Optimal Operation Strategy of Large-Scale CHP & Collaboration Experience with DTU

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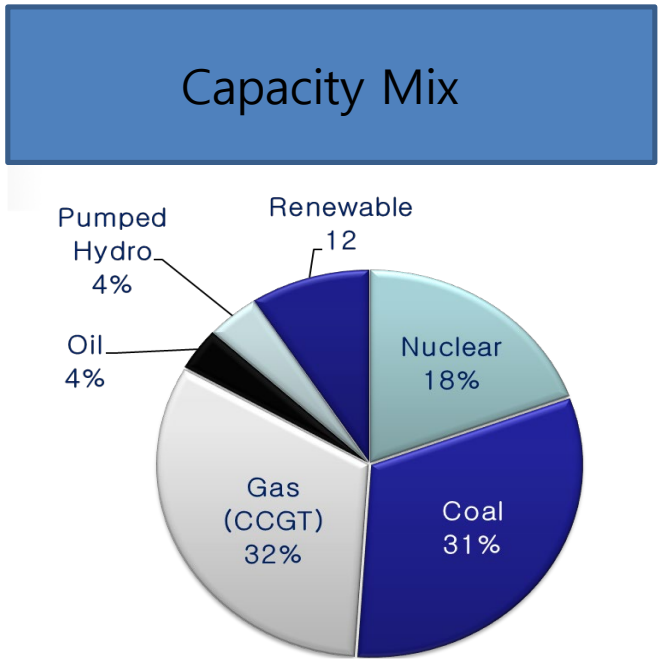
01. Overview of Korean Power System

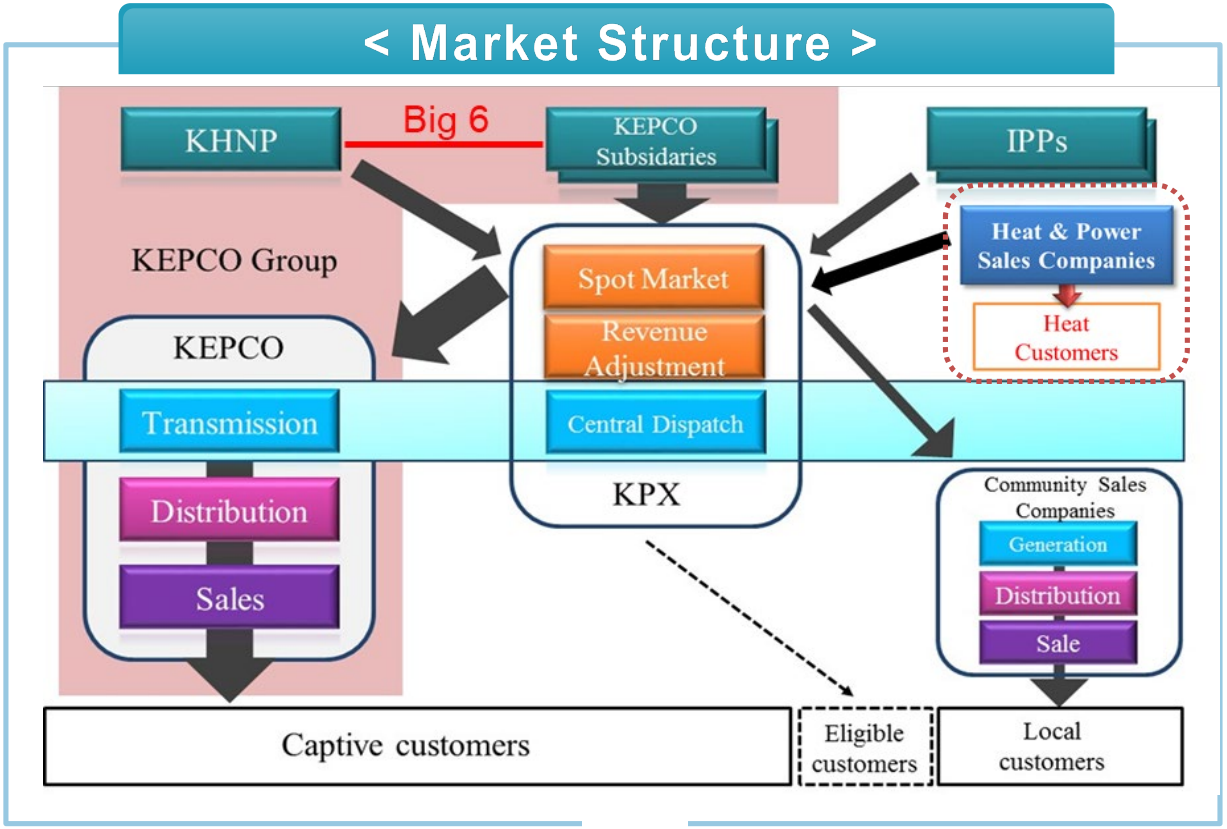
- Islanded power system due to geopolitical issue
- Installed capacity is around 128GW
- High density of the network due to concentration of supply and demand

