Multiple Energy Systems Towards Renewable Energy Integration

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Self introduction

- Chongqing Kang (M'01-SM'08) received the Ph.D. degree from the Department of Electrical Engineering in Tsinghua University, Beijing, China, in 1997. He is currently a Professor at the same university. His research interests include load forecasting, electricity market, power system planning and generation scheduling optimization.

- Ning Zhang (S'10-M'12) received both a B.S. and Ph.D. from the Electrical Engineering Department of Tsinghua University in China in 2007 and 2012, respectively. He is now an Assistant Professor at the same university. His research interests include multiple energy system integration, stochastic analysis and simulation of renewable energy, power system planning and scheduling with renewable energy.

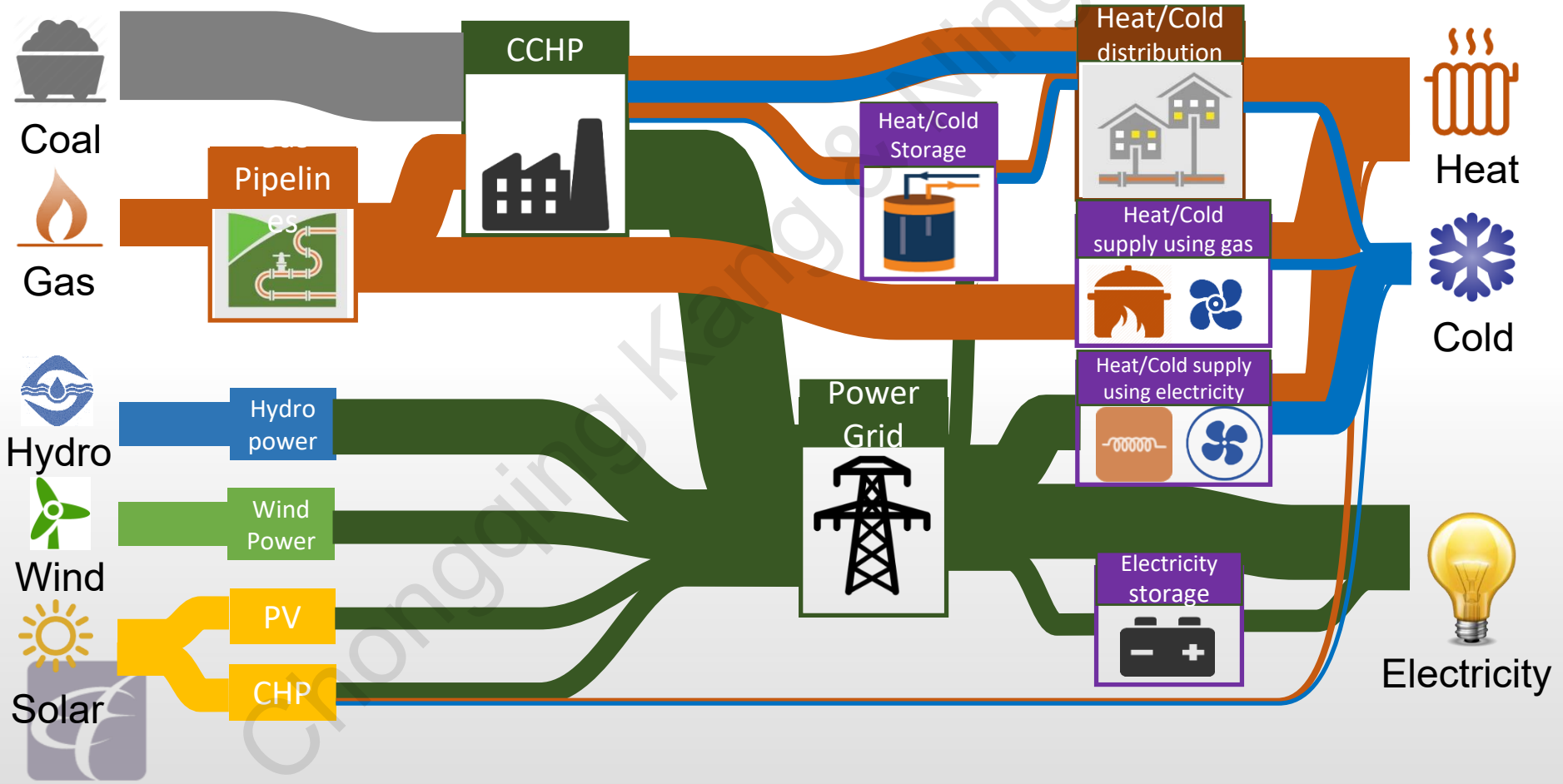
Outline

- Multiple Energy System and Energy Hub
- Electric-Heat Coupling
- Electric-Gas Coupling
- Standard Modeling of Multiple Energy System

Multiple Energy System and Energy Hub

Multiple Energy System

- What is multiple energy system?
- NREL: The process of optimizing energy systems across multiple pathways, scales and time horizons.



