Microgen'II - the 2nd International Conference on Microgeneration and Related Technologies

Harmonization of Centralized/Decentralized Energy Management for Energy System Integration

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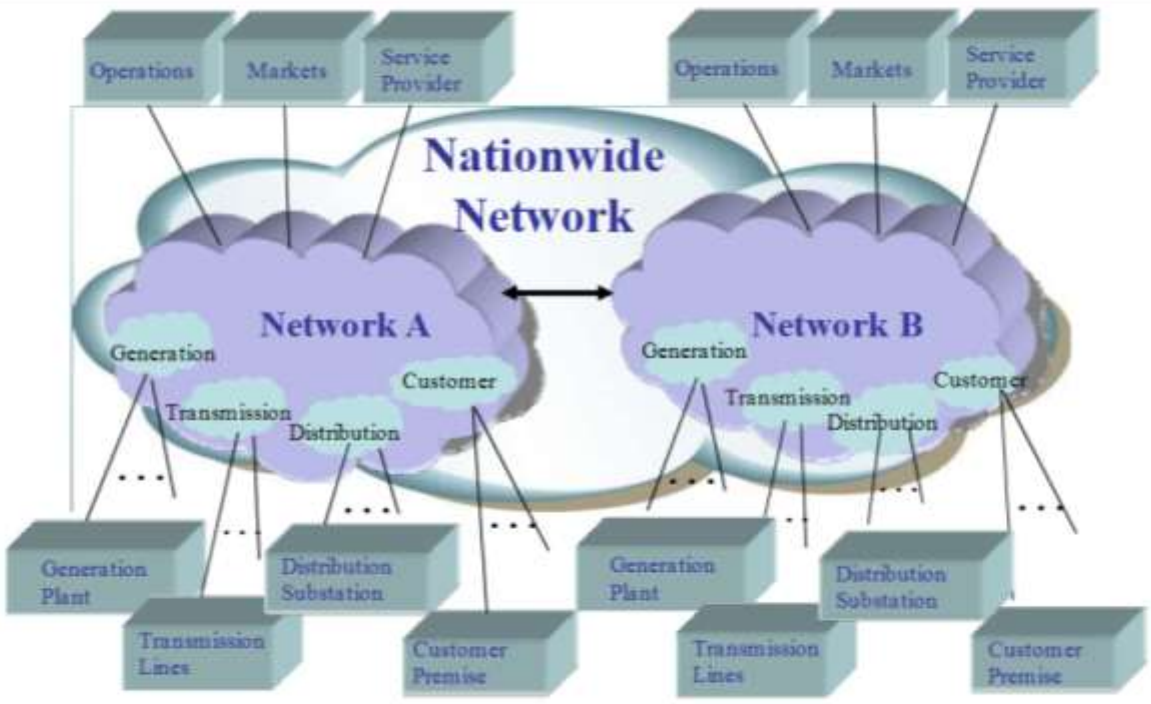
Harmonization of Centralized/Decentralized Energy Management for Energy System Integration

1. What is a smart grid?
2. Integration of Energy System
3. Smart Grid Demonstration Test in Japan
4. Our researches

What is a smart grid?

According to the US Energy Independence and Security Act of 2007:

The term "Smart Grid" refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.



Source: NIST Smart Grid Interoperability Standards Roadmap (2009.6)

What is a smart grid?

- Smart grids can take various forms depending on regional social and economic conditions and resources, and are adopted in various stages, including the implementation of technologies, the establishment of social infrastructure, and system reorganization. Adoption can thus take various paths through various combination of these forms and stages.

- The technologically new concept of a smart grid is to enhance the capability to balance supply/demand in a power system through the more active participation, both direct and indirect, of the power demand.

- Key technologies include communication between equipment, energy management, and storage of electricity

- Smart grids can enable energy use for the maintenance or improvement of living standards, expansion into other services, or a combination of these uses

- Discussions of smart grids can include super grids such as:
  - ✓ An East–West ”Green transmission highway” to transmit electricity generated at large-scale solar or wind farms in the central US
  - ✓ Electricity transmission cables linking European marine wind farms to demand centers
  - ✓ Supergrids such as the trans-Mediterranean grid

Smart grid, a catch-all term that means different things to different people, has become the latest buzzword in the electric power industry. Everybody is for it, even if nobody is sure what it means. *GE and Google Team To Promote Smart Grid, The Electricity Journal, Volume 21, Issue 9, November 2008*

Variable Nature of Renewable Energy Generation in case of PV

PV generation has a variable nature due to time and changes of weather. Here, the nature is referred as “variable”, based on the understanding that it varies but is predictable to a certain extent.

