The Role of Sector Coupling for Net-zero in Korea

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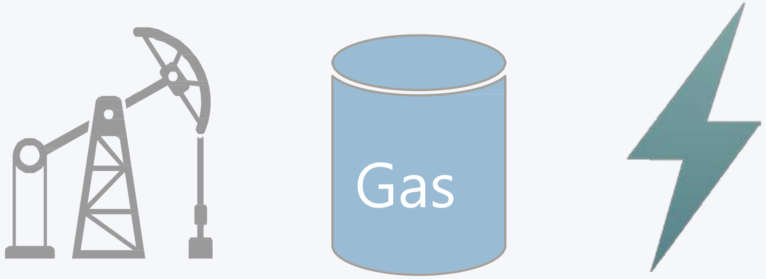
Concept of Sector

Energy sector

- **Energy sectors**, such as oil and gas, are physically and conceptually separated with their own market.
- **Electricity**, which is converted from primary energy in the energy sector, is also an energy sector.



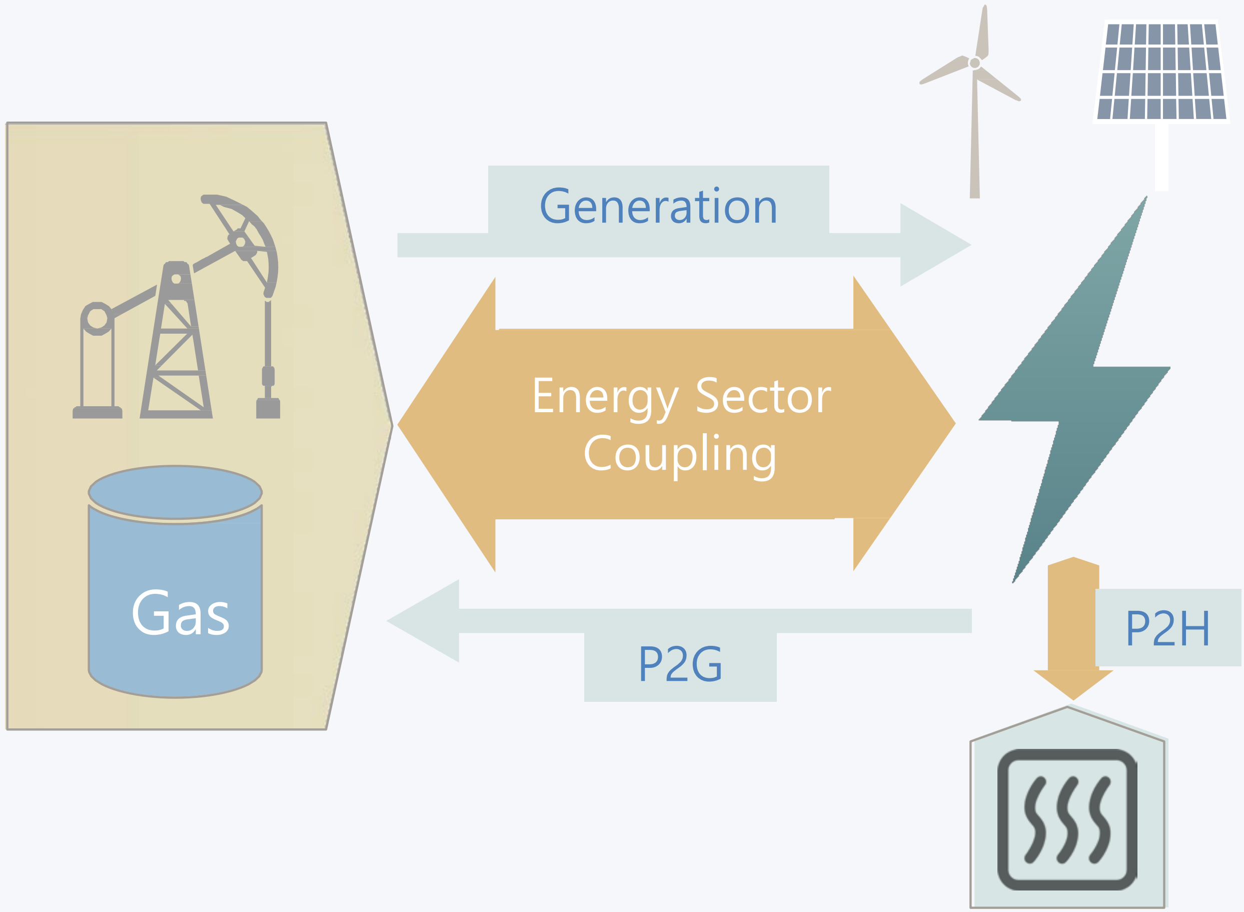
Economic sector

- Energy **supply side** provides primary/final energy sources
- Energy **demand side** consumes energy for such as transportation, buildings, and industry