Year	Installed Capacity (MW)	Peak Demand (MW)	Reserve Margin (%)
2020	127,819	89,091	10
2019	121,147	90,314	7
2018	117,205	92,478	8
2017	116,657	85,133	13
2016	100,180	85,183	9
2015	94,102	78,790	12
2014	93,216	80,154	12
2013	82,296	76,522	6
2012	81,806	75,987	5
2011	76,131	73,137	6
2010	76,078	71,308	6



02. Market Structure

- Not a full competitive market (Generation Competition)
- Retail competition is not opened (Monopoly of KEPCO in retail)



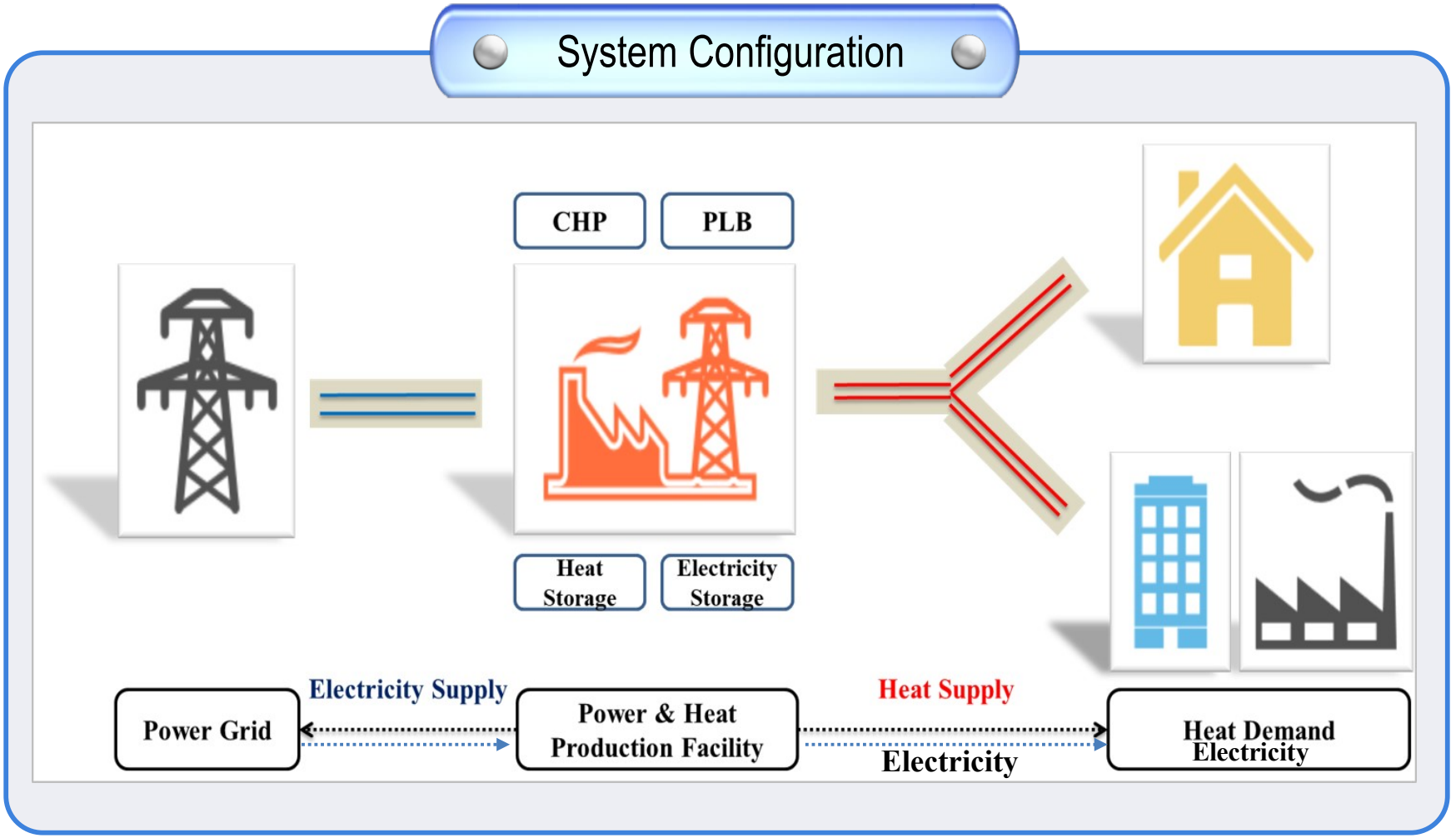
01. What is the District Heating Business