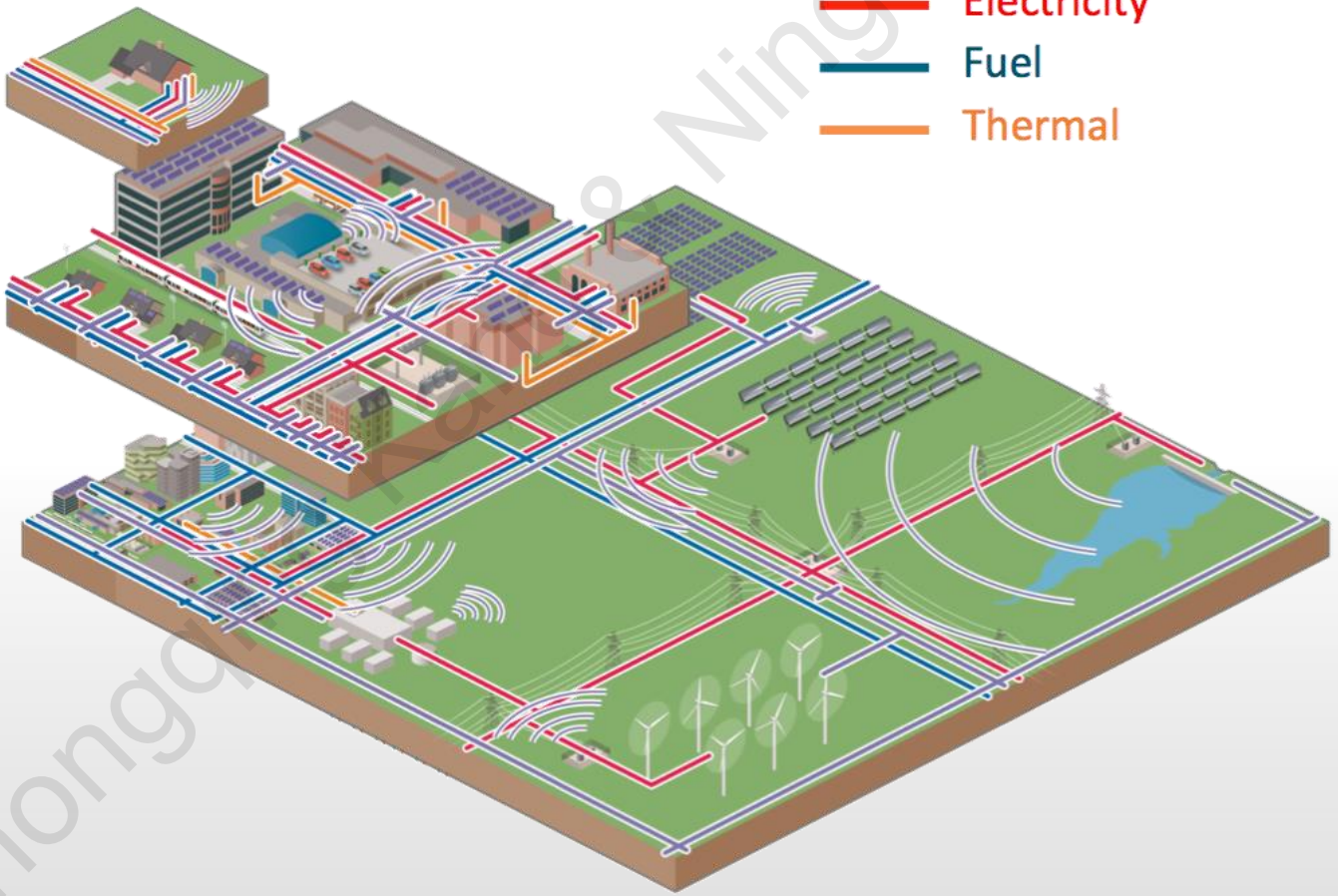
Multiple Energy System and Energy Hub

Energy System Physical Scales

Buildings

Campus, Fleet, Distribution

Regional



Energy Grids

- Electricity
- Fuel
- Thermal

Multiple Energy System and Energy Hub

	Generation	Transmission	Consumption
Electricity	•Centralized primarily •Renewable energy integration	•No delay, less loss •Real time balance, uneconomical storage •Long distance transmission	•Clean consumption, intelligence •Can be transformed into other energy
Heat	•Distributed：Low efficiency •Centered：Coupling of electricity and heat	•Have delay，more loss •Easy to stored •Local balance	•Heating and industrial use •Less intelligence
Gas	•Central development depending on the distribution of sources.	•Have delay，more loss •Easy to stored •Long distance transmission	•Used for power generation •Low efficiency •Pollution
Energy Internet	•Interconnection：Generation-Transmission-Distribution-Consumption in both power and information. •Interaction：Source-Network-Load, Multi-energy Supplement •Virtual：From real energy system to virtual information system		

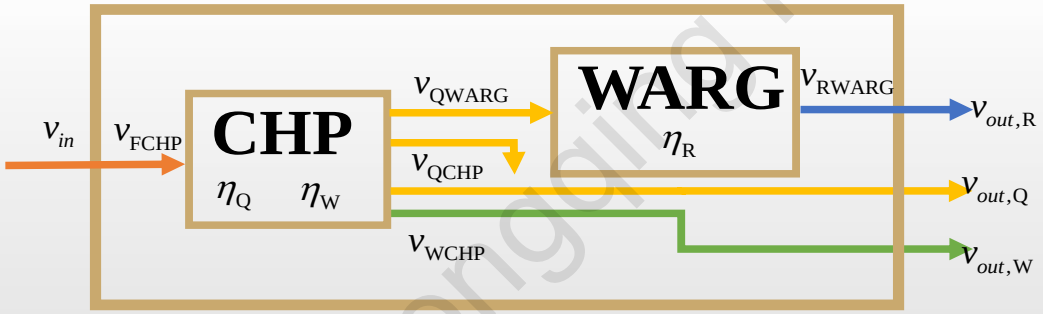
Large potential in supplementary for renewable energy accommodation

Power system is the core of the multiple energy systems

Multiple Energy System and Energy Hub

- **EH tries to model the energy conversion as port based unit with multiple inputs and multiple outputs.**

$$\boldsymbol{V}_{\text{out}} = \boldsymbol{C}\boldsymbol{V}_{\text{in}}$$



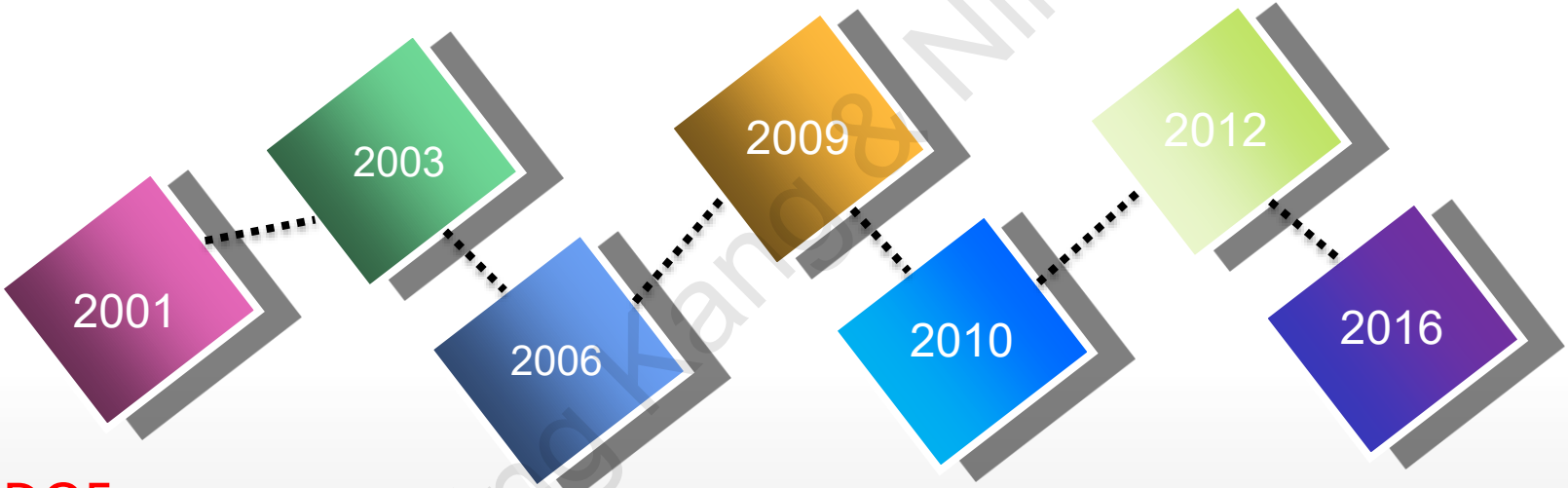
$$\boldsymbol{V}_{in} = \left[v_{in,\text{F}} \right]$$

$$\boldsymbol{V}_{out} = \left[v_{out,\text{R}} \;\; v_{out,\text{Q}} \;\; v_{out,\text{W}} \right]^{T}$$

$$\boldsymbol{C} = \left[\eta_{\text{Q}}\alpha_{\text{R}}\eta_{\text{R}} \quad \eta_{\text{Q}}\alpha_{\text{Q}} \quad \eta_{\text{W}} \right]^{T}$$

Multiple Energy System and Energy Hub

- **Switzerland ETH** Vision of Future Energy Networks
- **Canada** Government report on MES
- **Denmark** Energy comes together in Denmark



- **US DOE** integrated energy system , IES Plan
- **Japan** New national energy strategy
- **German Government** Draft German Energy Concept
- **China** The concept of Energy Internet

Multiple Energy System and Energy Hub

A glimpse of researches on MES

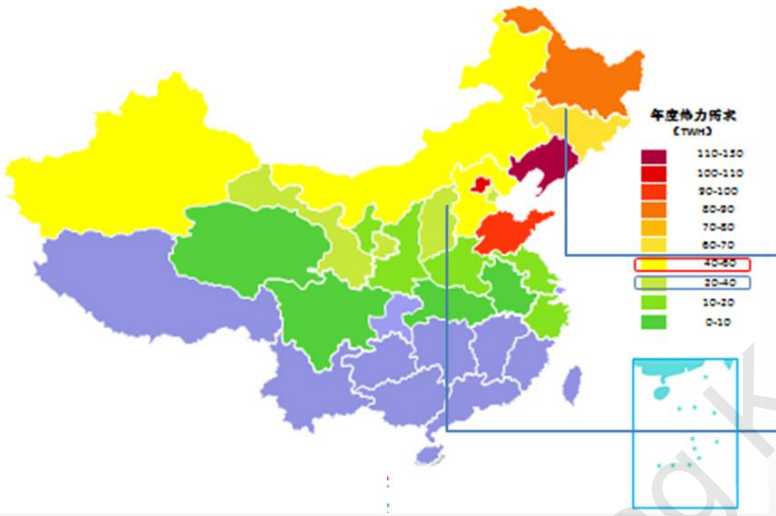
- MES
  - Modeling: Energy Hub, Microgrid, Virtual Power Plant
  - Operation
    - Energy flow calculation and steady state analysis
    - Electricity-gas Unit commitment, economic dispatch
    - CHP unit for renewable energy accommodation
  - Planning
    - Coordinate planning of electricity-gas systems
    - Energy hub based planning
  - Flexibility
    - Virtual storage by heat and cooling
    - Power-to-Gas technology.