Integration between Sectors

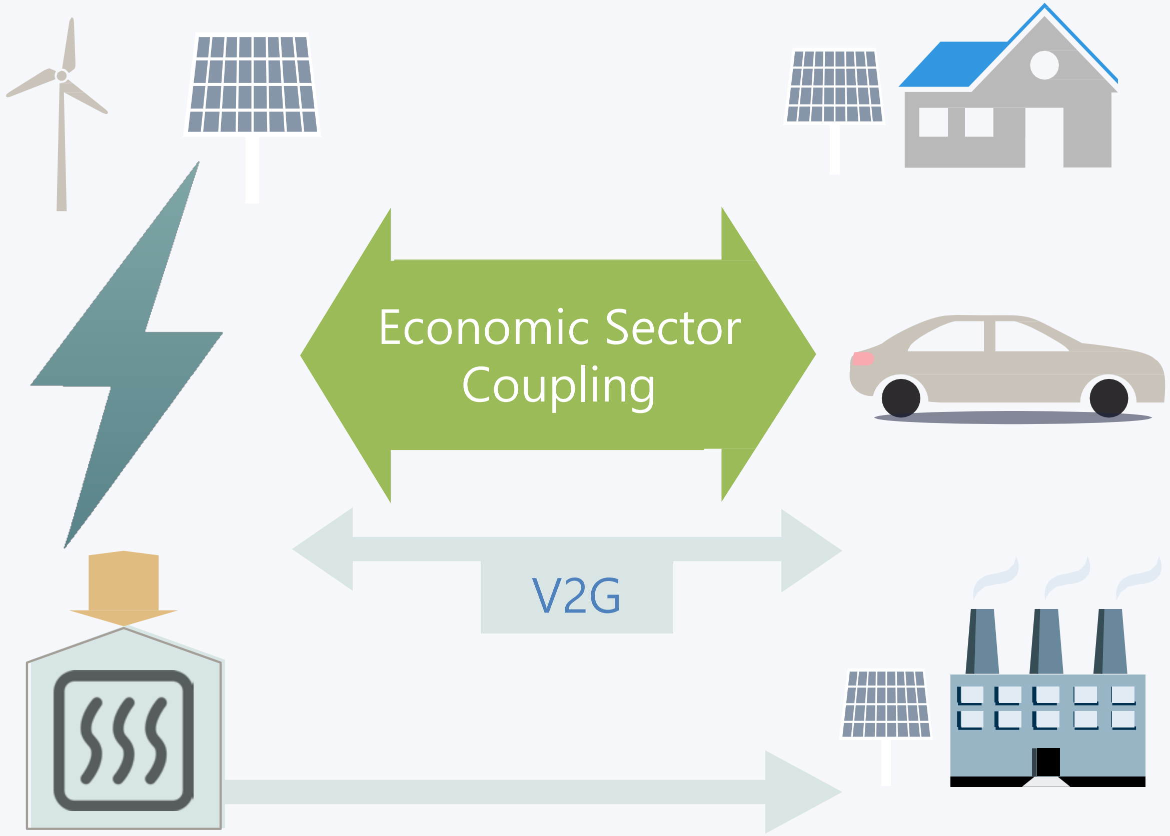
Energy Sector Integration

- **Energy sector coupling** makes the **electricity system** more **flexible** by converting surplus power from renewable energy into other energy sectors.
- **A more flexible power system can contain more renewable energy in the system** to achieve carbon neutrality.
- **Renewable energy** can provide not only **electricity** but also **hydrogen**, which is an essential ingredient for a net-zero economy, through a water electrolysis system.