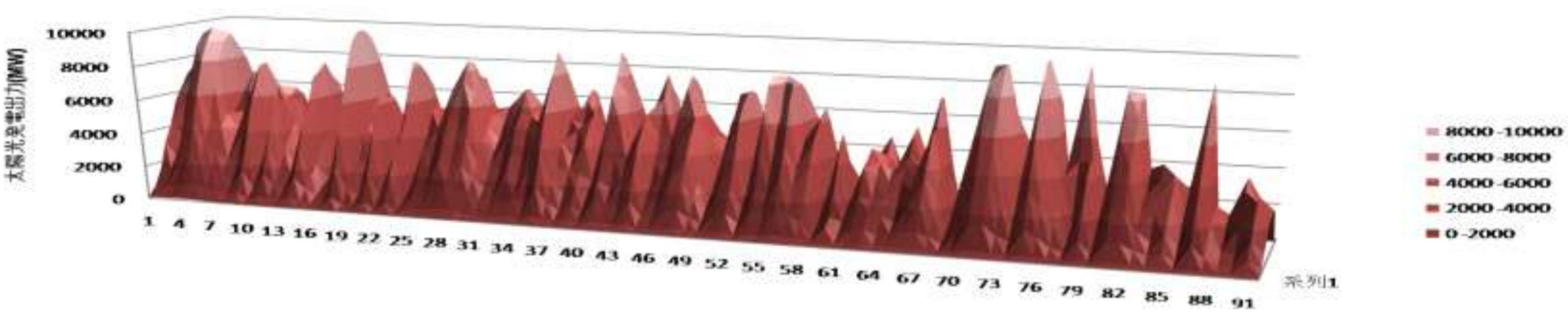


Fig. 24hour PV output variation in 90days in summer

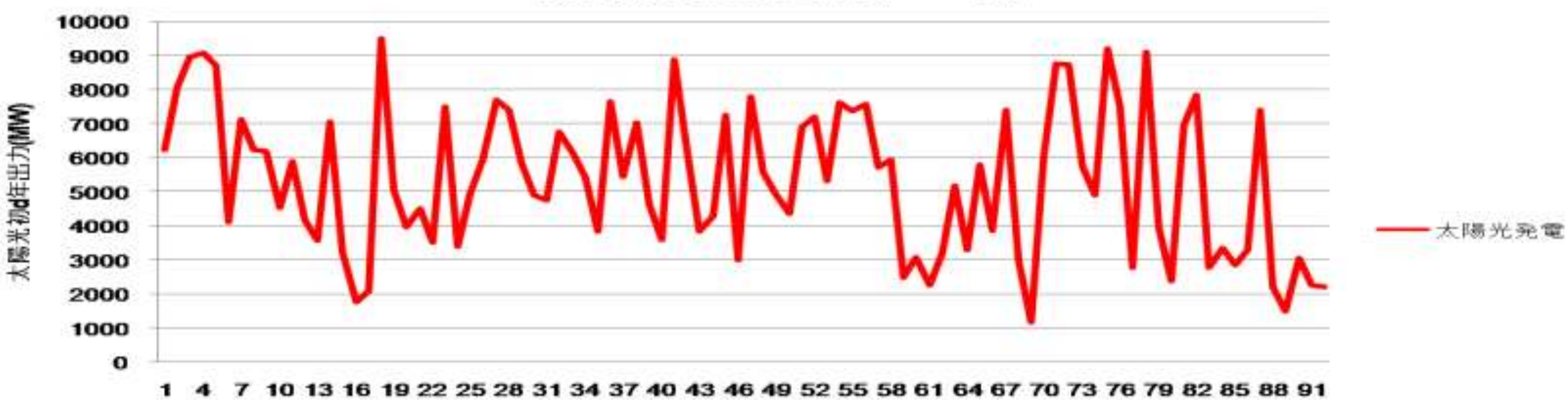


Fig. PV output variation at 14:00 in 90 days in summer

What will happen?

Impact of PV Penetration on Demand-Supply balance

- ✓ The ultimate impact of PV Penetration on a power system is the difficulty of supply and demand balance.
- ✓ A power system is requested to keep the stability of various time range under reduced regulation capability and increased variability.