Electric-Heat Coupling

Electric-Heat Coupling

- Why is the electric-heat coordination important?

Heating demand distribution in China

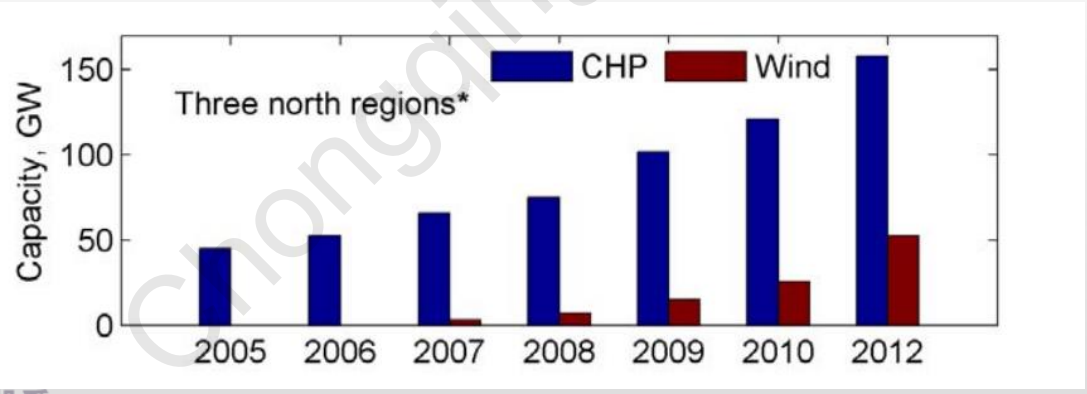


Percentage of CHP in coal-fired units:

National: 18%

North East: 70%

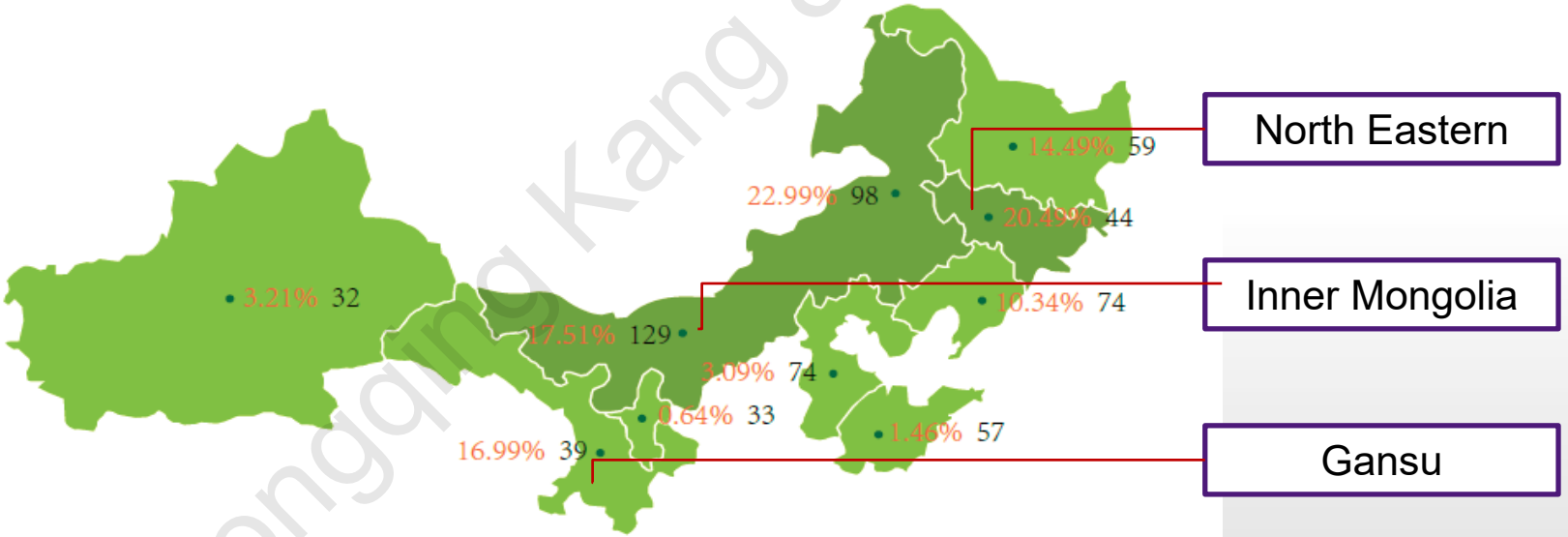
Northern China: 50%



- Large-sized Combined Heat and Power (CHP) units have been installed
- The output power of CHP is determined by heat demand, which makes the CHP units less flexible
- This leads to huge wind power curtailment