District Heating in Korea

- The District Heating Business is defined as a service that collectively supplies energy (heat or heat and electricity) produced at one or more energy production facilities such as cogeneration plants, heat- only boilers, renewable energy sources, and resource recovery facilities to multiple users.

District Cooling and Heating	A service that supplies heat or heat and electricity to various buildings such as apartment houses, shopping centers, and business facilities in a certain area (large- scale residential area)
Industrial Complex Integrated Energy Supply	A service of supplying process heat (steam) or heat and electricity to companies in the industrial complex

02. System Configuration of District Heating Business



03. Status of District Heating Business in Korea (2018)

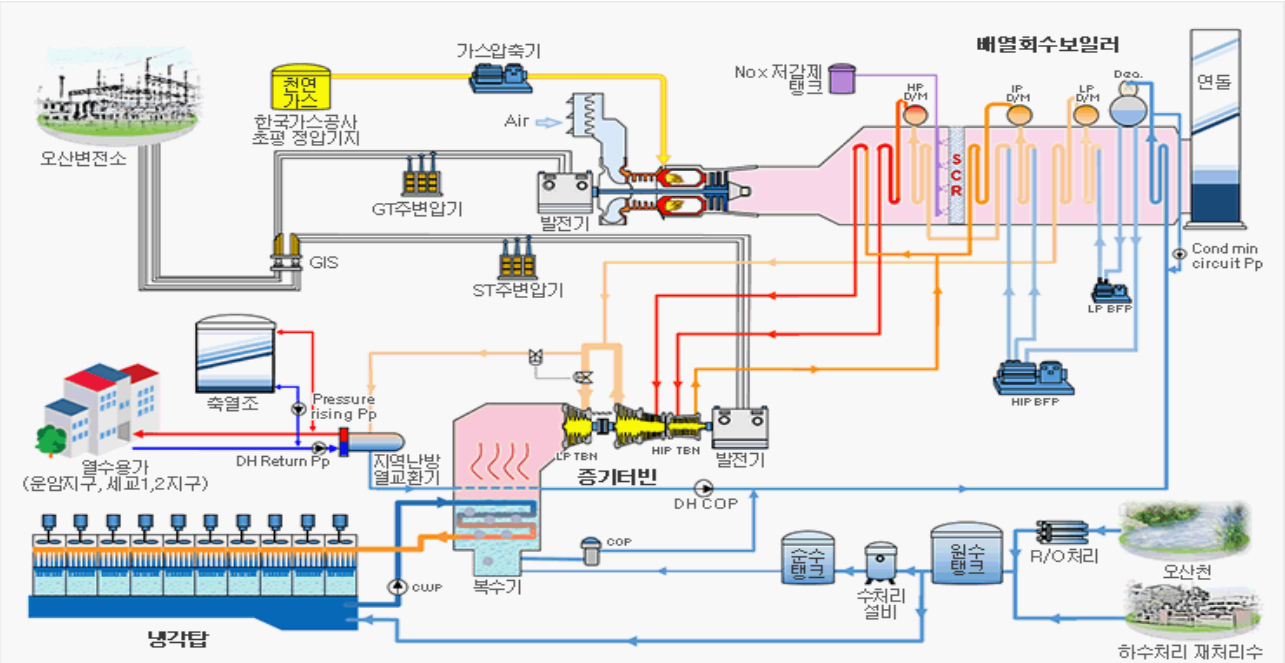
- About 14% of total 21,930,578 households in Korea use district heating and cooling
- It accounts for about 9.5% of Korea's total power plant capacity
- Electricity production accounts for about 10.6% of Korea's total annual sales generation