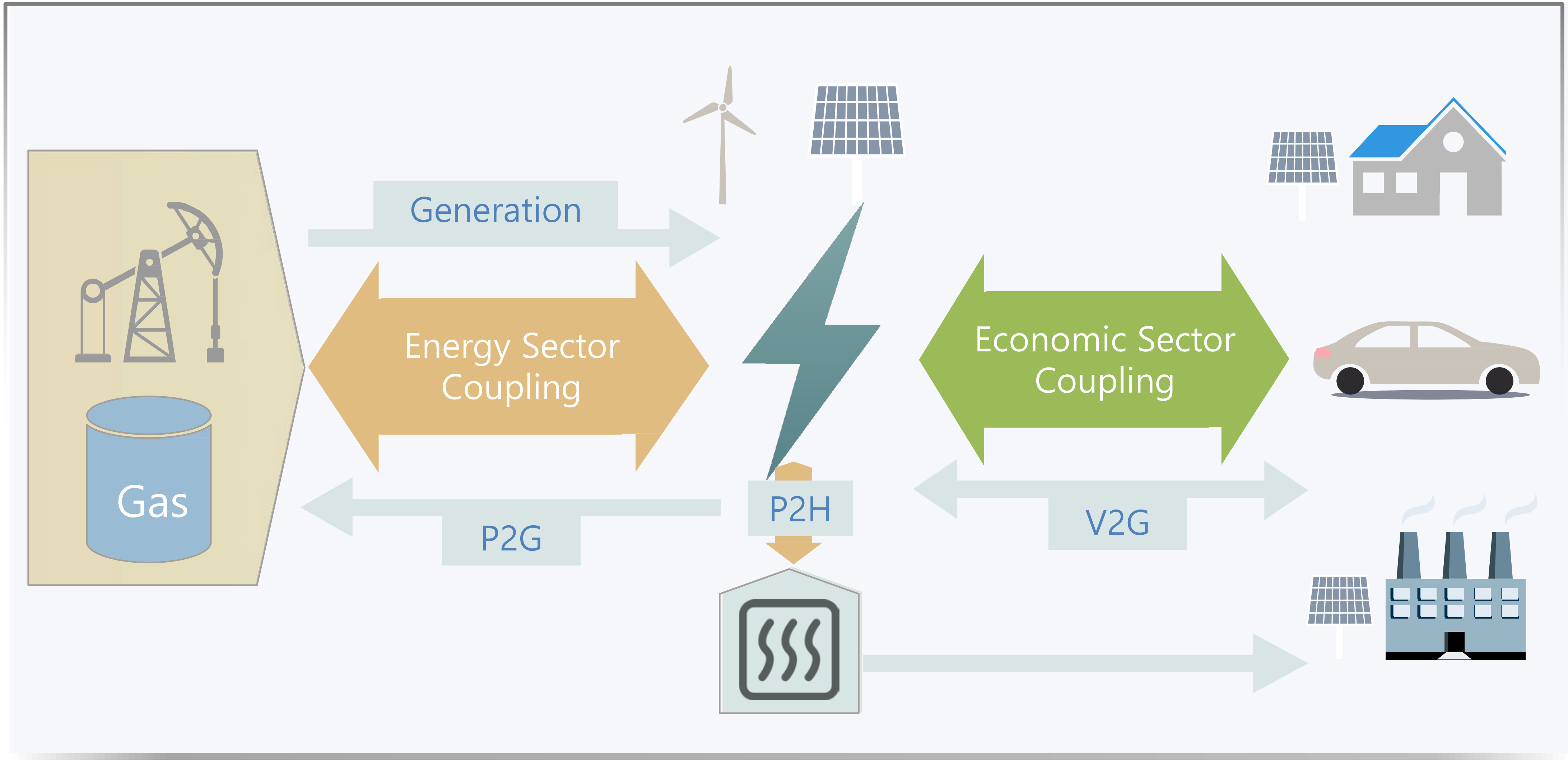


Economic Sector Coupling

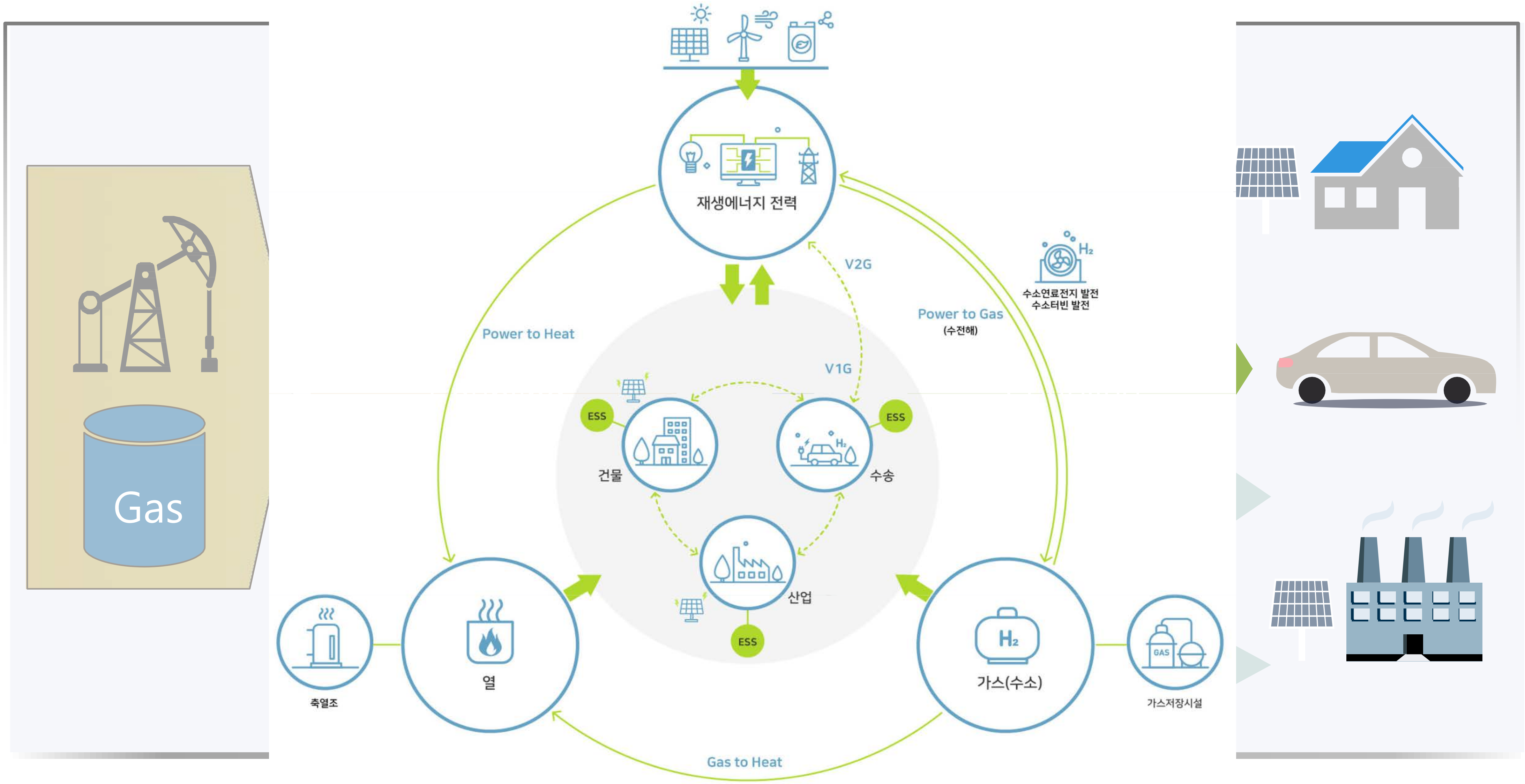
- Ideal **renewable energy** helps energy consumers become energy **self-sufficient**.
- It serves as a **distributed energy resource** by selling power when more power is produced than consumed.
- It is possible to provide **service to the electricity system** by supplying power to the grid or absorbing the surplus power from the grid.



Sector Coupling Diagram



Sector Coupling Diagram

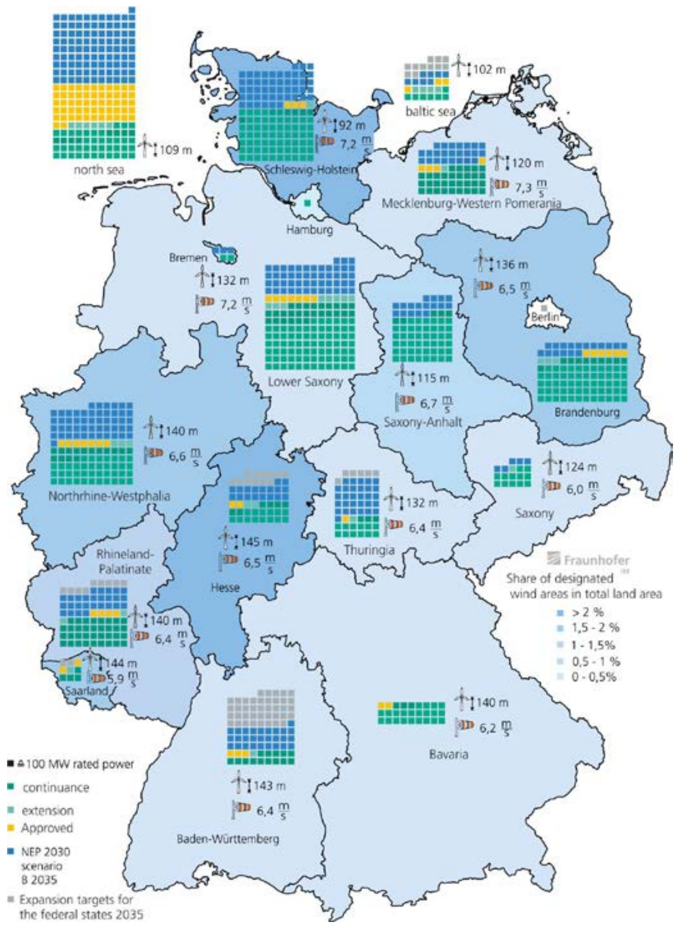


Purpose of Sector Coupling in Germany

More than 40% of all P2G projects in Europe are driven by Germany

VRE integration

- **Germany** supplied **43%** of its total power generation in 2019 with renewable energy, excluding coal, natural gas, and nuclear power.
- With an already high rate**(28%) of variable renewable energy**, it is **difficult to absorb more VRE** in the current system.
- Germany needs to secure a transmission grid enough to **deliver electricity generated from large-scale wind farms in the north sea** to the south, where demand for electricity is high.



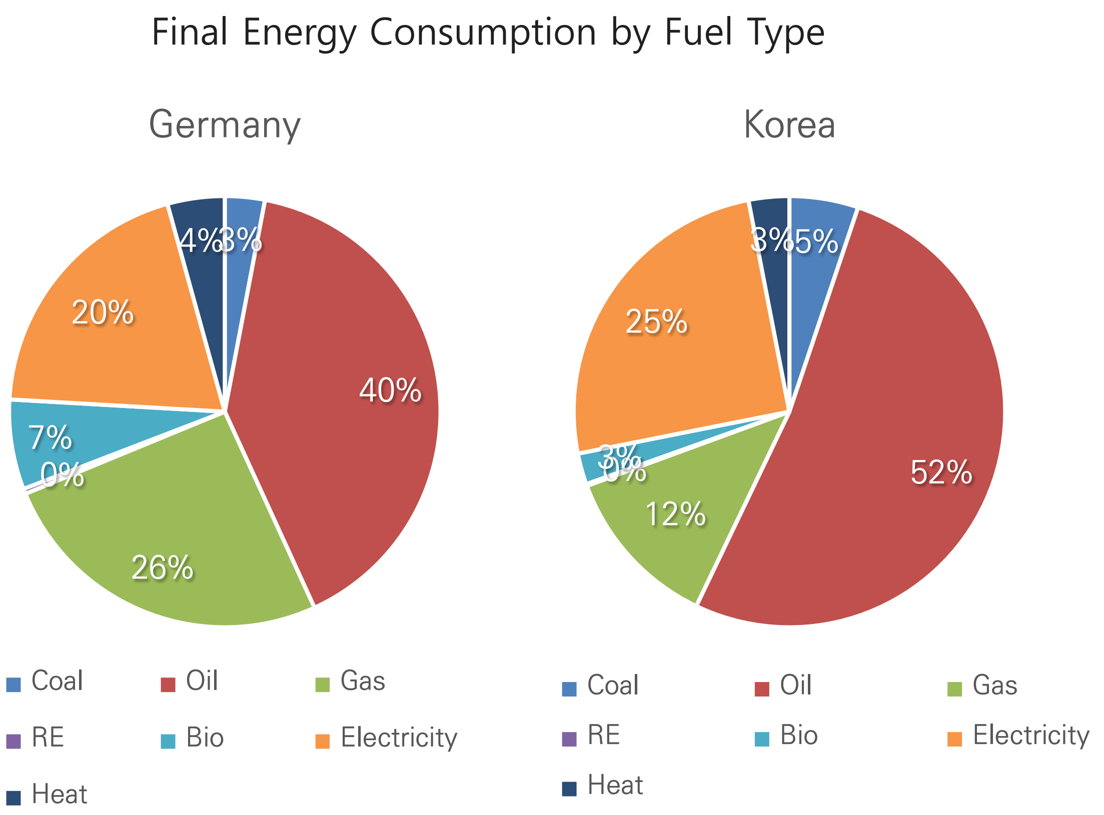
Source: Wind Monitor, Fraunhofer; based on 2018 data