Electric-Heat Coupling

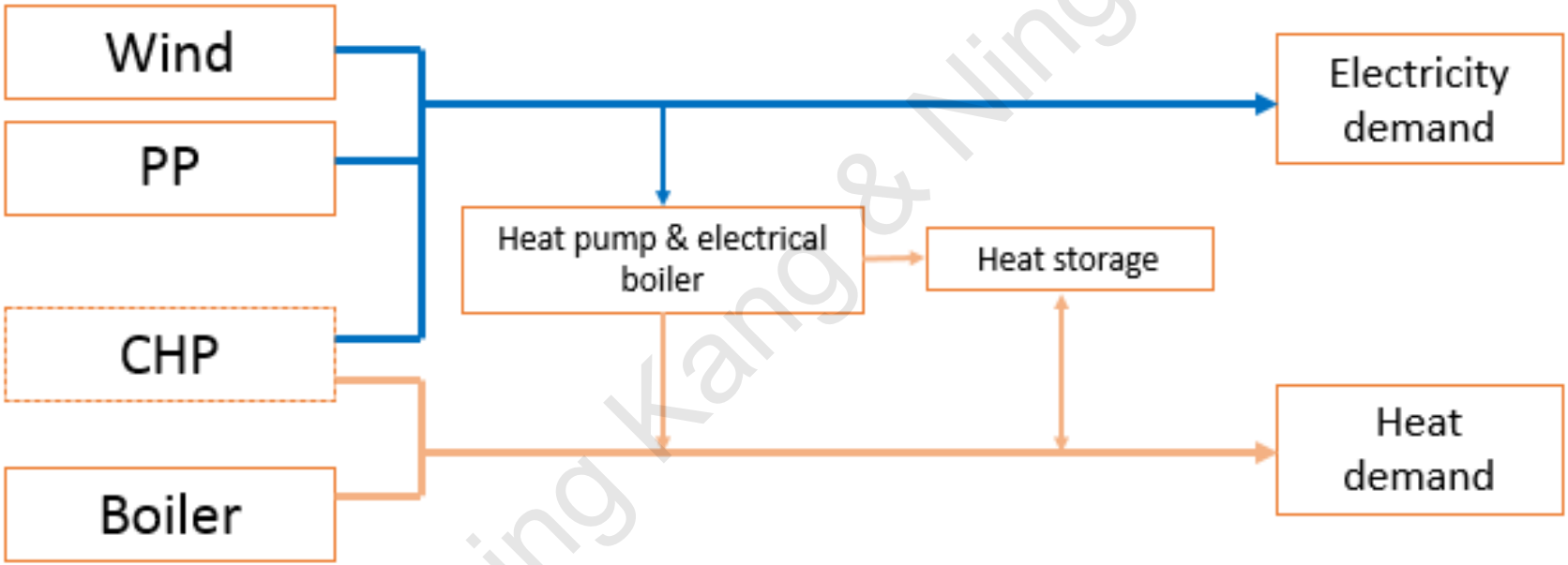
16% of wind power curtailed



Curtailment rate Surveyed wind farms

Electric-Heat Coupling

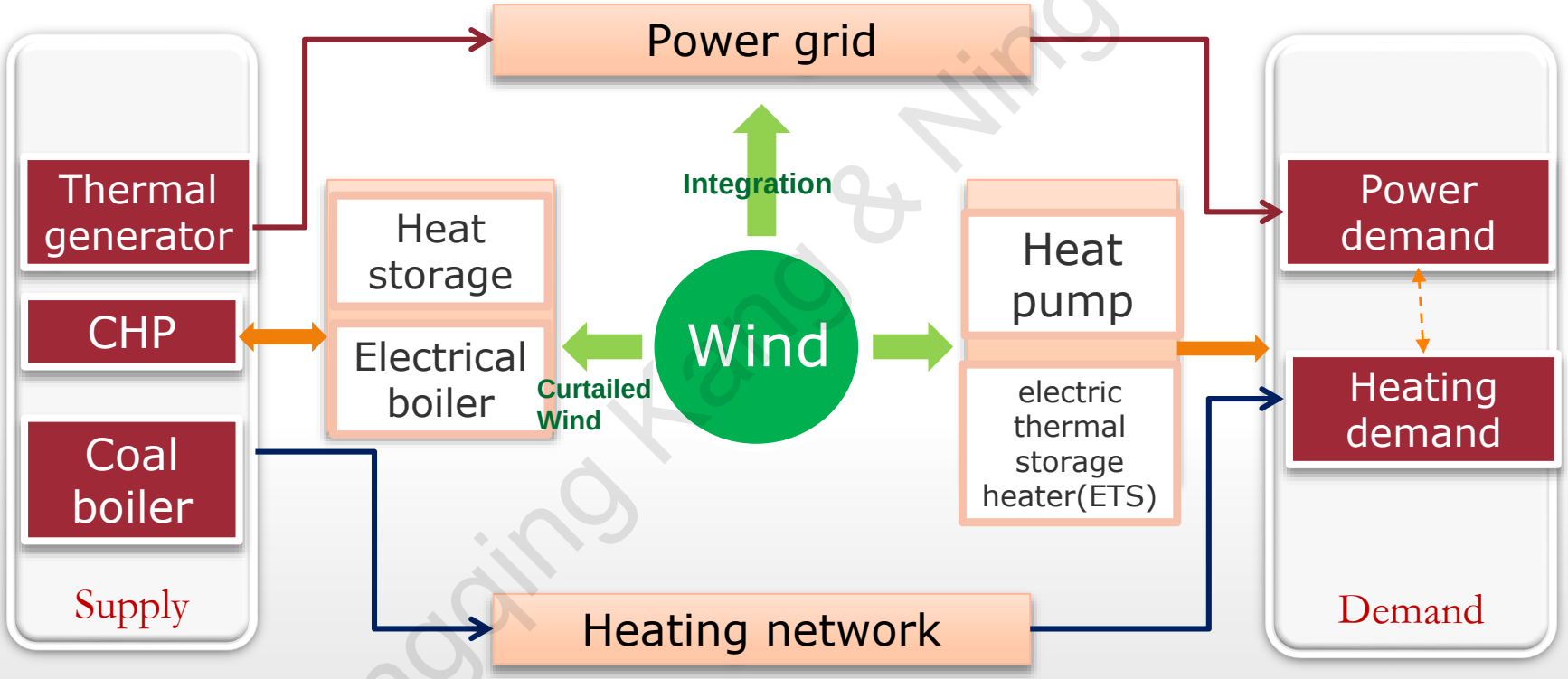
- How to solve the problem? Use heat system as virtual storage!



Virtual power storage: the electricity system can use the storage capability from other energy sectors

Electric-Heat Coupling

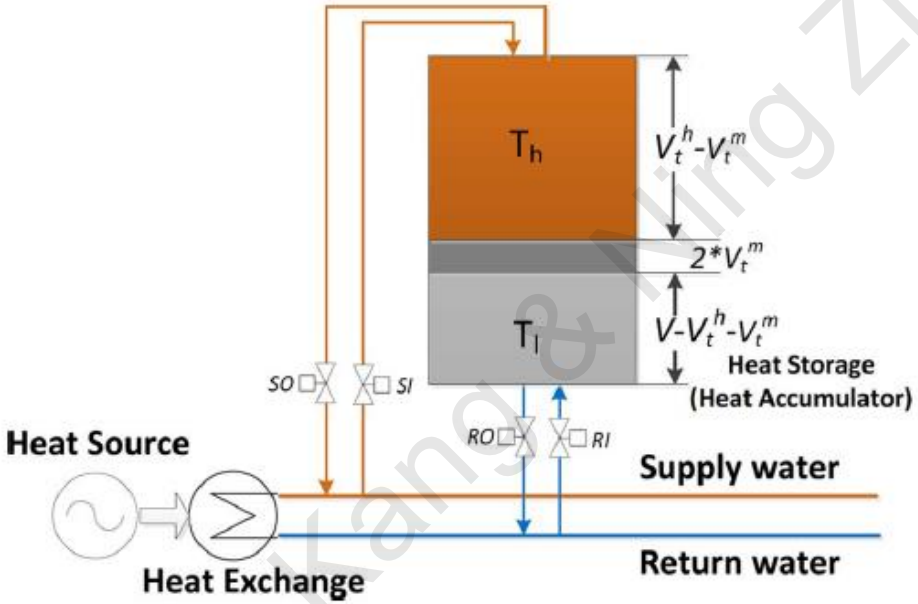
The framework of integrated power and heat energy systems

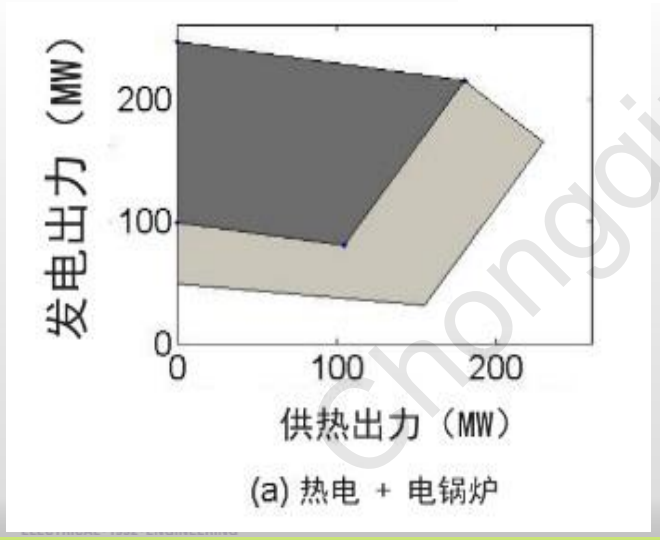


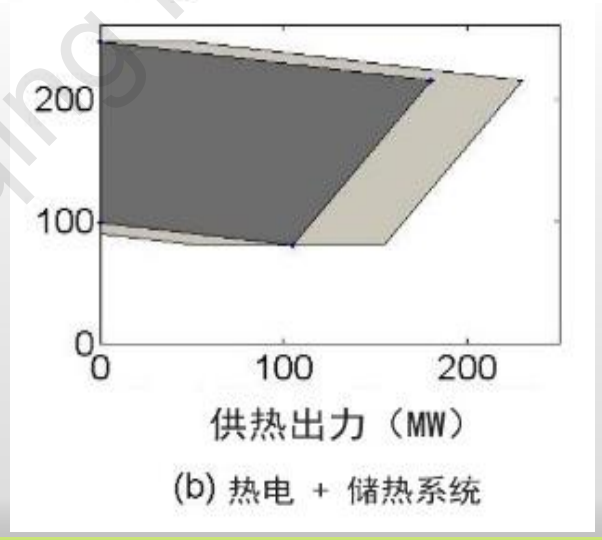
1. Supply side：
Increasing the flexibility of CHP by interacting with heat storage, electrical boiler and wind power