	The number of				Capacity		Sales	
	Co.s	Sites	Residential Customers	Industrial Customers	Heat (Gcal/h)	Power (MW)	Heat (Tcal/h)	Power (GWh)
D.C.H. (1)	32	61	3,017,347		18,331	7,665	25,348	32,170
I.C.I.E.S. (2)	39	41		862	16,018	2,506	32,189	17,563
Both (3)	6	6	8,637	72	2,209	911	1,862	5,529
Total			3,105,984	934	36,558	11,082	59,398	55,262

(1) District Cooling and Heating, (2) Industrial Complex Integrated Energy Supply

01. Large-Scale CHP Overview

- It is a combination of gas turbines and steam turbines and can produce heat and electricity at the same time.
- Depending on the use of steam turbines, various production of heat and electricity combinations are possible.



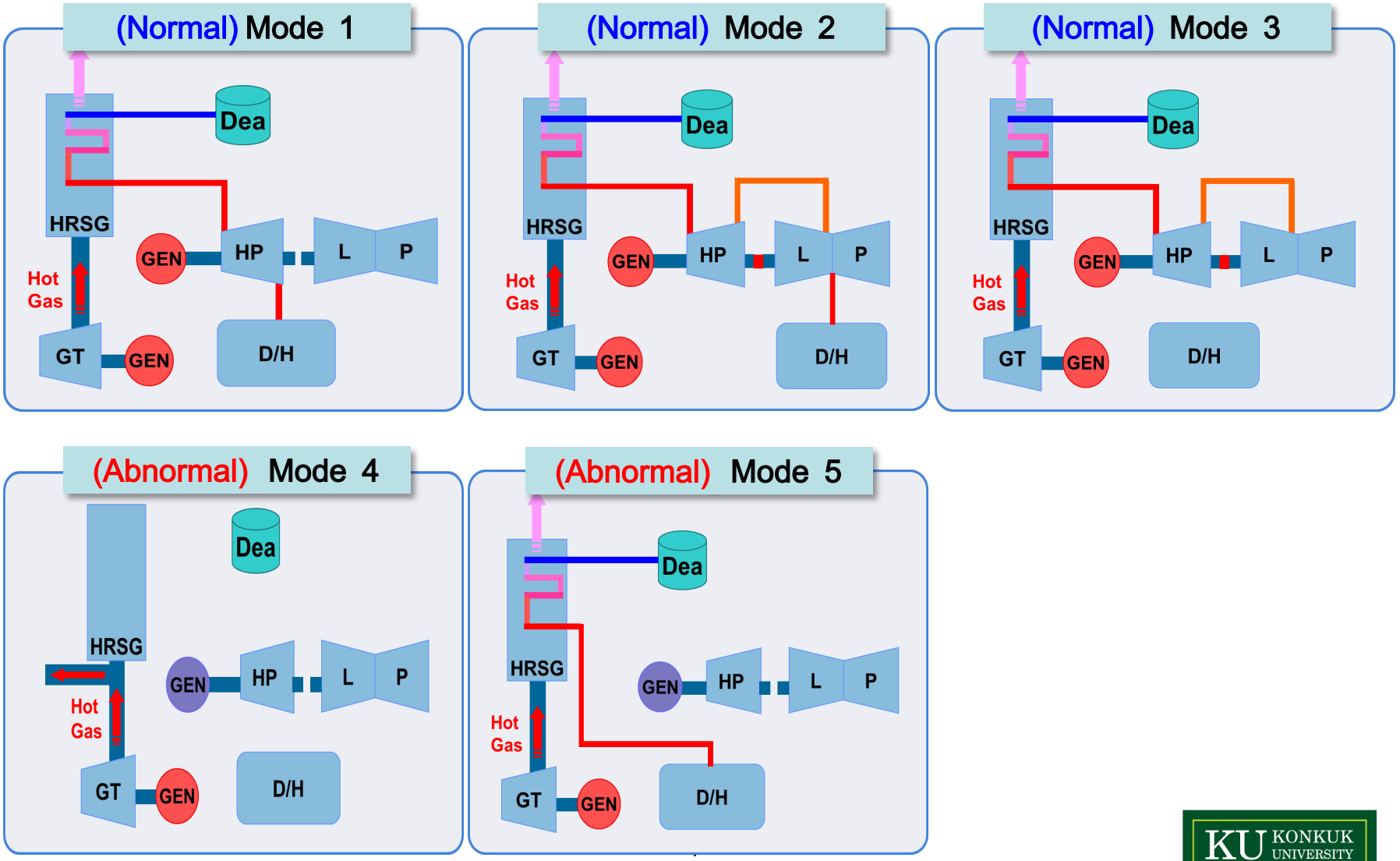
Ref: DSPOWER, https://www.dspower21.co.kr/biz/electric_info.aspx