Purpose of Sector Coupling in Germany

Tools for GHG reduction

Effort to reduce GHG

- **Phase-out nuclear power by 2022**
- The **greenhouse gas reduction effect** achieved by increasing renewable energy supply is **offset** by decreasing nuclear power.
- Due to the **high demand for natural gas for heating**, the consumption of natural gas in the energy system is firm.
  - Carbon emissions from the residential sector accounted for more than 10% of the total emission(86Mt CO2 as of 2019)
  - Carbon emission from the residential sector in Korea is 5%, emitting 34Mt CO2.



Source: Germany 2020 IEA 2020, Korea 2020 IEA 2020

Means of carbon neutrality and electricity security

Role of P2G in Korea

- In **Europe**, where system stability is secured with interconnections between countries, **sector coupling focuses more on the means of decarbonization**.
- In **Korea**, which operates the **power system without interconnection**, **sector coupling** is required not only for **carbon neutrality** but also for **electricity system security**.
  - In **Korea**, when the rate of renewable energy is high, **sector coupling is required for the long-term, even seasonal mismatch of electricity supply and demand.**
  - Facilities that can absorb the excess supply of renewable energy, such as **P2G, P2H, are essential for stable system operation.**

1. Flexibility
2. Operational security
3. Long-term planning
4. Market improvements
5. Cyber and climate resilience

Coping with renewable energy

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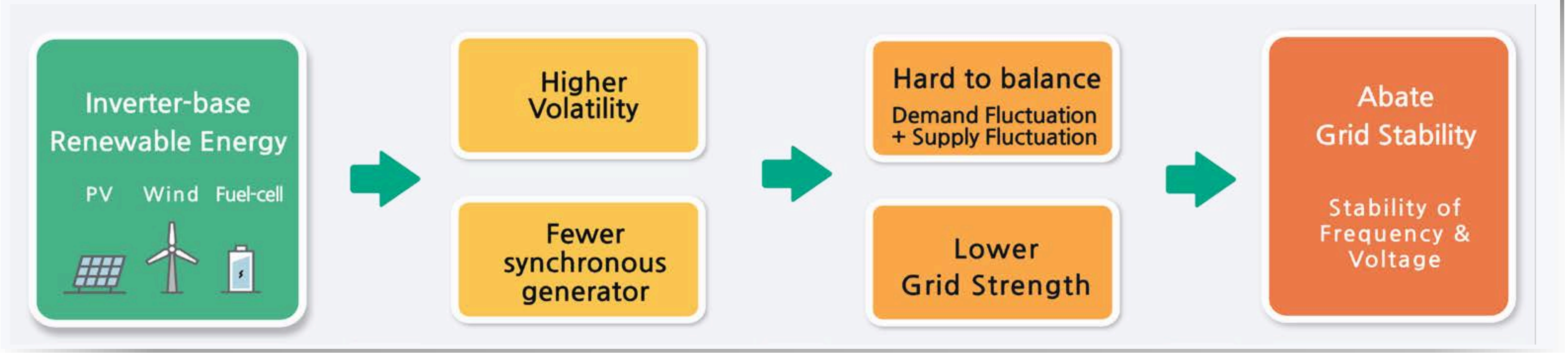
Inverter-based variable renewable energy(VRE) affects system operation

Variability and Grid Strength



Source: Lee(2020)

Curtailment: the reduction of renewable energy output

By Surplus, Grid-restriction

- In case that surplus presents due to renewable energy, curtail renewable for balancing.
- Limit the output of VRE for stable system operation(maintains synchronous generator ratio)
  - e.g.) Ireland EirGrid limits System Non-Synchronous Penetration(SNSP) to 65%.

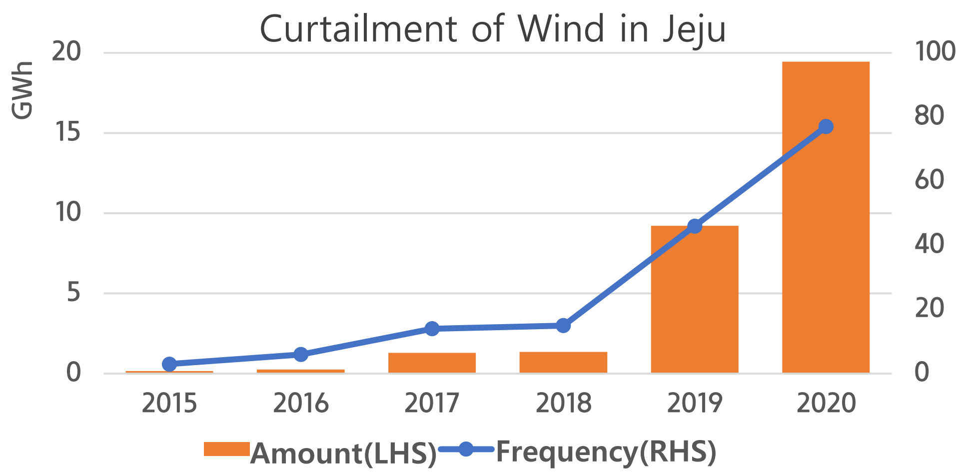
Impact of Renewable Energy in Jeju Island

Curtailment in Jeju

- Curtailment started in Jeju in **2015 (3 times, 152MWh)** and exceeded **19GWh at 77 times in 2020.**
  - Due to Covid-19, fallen tourism demand in Jeju Island is also a factor of rapid increase of curtailment.
  - In 2021, curtailments decrease to 12GWh(64 times) since excess power starts to be transmitted back to the mainland via HVDC#1

Jeju Characteristics

- **PV generation**, which shows **daily variability**, has a significant impact on **system operation and curtailment**.
- The capacity of **solar and wind** power generation facilities in Jeju is **1:1**(without PPA)
- The amount of power generated by wind power is twice that of PV.