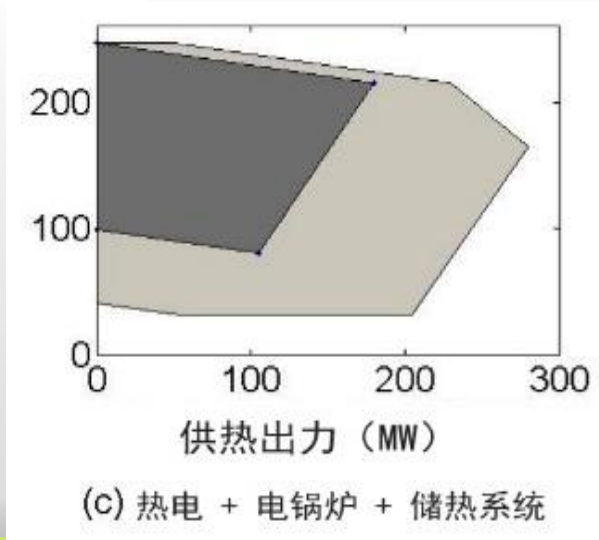
2. Demand side：
Synergize the wind power and space heating demand, using thermal inertia to mitigate the fluctuation from wind power

Electric-Heat Coupling

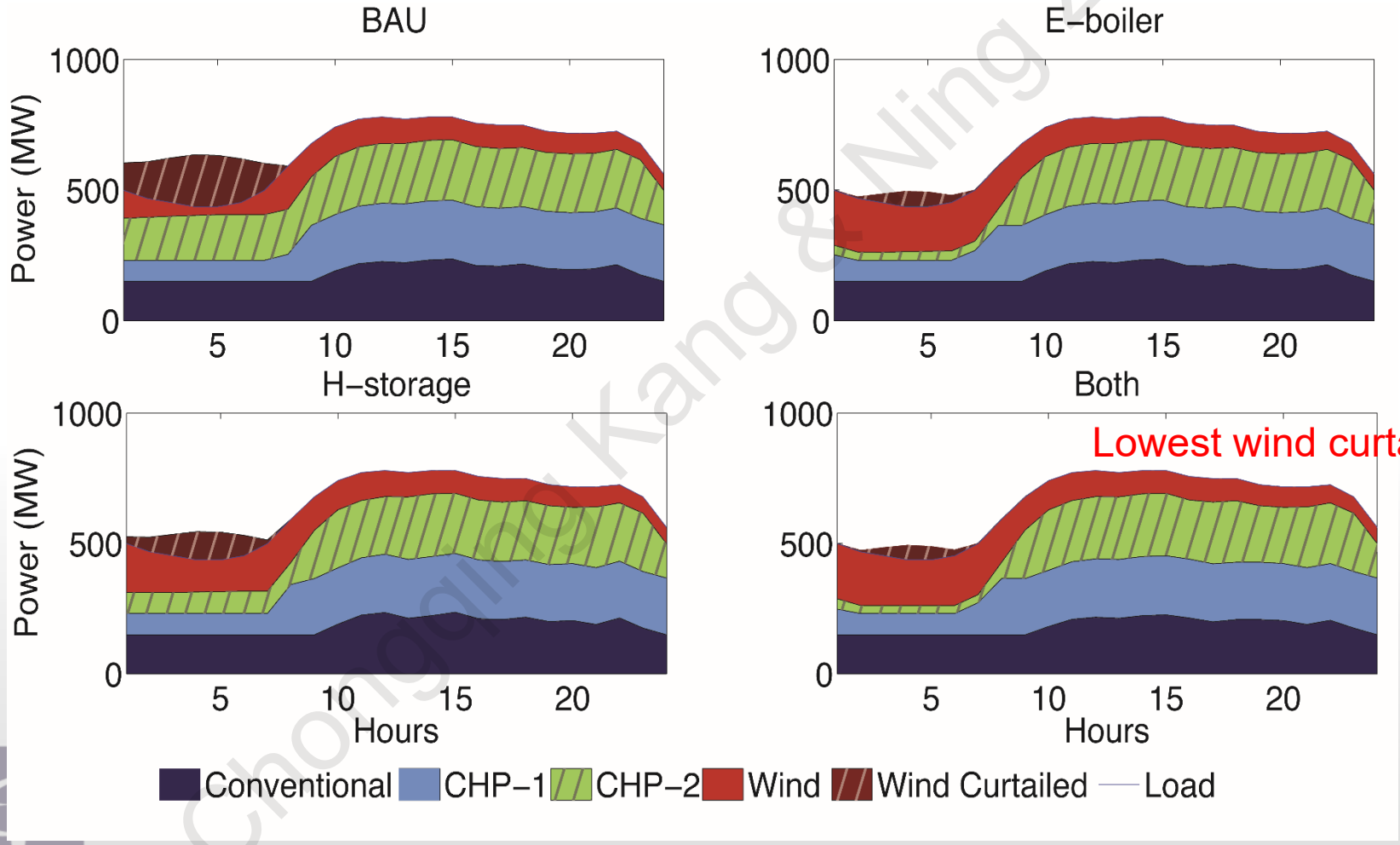








Supply Side: Power Balance



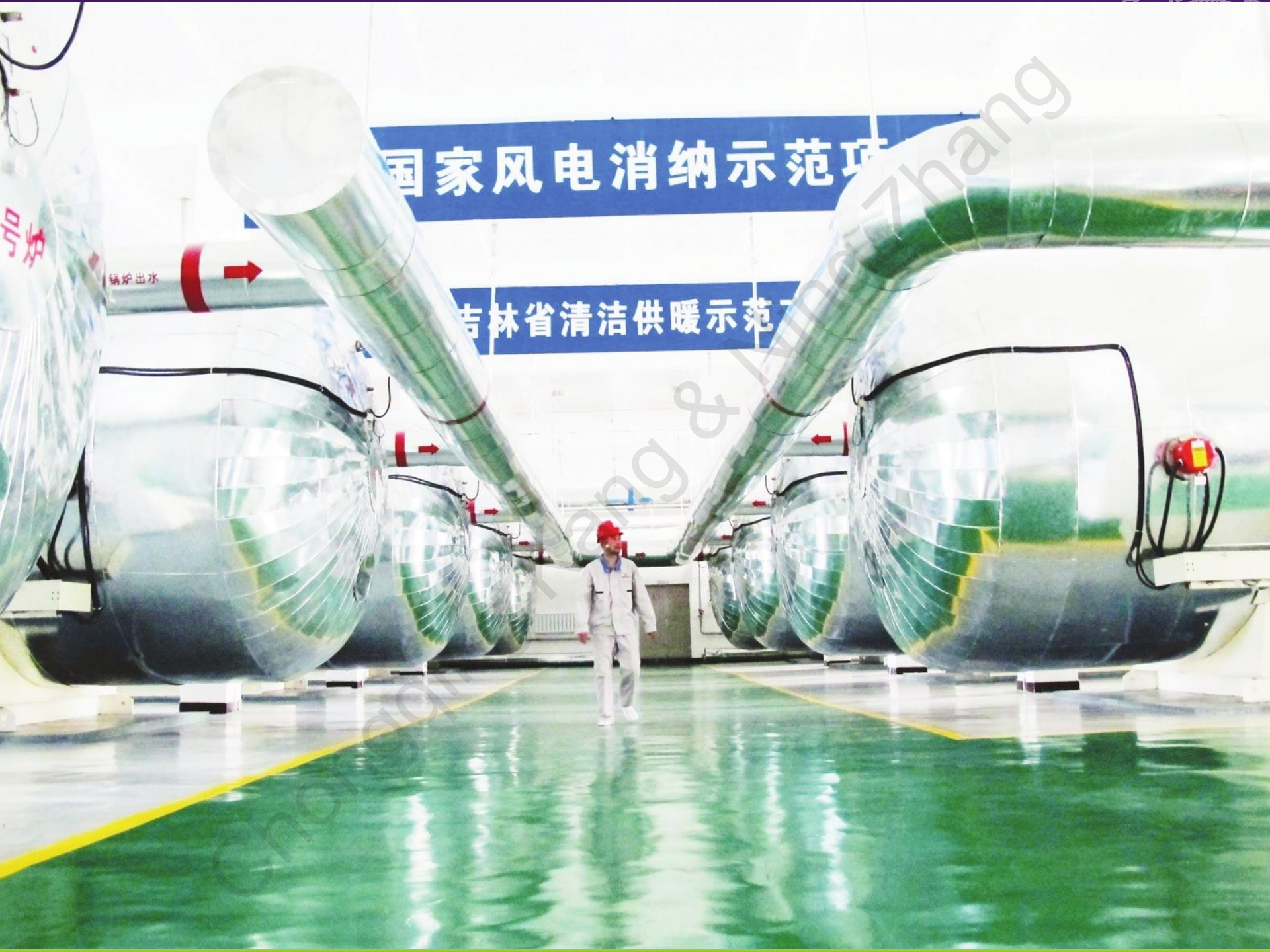
Electric-Heat Coupling

- Review of Current Situation

- 6 wind heating projects
- 1,200,000 m^2 heat supply by wind

- 9 wind heating projects
- 1,600,000 m^2 heat supply by wind
- 250 GWh additional wind power could be integrated during the heating period in winter