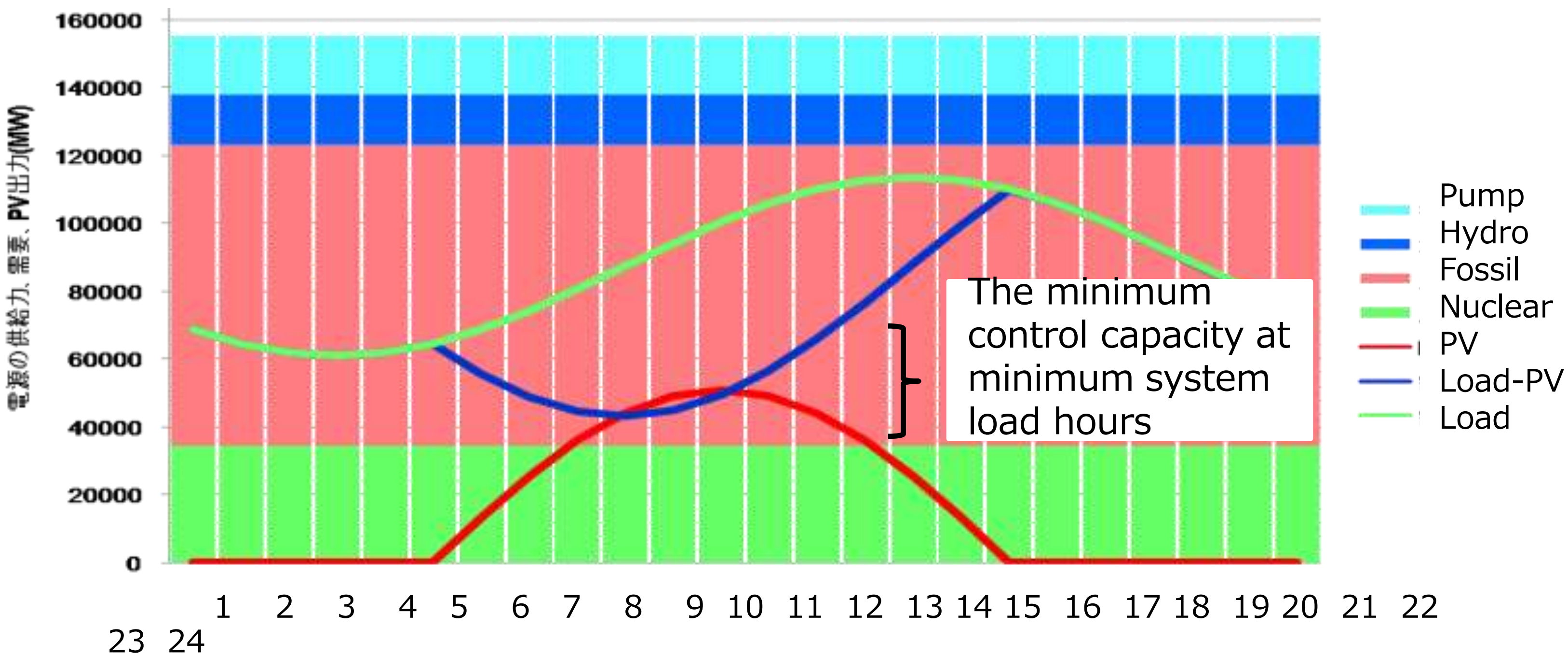


Fig. Comparison of hourly system load, PV generation, and an equivalent load on a holiday in May.

What will happen in the long period?

- ✓ In the progress to a low carbon power supply with security, the share of electricity will increase in the total end-use energy consumption.
- ✓ Te increase of carbon-free RES, nuclear, and fossil generation will make a power system less capable to keep the supply-demand balance of power.