Source: Lee, Tae Eui & Lee, Yoo Soo(2020) revised

PV and Wind in Jeju

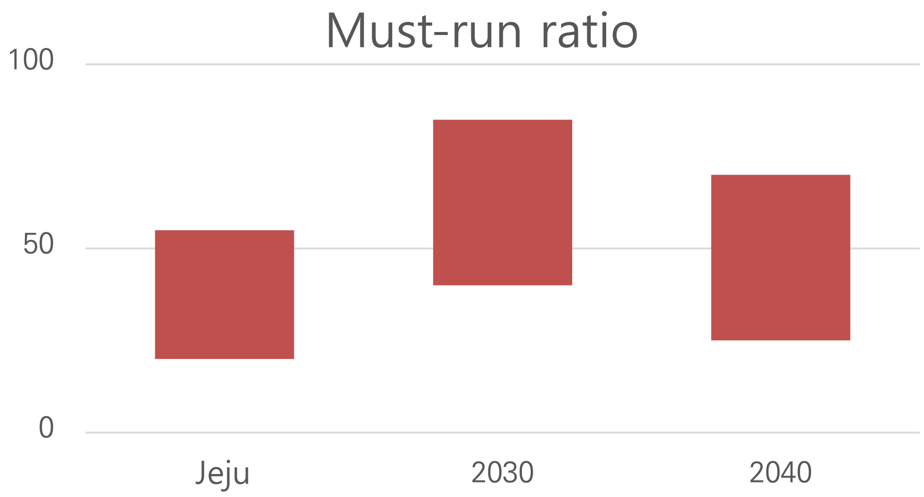
Year	Capacity(kW)		Generation(MWh)	
	PV	Wind	PV	Wind
2015	86,040	221,260	72,802	344,678
2016	102,525	271,510	89,466	463,613
2017	120,578	273,510	141,150	535,384
2018	168,329	267,060	170,671	533,618
2019	261,300	290,190	268,483	546,846
2020	298,634	294,600	340,369	574,861
2021	318,119	294,600	358,730	524,929

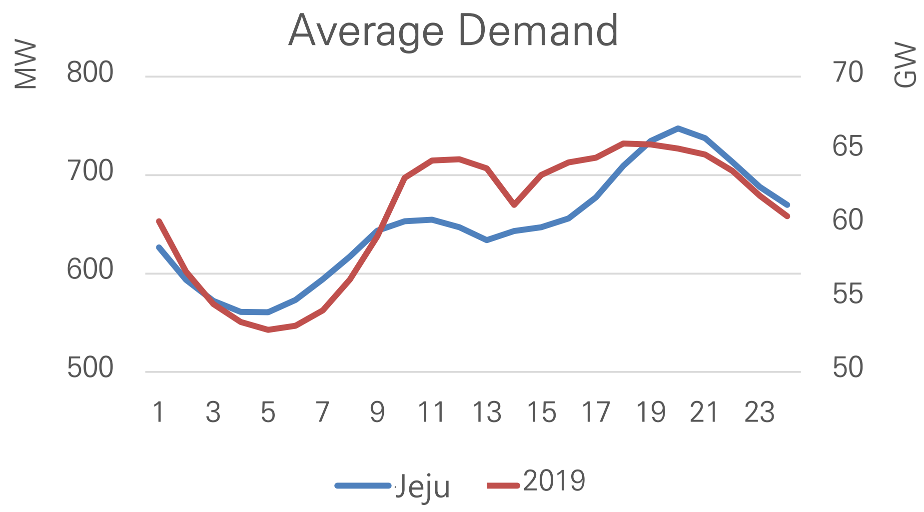
Source: Lee, Tae Eui & Lee, Yoo Soo(2020) revised

Jeju Island as a Benchmark?

Jeju Characteristics

- Jeju has interconnection lines like the European power grid.
  - About 6GWh of electricity has transmitted to the land in the first half of 2021
  - Impact of RE in Jeju compared to land (-)
- The must-run rate is low because there are no rigid power sources such as nuclear power and coal.
  - During normal operation, must-run includes the HVDC line and the minimum generator of 4-7 units.
  - Impact of RE in Jeju compared to land (-)
- Due to the industry difference, demand patterns are dissimilar.
  - Based on the annual average, daytime electricity demand is relatively low.
  - Impact of RE in Jeju compared to land (+)





P2G Business Model Based on Electricity System

Off Grid

- **RE P2G** as a hydrogen production facility **without connection to the grid**.
  - The **most accessible** P2G operation model **at the current level of technology**.
  - In the long term, **mass production of green hydrogen** from a **large-scale offshore wind farm** is a possible business model.
  - Large-scale wind and solar power plants are remotely located from high-demand urban areas, which makes the **storage and transportation** of hydrogen **a challenge.**

DSO Level

- **Operate as a distributed energy resource(DER)**
  - **Variability** can be **directly absorbed** within the VRE area
  - As a DER, renewable energy can **minimize the load of transmission and distribution networks**.
  - Hard to achieve **economies of scale**, and if there is not enough hydrogen demand in the region, **hydrogen storage and transportation are costly**.
- **Operation through aggregators**
  - For **economies of scale**, P2G aggregates renewable energy
  - Need to expand **transmission and distribution** facilities

TSO Level

- **Large-scale wholesale market concept** operation method for system balance
  - In the long-term, **the most reasonable hydrogen production facilities,** considering the priority installation of **hydrogen infrastructure for large-scale facility.**
  - Provides **ancillary services** so that has additional profit from the ancillary service market.
  - **Supplement** for the **capacity limitations of existing storage** such as ESS, pumped water.

Flexibility for Electricity System

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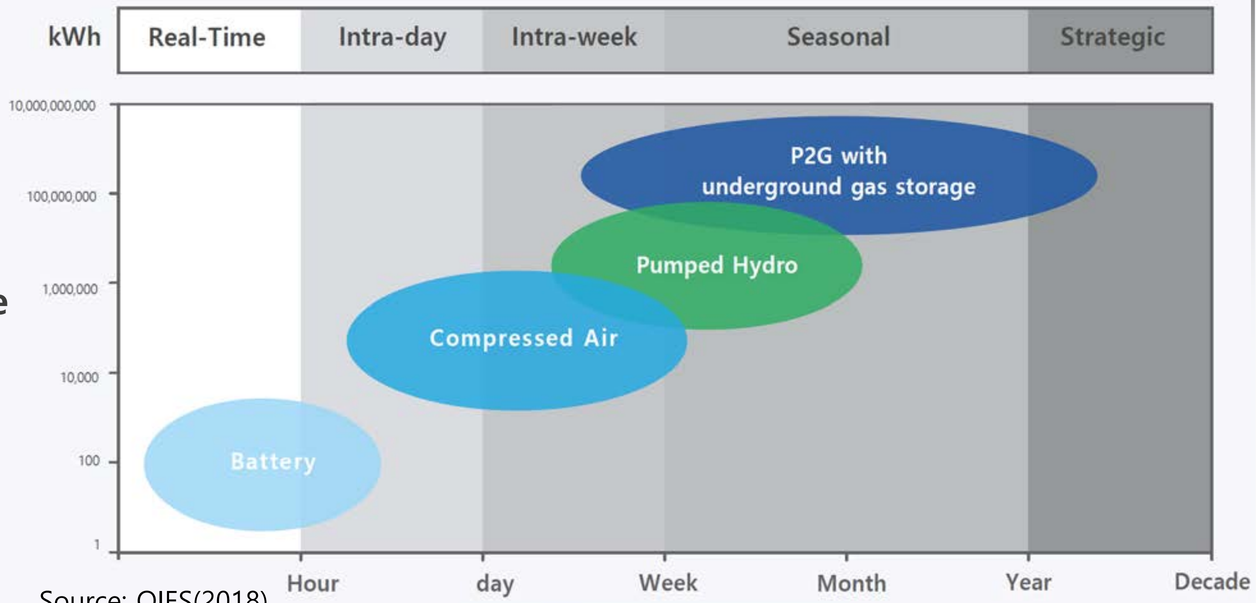
Securing flexible resources