- 1 demo project
- 100,000 m^2 heat supply by wind
- 17 GWh additional wind power could be integrated during the heating period in winter


国家风电消纳示范
锅炉出水

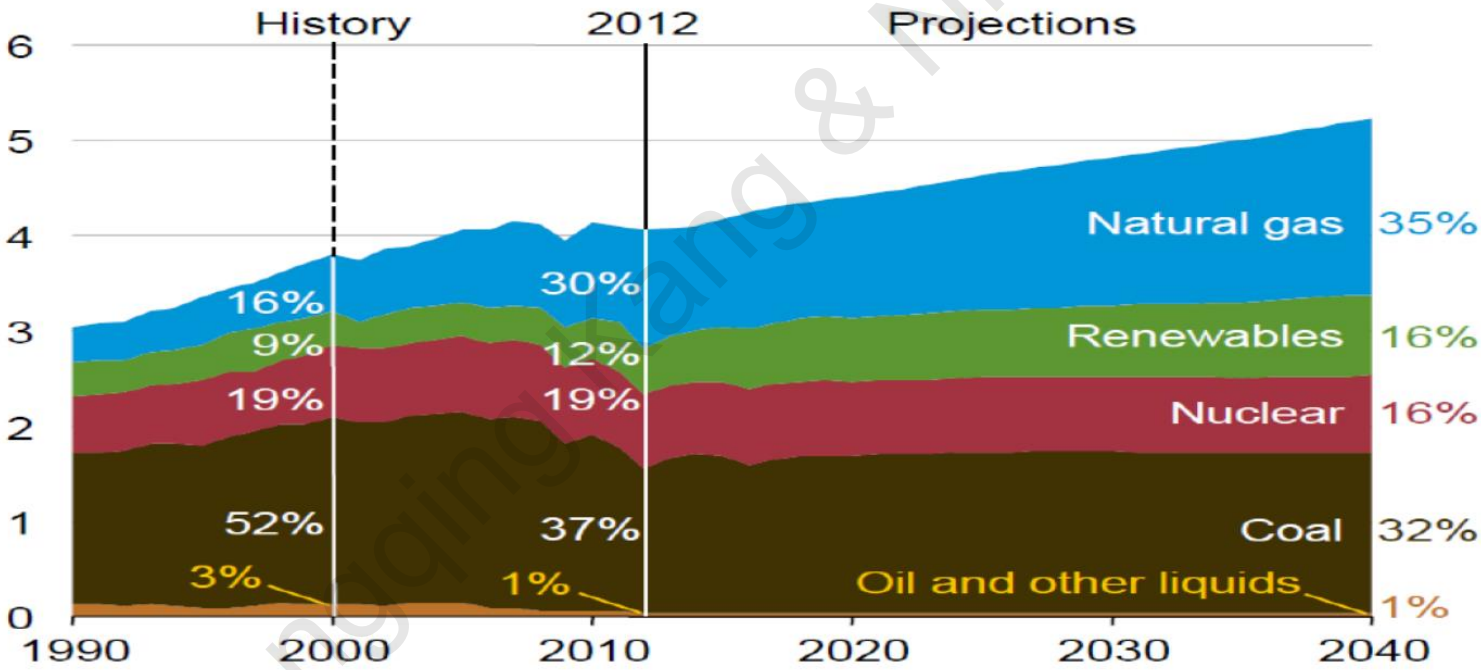
Electric-Heat Coupling

Electric-Gas Coupling

- Why is the electric-gas coordination important?

Change in US Electric Energy Portfolio

Electric energy generation by fuel, 1990-2040 (trillion kW-hrs)



U.S. Gas-fired units in 2014:
-Installed capacity : 42%, largest sector
-Electricity generation : 33%, the same as coal-fired units

Electric-Gas Coupling

- What are the problems?

Modelling

- Modelling the natural gas network
- Modeling the dynamics of natural gas flow

Operation

- The uncertainty and security of gas supply system
- Coordinated operation of gas-electricity system

Planning

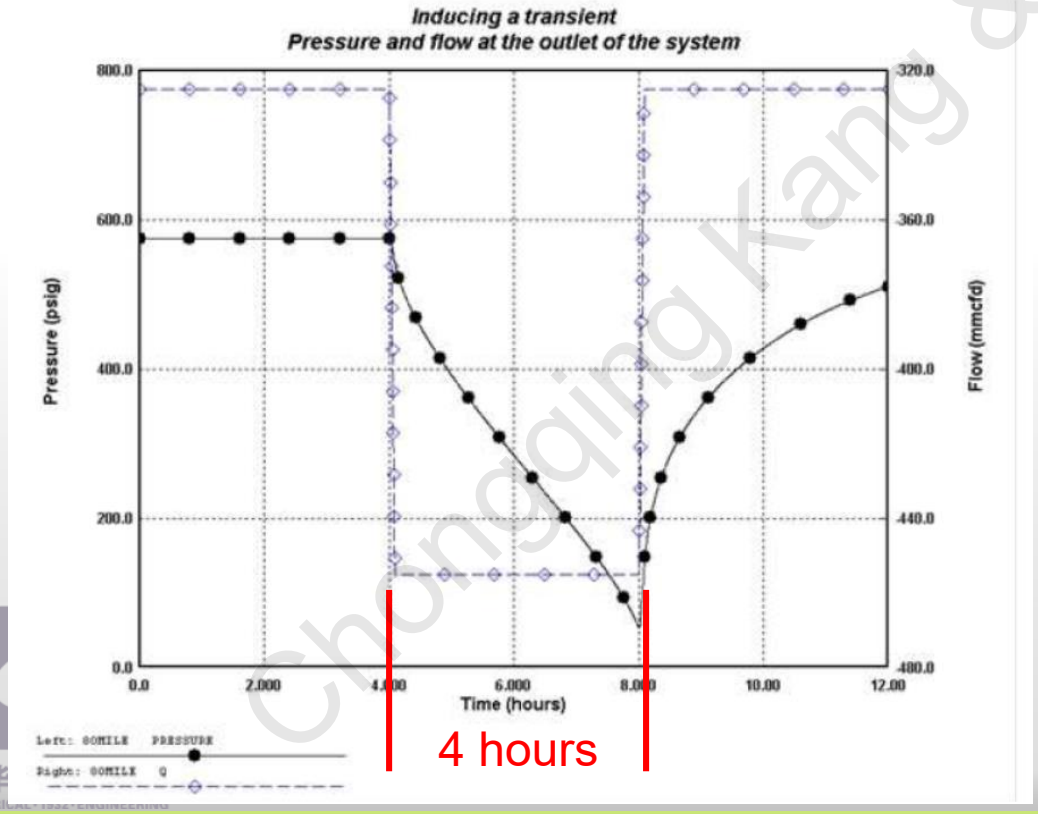
- Co-planning of electric generation, electric transmission and natural gas pipeline

Marketing

- Coordination of day-ahead natural gas and electricity bidding

Modelling technique: From steady-state to transient model

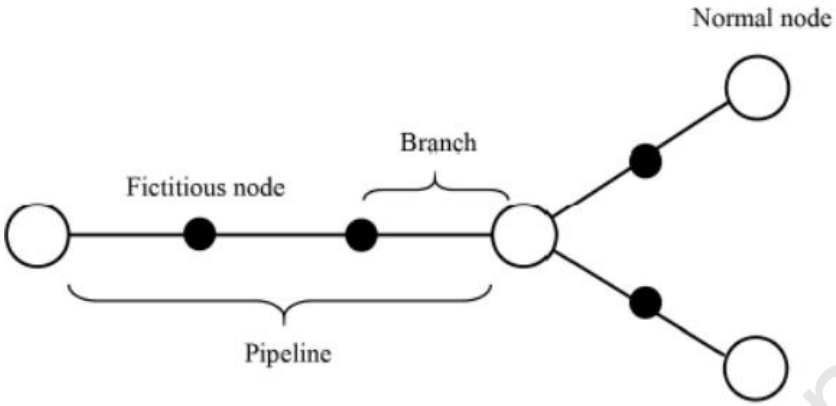
- The time constants of natural gas system is several minutes or hours. A steady-state model is not capable to depict the dynamics of gas system.