02. The Operation Modes for CHP - 1

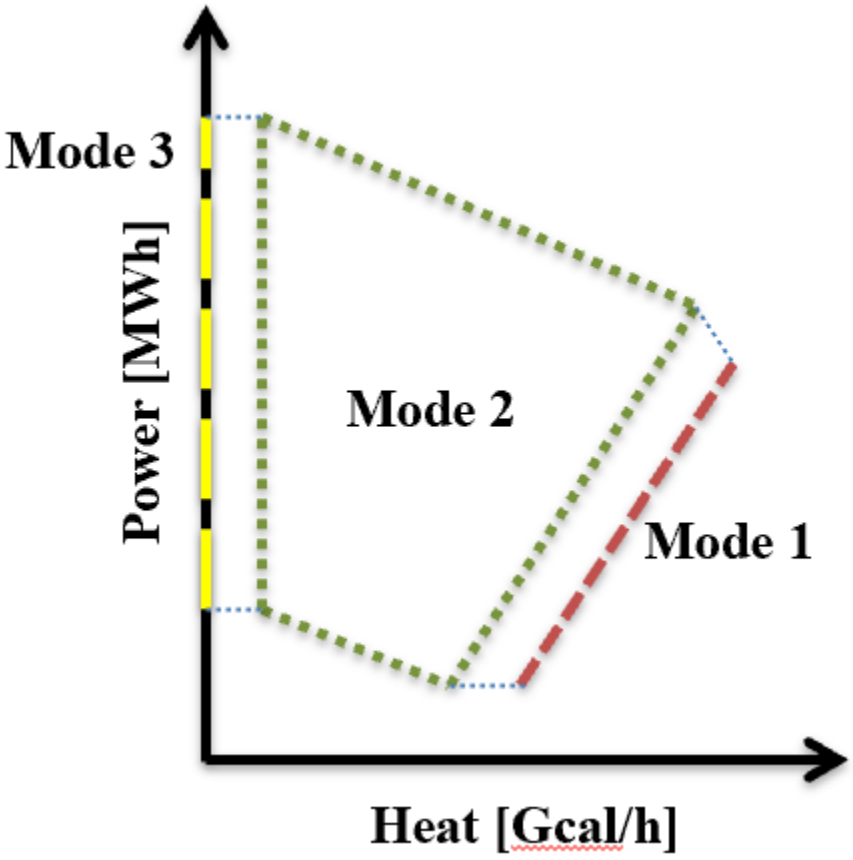
- There are five operation modes depending on the utilization of the steam.