- **Securing flexible resources to absorb/store surplus is necessary**
  - Consider **storage facilities** such as batteries and pumped-water power generation, and **conversion facilities** such as P2G
  - **The Inefficiency** of direct **hydrogen storage** for power supply
- **Direct consumption of hydrogen after electrolysis**
- **Seasonal balancing by controlling hydrogen supply(such as import)**



Source: OIES(2018)

Needs for flexible resources

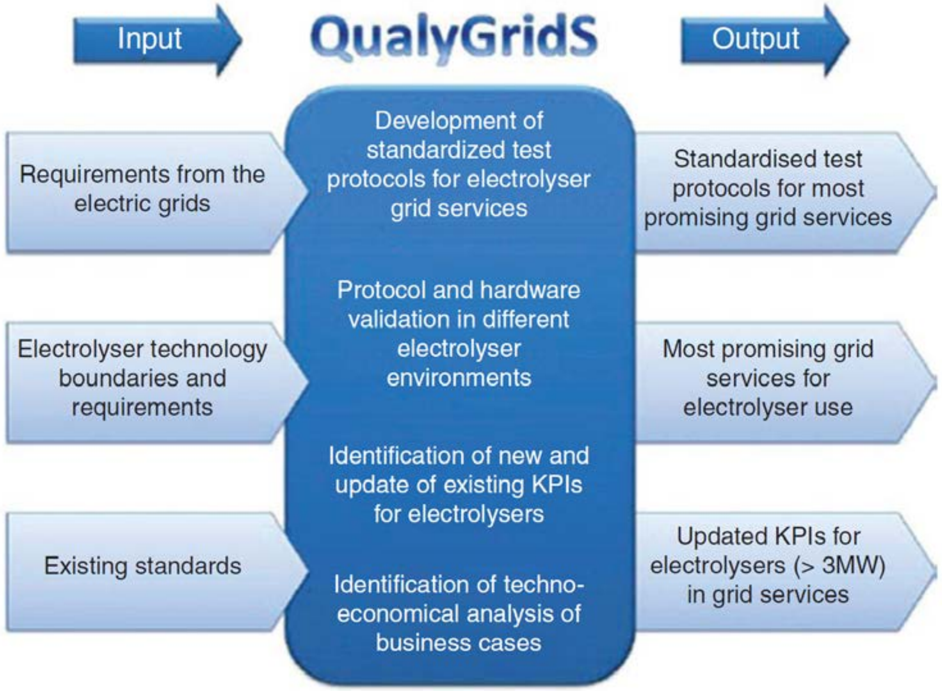
- **During the holidays**, boric acid was added to **Shin-Gori #3 and #4 to control the nuclear reactor**.
- Nuclear power output is being adjusted for **every holidays after May 2020**

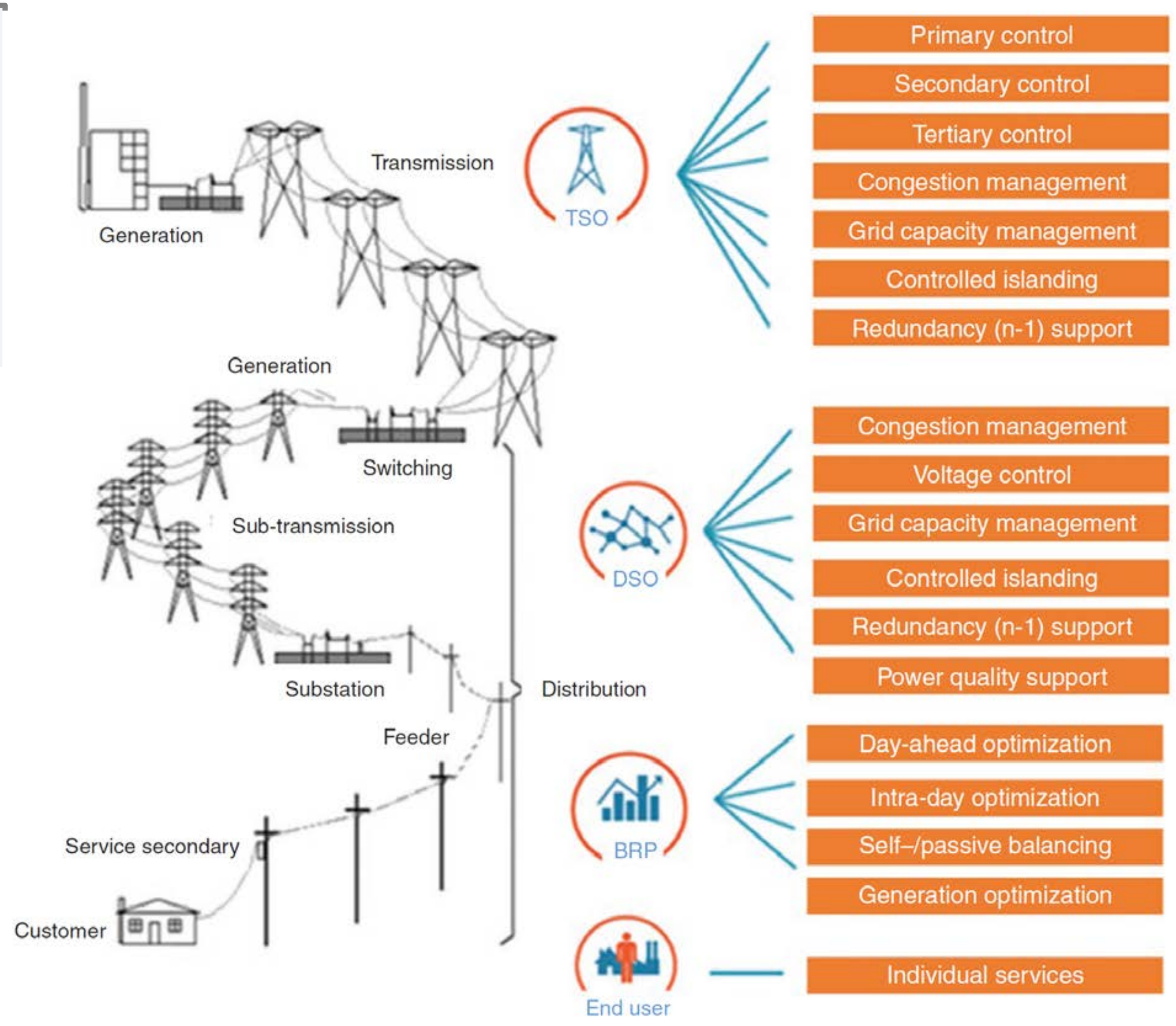
Source: Lee(2020)