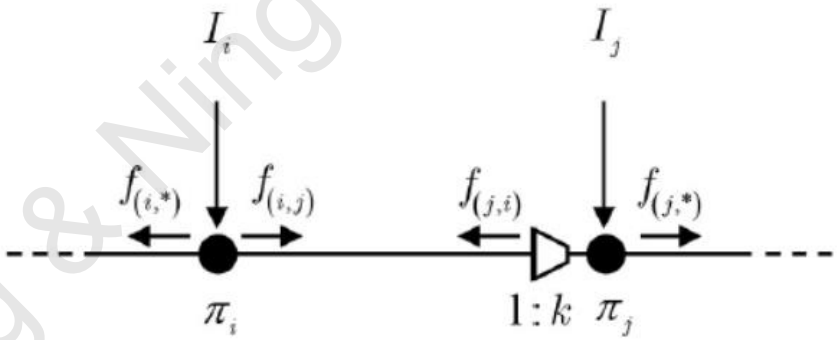


- An example: a typical gas transmission pipeline
- When the gas demand changes abruptly, the nodal pressure changes slowly。

Electric-Gas Coupling

A Transient Node-Branch model





- Step 1: Redefine the Branches and Nodes in gas network

- Step 2: General branch equations

$$\frac{\partial \pi(x,t)}{\partial t} = -C_1 \frac{\partial f(x,t)}{\partial x}$$
$$\frac{\partial \pi^2(x,t)}{\partial x} = -C_2 f^2(x,t)$$

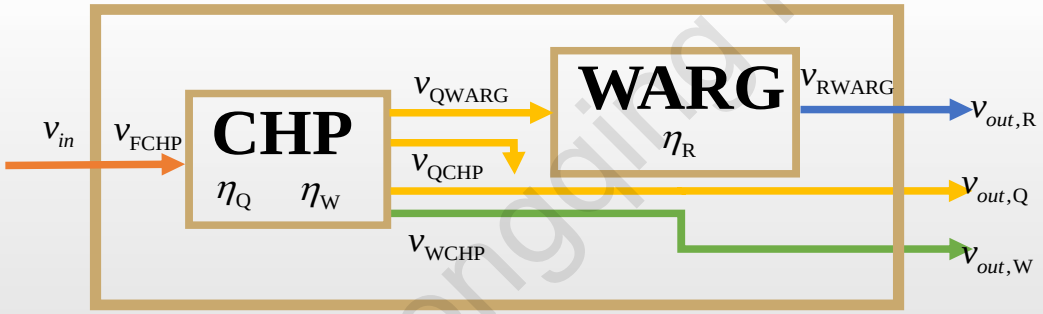
$$\frac{\pi_i(t) - \pi_i(t-\delta t)}{\delta t} = C_1 \frac{f_{(i,j)}(t) + f_{(j,i)}(t)}{l_{(i,j)}}$$
$$\frac{\pi_i^2(t) - \pi_j^2(t)/k^2}{l_{(i,j)}} = C_2 f_{(i,j)}^2(t)$$

Standard Modeling of Multiple Energy System

Multiple Energy System and Energy Hub

- **EH tries to model the energy conversion as port based unit with multiple inputs and multiple outputs.**

$$\boldsymbol{V}_{\text{out}} = \boldsymbol{C}\boldsymbol{V}_{\text{in}}$$



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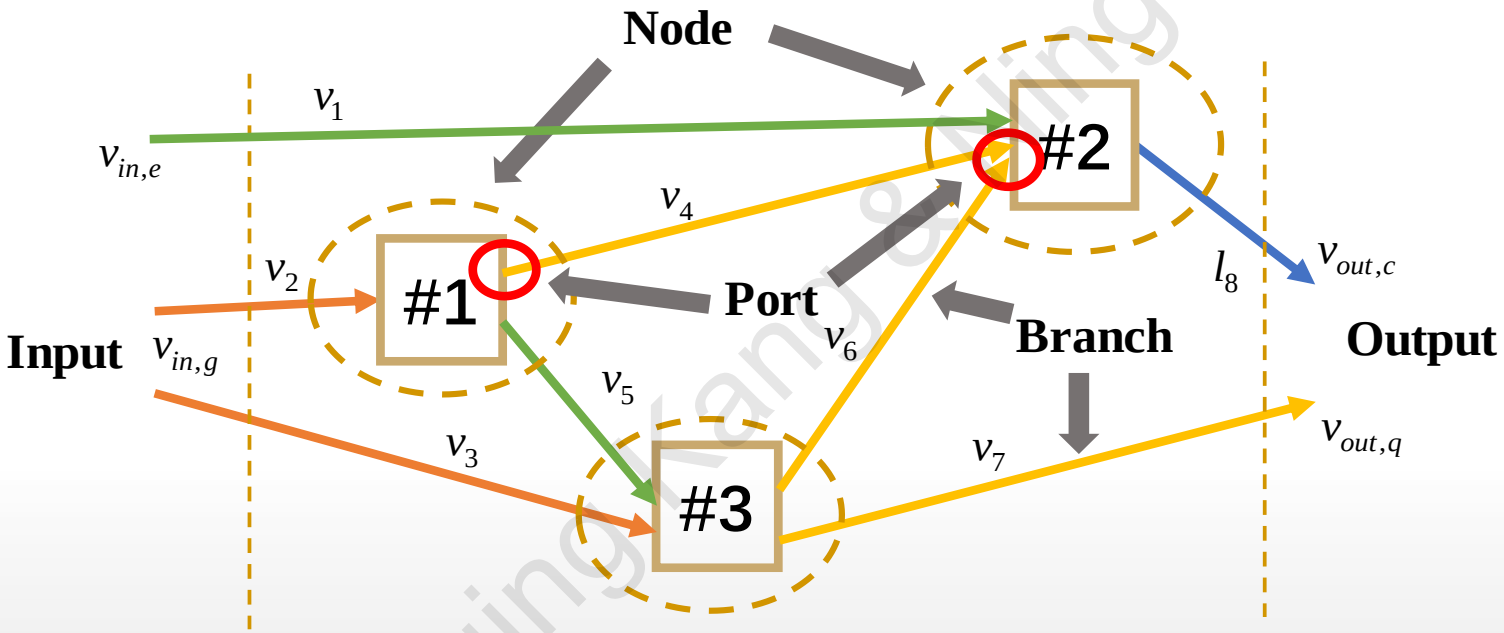
Standard Modeling of Multiple Energy System

- A MES consists of two basic elements: **energy conversion devices** and **their connection relationship.**



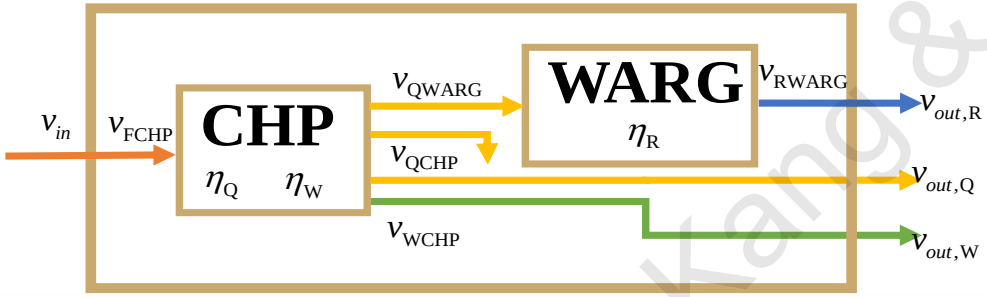
Branch, describes the energy flow.
Node, is the abstract of the energy converter, but also the abstraction of branch endpoints.
Port, is defined as the interface of a node that exchange energy with others.