Operation Mode		Classification of operation	Operation Function	Operation facility	Period	Remark
Normal	Mode Ⅰ	Back pressure operation	Power and heat supply	GTs+HRSGs+ST +DH HTR 1 & 2	Mainly in winter	Main operation mode in winter
	Mode Ⅱ	Extraction/ condensing operation	Power and heat supply	GTs+HRSGs+ST +DH HTR 1 & 2	Four season	Operates according to heat load
	Mode Ⅲ	condensing operation	Only power supply	GTs+HRSGs+ST	Mainly in summer	Maximum power generation
Abnormal	Mode IV	Simple Cycle	Only power supply	GTs	-	Generator failure or emergency
	Mode Ⅴ	ST Bypass	Power and heat supply	GTs+HRSGs +DH HTR 1 & 2	-	Restart after maintenance, follow Peak Heat Load, operate in case of emergency

02. The Operation Modes for CHP - 2



03. Output Characteristics of Normal Operation Modes



- Mode 1 has the highest overall efficiency among the operation modes. The output of heat and electricity is proportional.
- Mode 2 has the widest range of operation for heat and electricity.
- Mode 3 is capable of producing maximum electricity.

04. Issues on the Operation of Large -scale CHP

- Large-Scale CHP could maximize profits by utilizing various operation modes depending on seasonal heat loads and electricity prices.
- However, it is difficult to establish an optimal operation schedule due to the presence of many operation modes and physical constraints between switching operation modes.

1. Large-scale CHP can be operated in 3 modes when operated normally, and the output range of heat and electricity is different for each operation mode.
2. It takes time to change the operation mode, and it can produce electricity and heat while changing the mode.
3. When changing the operation mode, the possible operation modes are limited. (Example: It is not possible to change directly from Mode 1 to Mode 3.)
4. Generator start/stop is only possible in Mode 1 or Mode 3.

IV. Optimal Operation Strategy of Large-scale CHPs

01. Summary

Goal of the Study

✓ Determine the optimal operation mode of large-scale CHP that can maximize profits while satisfying the heat demand and operating constraints of each facility and establish the optimal operation scheduling of district heating system facilities

Main research content

1. Model each operation mode of the large-scale CHP as an independent generator and formulate as the unit commitment problem
2. In order to define the output during conversion of the modes, modeling the intermediate mode between two modes
3. Modeling of district heating system production facilities (heat-only boiler, electricity and heat storages)
4. Constructs an objective function that can maximize profits according to power and heat prices and production costs of facilities
5. Constraints such as heat supply and demand conditions, output limits for each mode, and operation mode conversion constraints are considered.

02. Simple Case Study

- Analysis period: 2 weeks in winter
- Price and cost of electricity, heat, fuel: Korean market price in 2017
- Heat load: Applying a specific regional pattern in Korea in 2017
- Production facility data

Operation Mode	Power [MW]		Heat [Gcal]	
	Max	Min	Max	Min
Mode 1	391.4	141.9	268.8	154.8
Mode 1 $\leftrightarrow$ 2	399.6	151.2	221.5	111.3
Mode 2	418.8	192.8	174.1	26.9
Mode 2 $\leftrightarrow$ 3	435.1	170.8	26.9	-
Mode 3	462.5	181.0	-	-

