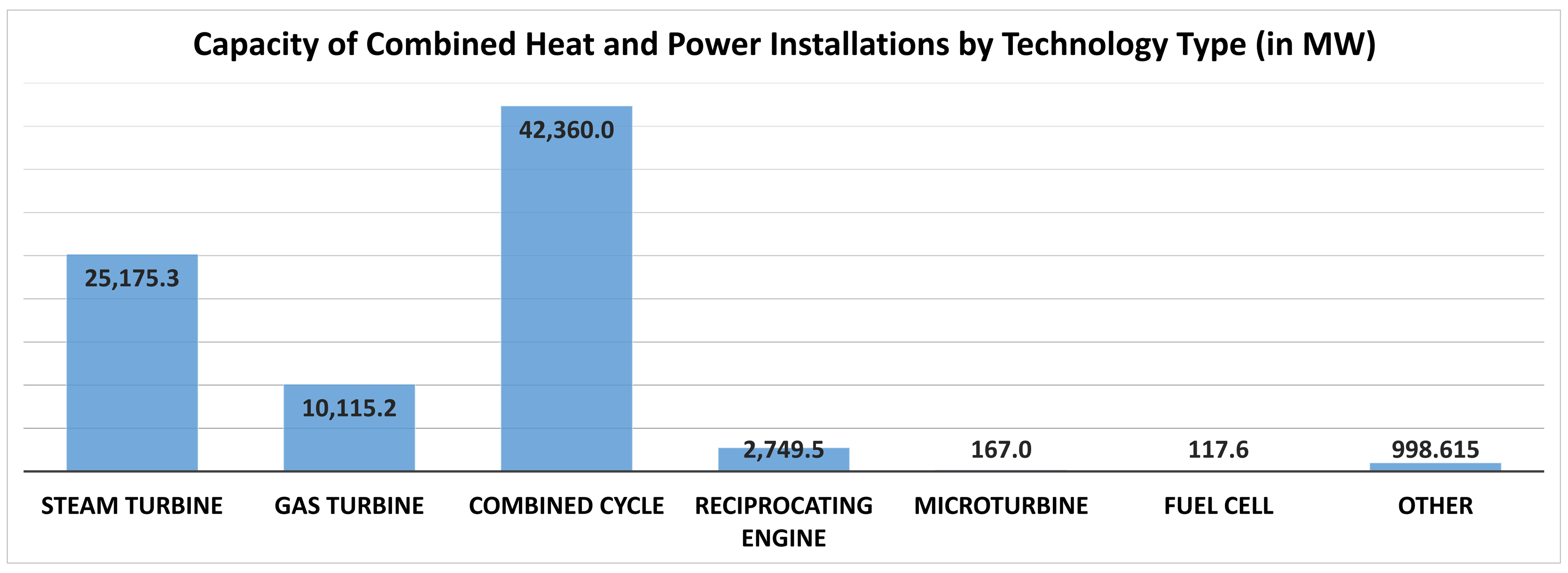

Figure 2. Capacity of Combined Heat and Power Installations by Technology in the U.S.

- **Two types for steam turbine CHP applications are extraction and non-condensing (also known as backpressure), as shown in Figure 3**