P2G Experiment for Grid Services

QualyGrids Project

- **Europe proposes a test protocol for system service using water electrolysis through a project called QualyGrids**
  - Goal: establishing standardized testing protocols for electrolysis to perform electricity grid services





Source: CEA(2019), QUALYGRIDS

Curtailment analysis of renewable energy

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The ratio of VRE to electricity demand increases rapidly

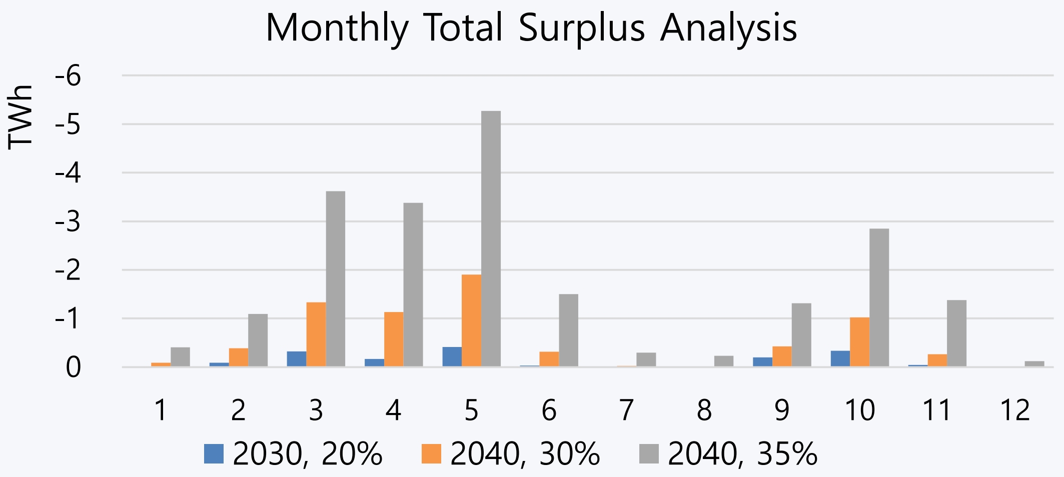
		2030 RE 20%	2040 RE 30%	2040 RE 35%
Assumption	PV Capacity	34GW	64GW	89GW
	Wind Capacity	18GW	29GW	30GW
Maximum VRE Rate	$\frac{Max(RE_t)}{Min(Demand_t)}$	67%	133%	172%
	$Max\left\{\frac{RE_t}{Demand_t}\right\}$	64%	106%	140%
Hourly base Curtailment Frequency (Total hours of Curtailment/8760 hours)		384 hours (4.4%)	781 hours (8.9%)	1,451 hours (16.6%)
Total Curtailment (yearly)		2,005GWh	7,894GWh	23,428GWh
Rate of Curtailment (Curtailment/Total VRE generation)		2.6%	5.8%	13.7%

Note: Assuming no additional storage adaption into the system from current system
Source: Lee(2020)

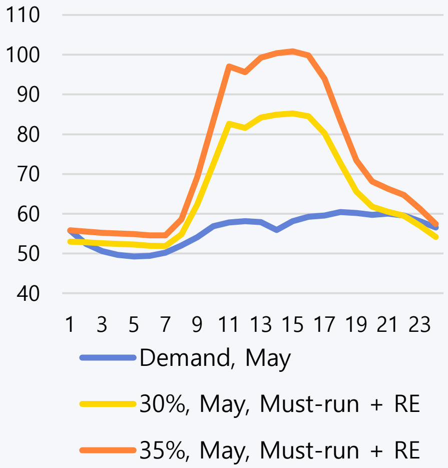
Seasonal Analysis of Electricity Surplus

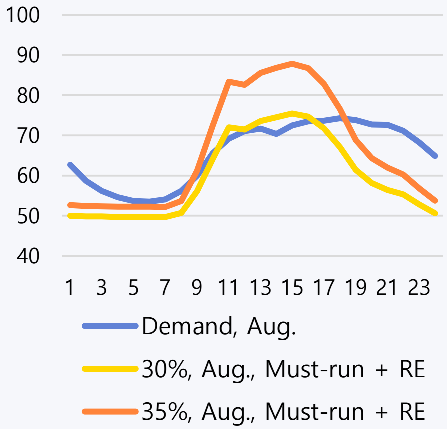
Monthly Surplus

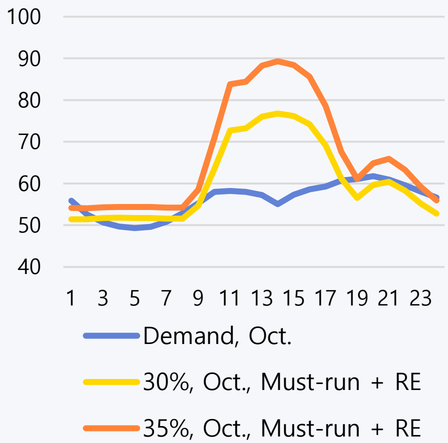
- Based on actual **demand** and **renewable** energy generation pattern **in 2019**, and **power plant** construction plan from the **9th BPLE**.
- **Assume no additional storage** such as pumped hydro, BESS, and DR.
- **Appropriate operation of storage** can **mitigate the level of surplus**.