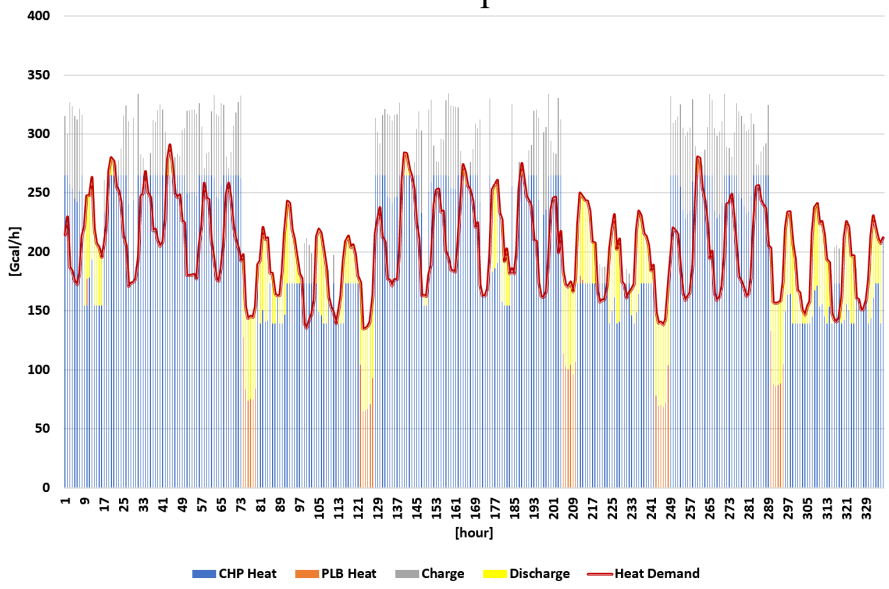
Table 1: Characteristic data by operation mode for CHP

- Peak Load Boiler(PLB, Heat only boiler) : 137Gcal/h
- Heat Storage tank (ACC): 1,960Gcal (Hourly Max : 70Gcal/h)
- Electricity Storage System (ESS) : 50MWh (Hourly Max : 10 MW/h)

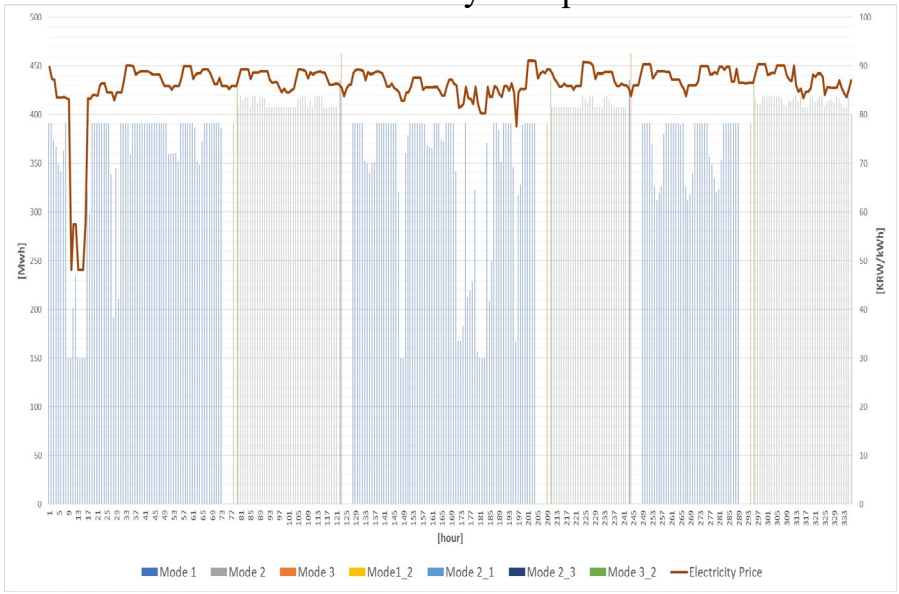
03. Results

		Single Mode 1	Single Mode 2	**Multi-Mode**
Obj. Func. [mKRW]		5,158	4,914	**5,363**
Gen.P [MW]		90,027	136,334	**118,696**
Gen.H	CHP [Gcal]	69,713	57,429	**65,353**
	PLB [Gcal]	290	10,614	**2,690**

<Heat Output>



<Electricity Output>



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V. Conclusions and Collaborations with DTU

Summary

- Overview of Korea's electricity market and district heating business
- Introduction of research on operation issues and optimal operation study of large-scale CHP