Standard Modeling of Multiple Energy System

The ***system energy conversion matrix Z*** is the combination of the nodal energy conversion matrix of all nodes in EH:

$$\boldsymbol{Z} = \left[\boldsymbol{Z}_1^{\mathrm{T}}, \boldsymbol{Z}_2^{\mathrm{T}}, ..., \boldsymbol{Z}_N^{\mathrm{T}} \right]^T$$

For the MES, the system energy conversion matrix $\boldsymbol{Z}$ is:



$$\boldsymbol{Z} = \begin{bmatrix} \eta_{\mathrm{Q}} & -1 & -1 & 0 & 0 \\ \eta_{\mathrm{W}} & 0 & 0 & -1 & 0 \\ 0 & \eta_{\mathrm{R}} & 0 & 0 & -1 \end{bmatrix}$$

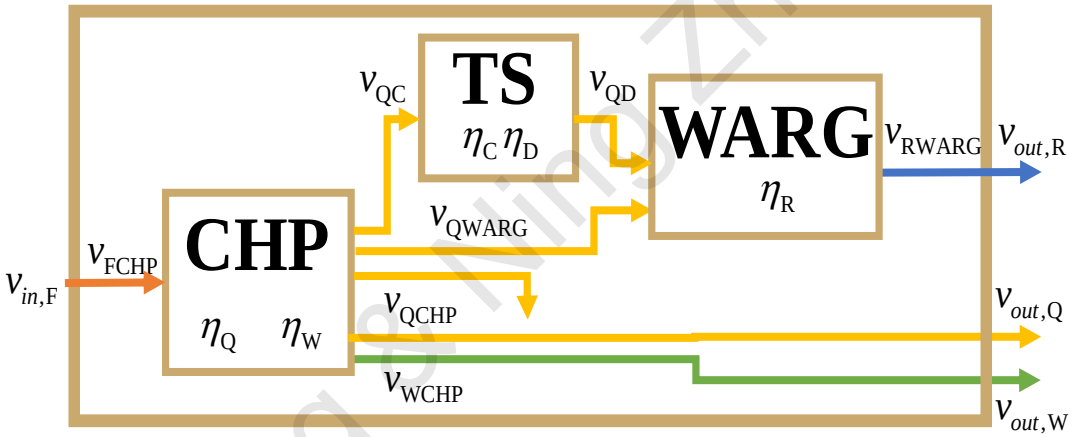
Then, we can obtain the ***energy conversion equation*** of the EH:

$$\boldsymbol{ZV} = \boldsymbol{0}$$

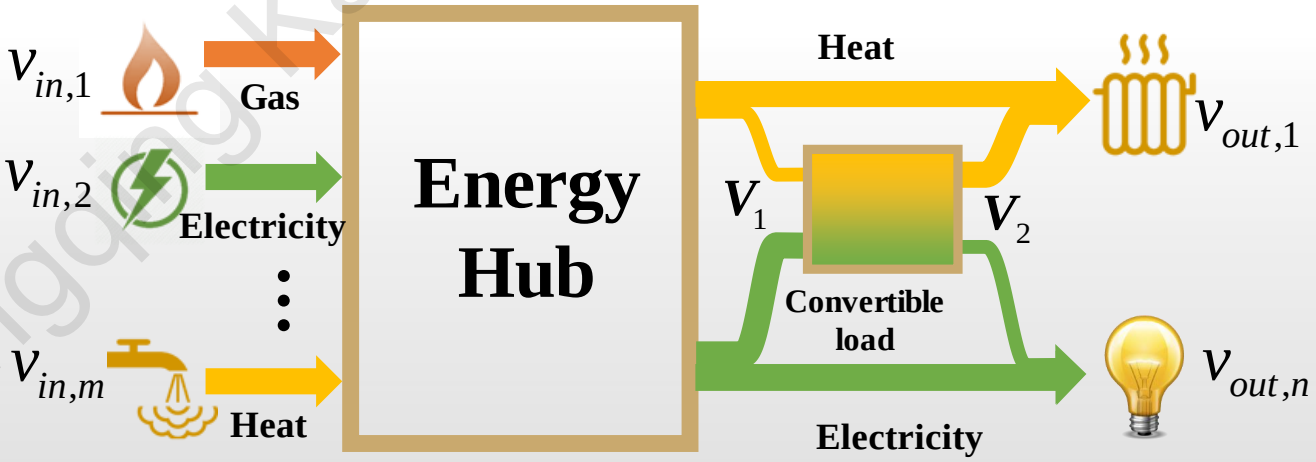
Standard Modeling of Multiple Energy System

Extension:

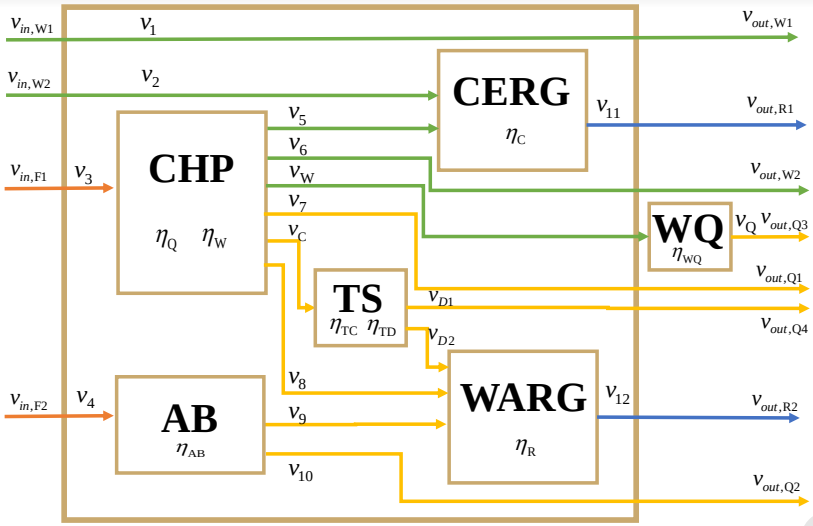
- **Storage**

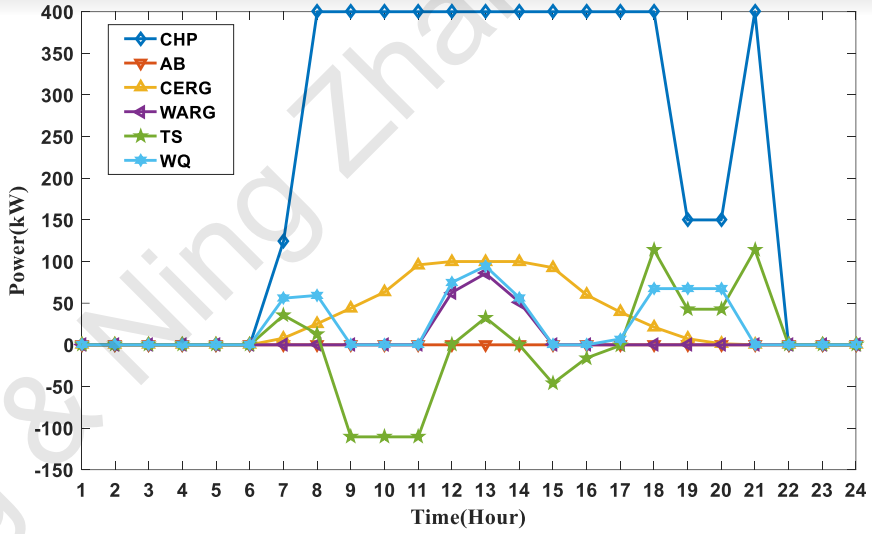


- **Integrated demand response**



Standard Modeling of Multiple Energy System





Concluding Remarks

- Multiple energy system integration is helpful for integrating high penetration of renewable energy.
- Electric, heat and gas system can be jointly modeled as algebraic equations, and can be optimized as an MILP or MINLP on both planning and operation time horizon.
- The concept of Energy Router facilitate the modeling of district energy system.

Reference

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Thanks

Q&A