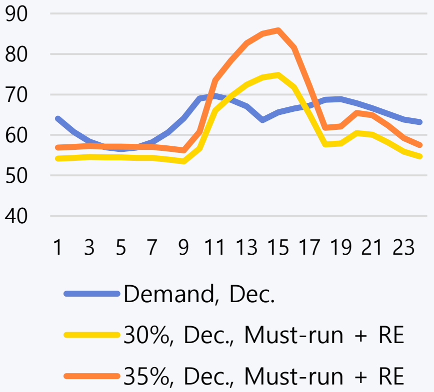


2040, RE 30% RE 35% Demand and Must-run (including RE)









Hydrogen Supply and Curtailment Mitigation

Curtailment Analysis according to RE Mix

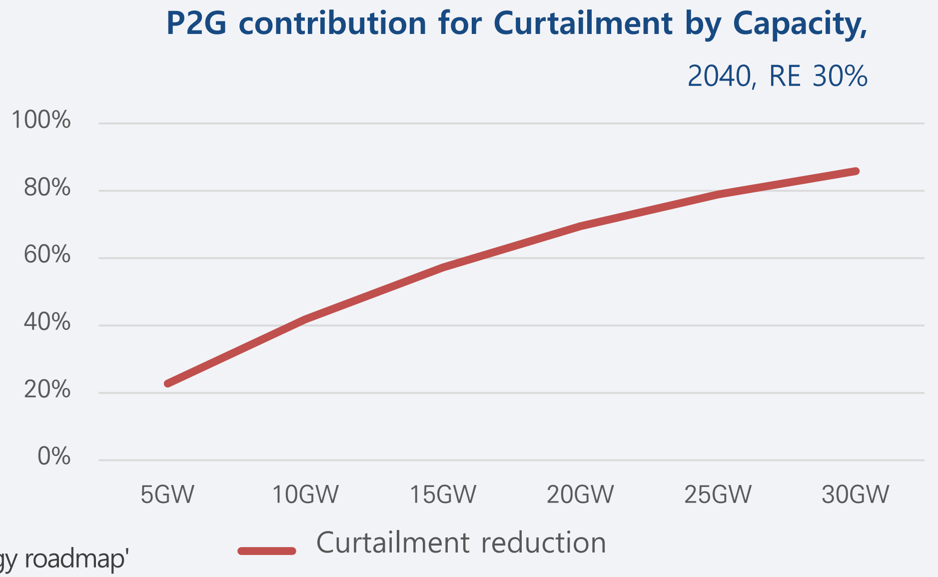
Average Hourly Curtailment (when it occurs)	2030, RE20%	2040, RE 30%	2040, RE 35%
Average	5.2GWh	10.1GWh	16.1GWh
Median	3.8GWh	8.7GWh	14.3GWh
Maximum	19.6GWh	38.6GWh	59.3GWh

P2G Contribution Analysis

- 10 GW of facilities can produce about 1 million tons of electrolytic hydrogen

*Assumption: Grid-connected, 50% load factor

	2040 RE 30%
Electrolysis Capacity	10GW
Hydrogen Production	1.05mt



Note: Assuming electrolysis efficiency target 43kWh/kg-H_2 based on '2040 hydrogen technology roadmap'
Source: Lee(2020)

Grid-level response to the spread of renewable energy

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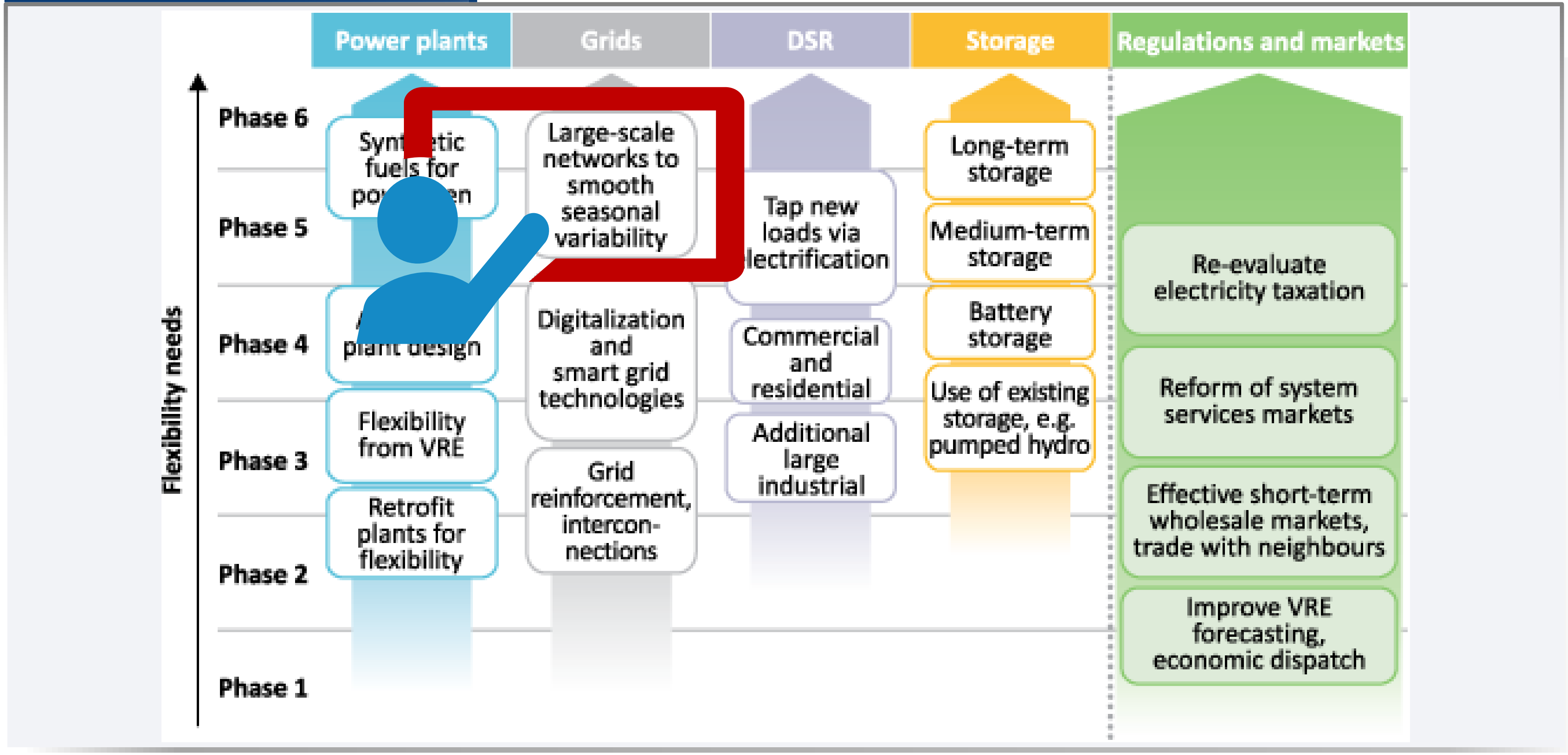
Flexibility requirement is higher without interconnection

Sources of flexibility



Source: World Energy Outlook, IEA(2018),

Roadmap of Sector Coupling

From distributed energy (short-term) to integrated system (long-term)

Resource of Distributed Energy

- As a distributed resource, **sector coupling technology**, storing and converting energy, allows **renewable energy more accessible to the grid**.
- Institutional changes such as the establishment of the **DSO/TSO operating system** for efficient VPP operation.

Short-term	System	Local
Energy		P2H
Economy		DR, V1G

Integrated Energy System

- The fact that the locational differences of the **large-scale electricity demand and the generation** makes the Korean electricity system challenging to operate only with distributed energy resources.
- **P2X** can participate in the **wholesale market** and providing **auxiliary services**
- **An appropriate regulatory framework** for the **integrated operation** of electricity and gas (hydrogen) market is required.

Long-term	System	Local
Energy	P2G	P2H
Economy	V2G, DR	

Thank you

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