Collaboration with DTU

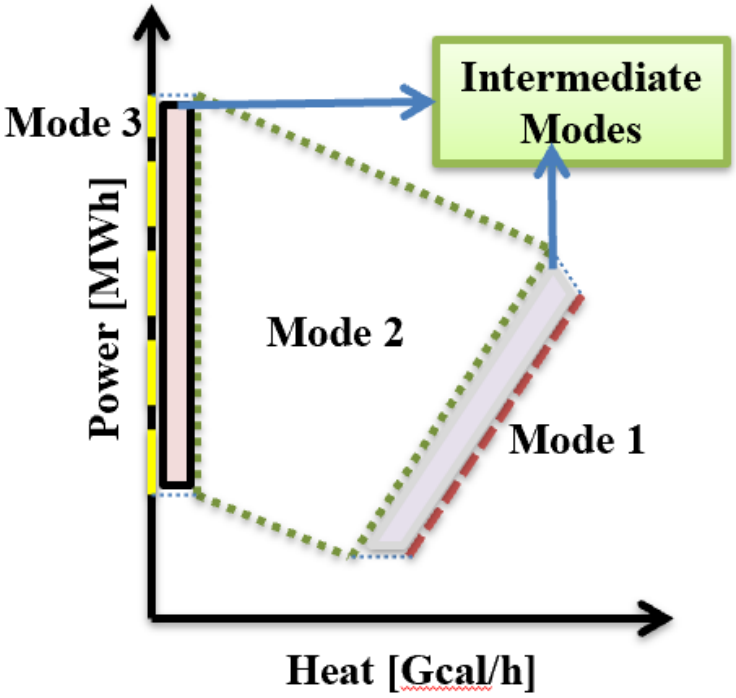
- DTU and Konkuk graduate students exchange (Ph.D. Ignacio Blanco)
- Collaboration Research
  - ✓ *Optimization of CHP and Thermal Storage under Heat Demand.* 12th IEEE international Conference (2015)
  - ✓ *Optimal Operation Strategy of Large-Scale CHP in District Heating System.* Energy. (2020, Revised version submitted)

Future Collaboration Topic

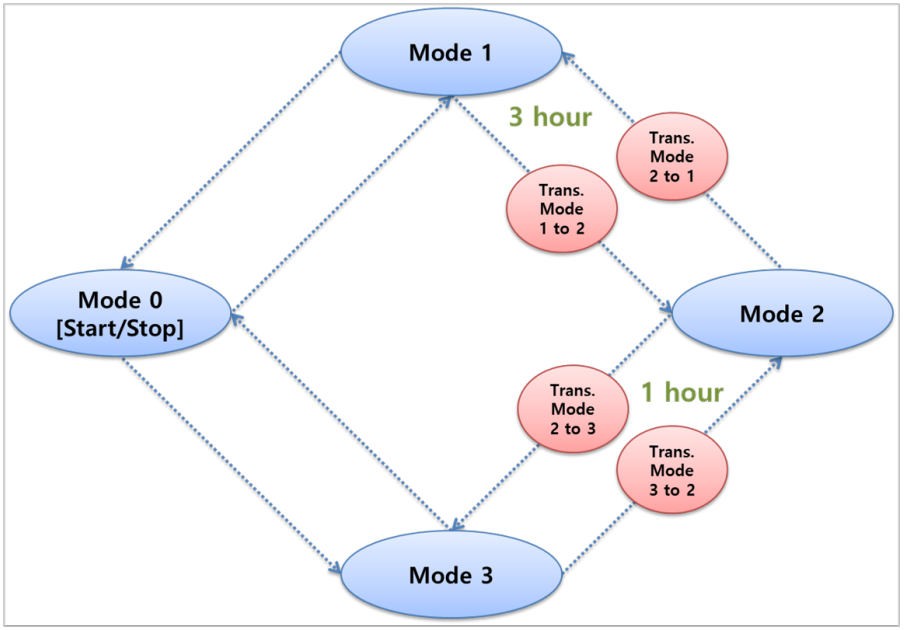
- Role of CHP and Heat Storage for Increasing the Power System Flexibility (Theory and Field Test in Korea).
- Renewable Target in Korea 20%(2030), 35%(2040), Net-zero(2050)

Appendix

The concept of intermediate mode



Operation mode conversion constraints



Thank you

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