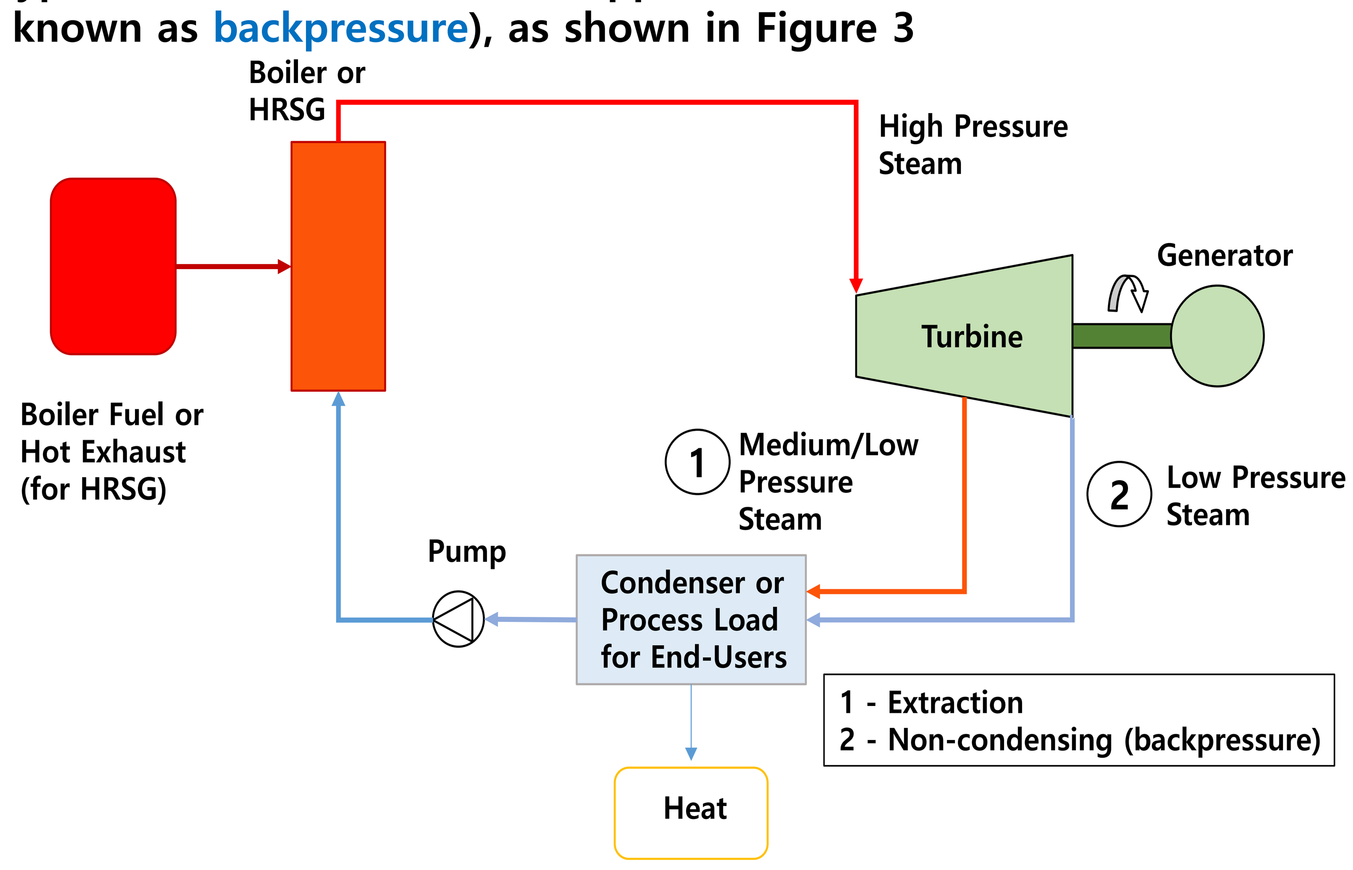

Figure 3. Combined Heat and Power Cycle Configuration for a Typical Steam Turbine

3. Status of Power Generation in Korea

- **To understand applicability of CHP to the nuclear power plants (NPPs), it is necessary to understand the structure of the power generation market in Korea**
- **Countries like U.S. and U.K. have many different companies for generation, transmission, distribution, and sales (i.e. competitive markets) which opens doors for private companies to start the CHP business based on cost-benefit analysis**
- **In Korea, most power generation occurs at southern parts of the country while majority of energy uses are in the metropolitan area, resulting in vertically-integrated companies (i.e. KEPCO and its subsidiaries) responsible for generation, transmission, distribution, and sale of electricity to control most of the power market (Table 1)**
- **Therefore, to apply CHP installations to the NPPs in Korea, the government and its subsidiary companies must take initiative, resulting in the decision based not only on technological/economical pros and cons but also on political incentives**

Table 1. Status of the Power Generation Companies Registered to the Korea Power Exchange (KPX) in 2020

Description			Number of Registered Companies	Installed Capacity (MW)
Retail Supplier (KEPCO)			1	-
Generation Companies	KEPCO's Subsidiary Companies		6	83,840
	Independent Power Producers		20	22,118
	Renewable Energy Companies	Solar	4,006	4,369
		Small Hydro	22	92
		Wind	71	1,539
		Bio Energy, Landfill Gas	39	242
		Fuel cell	19	254
		Tidal	2	2
		Renewable Energy subtotal	4,159	6,498
	Integrated Energy Supply		28	6,915
	Wastes		41	178
	Others		5	51
	Generation Subtotal		**4,259**	**119,600**
Self-generation Plant Owners			22	4,111
Community Energy Systems			10	881
Total			**4,291**	**124,592**

4. Limitations of using CHP in Korean NPPs

- **Limitations of applying CHP technology to the Korean NPPs are listed in Table 2**
- **With current NPPs, the maximum temperature of steam is roughly around 300°C, and if power is generated partially, the temperature of the extracted steam through extraction turbine (Figure 3, #1) is even lower (usually lower than 200°C)**
- **Low temperature of extracted steam would only allow applications such as district heating (already commercialized in Korea with gas-turbine combined cycle plants)**
- **Development of higher-temperature next-generation reactors would allow better nuclear applications of CHP in the future**
- **Applying district heating application to the current NPPs would need to overcome economical and political issues**
- **Possible regional backlash may exist (see district heating pipe rupture accident in 2018.12.4 in Baekseok Station, Goyang, Korea)**

Table 2. Limitations of CHP applications for Nuclear Power Plants

Limitation	Type of Limitation	Possible Solutions
Relatively low temperature of the steam	Technical	- Long-term answer: development of higher-temperature reactors (high-temperature gas reactor, molten-salt reactor, sodium-cooled fast reactor, etc.) - Short-term answer: use heat for low-temperature uses (district heating, desalination)
Reduction in power efficiency	Economical	- Cost-benefit optimization for the operation (between full power generation vs partial power generation + heat energy uses)
Additional investment to construct the required heat transmission network	Economical	- Extensive economic analysis (for the existing plants) - Designing the network at a building stage of the nuclear plants when the capital cost of heat extraction technology is small compared to the whole plant capital cost
Impact on the plant operation safety	Technical	- Additional extensive examinations on the safety, security, and environmental impacts of adding CHP applications to the nuclear plants
Shortening lifetime of the control systems	Technical / Economical	- Optimization for the operation - Additional research on materials to increase lifetime
Public acceptance (public backlash)	Political	- Education to the public - Improvement on company image (see KTH's example) - Financial and other regional incentives (see CopenHill)

NENS Nuclear energy Environment and Nuclear Security Laboratory