Necessity for additional supply-demand balancing resources

Nuclear

IGCC, IGFC

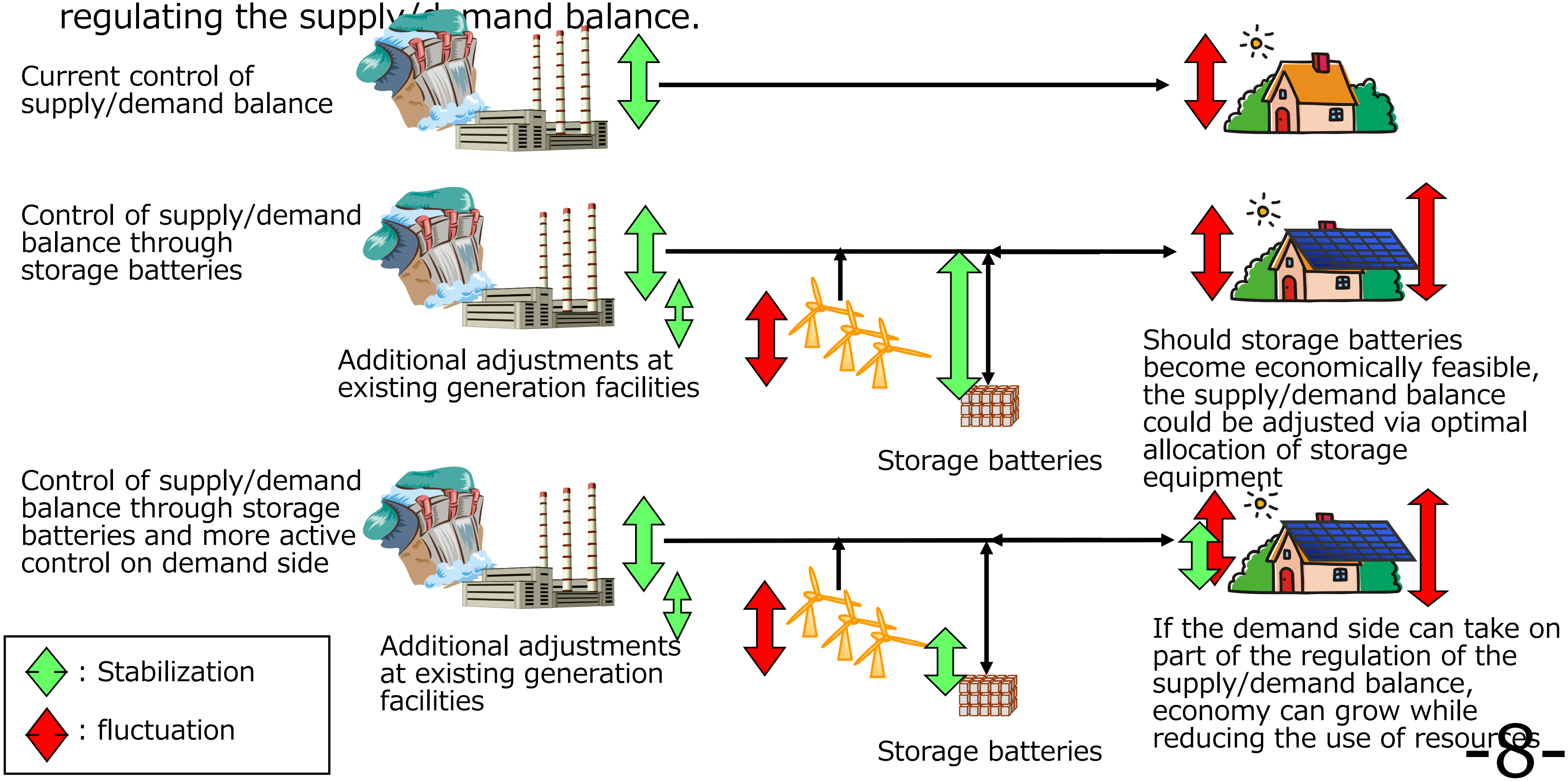
Gas combined generation

PV, Wind

Source of figures：CoolEarth Innovative Energy technology Program

Smart grids support the mass adoption of renewable energy

The electricity supply/demand balance is currently regulated through concentrated energy management at major power generation facilities. In the future, when renewable energy generation is added to the mix, distributed energy management leveraging greater engagement by the demand side could lead to a better division of labor in regulating the supply/demand balance.



Distributed Energy Management

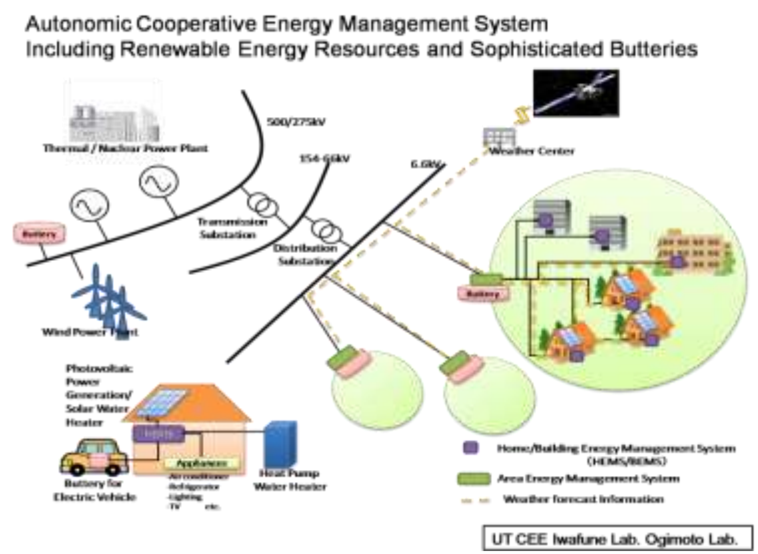
Home, Building, and Area Energy Management

- ✓ HEMS and BEMS are the appropriate hub for the autonomic and distributed energy management because they can pursue three targets:
  1) enhancement of quality of life and work environment,
  2) improvement of economy and environmental impact,
  3) reinforcement of balancing capability of a power system
- ✓ The distributed energy management autonomously control demand, energy storage and others.

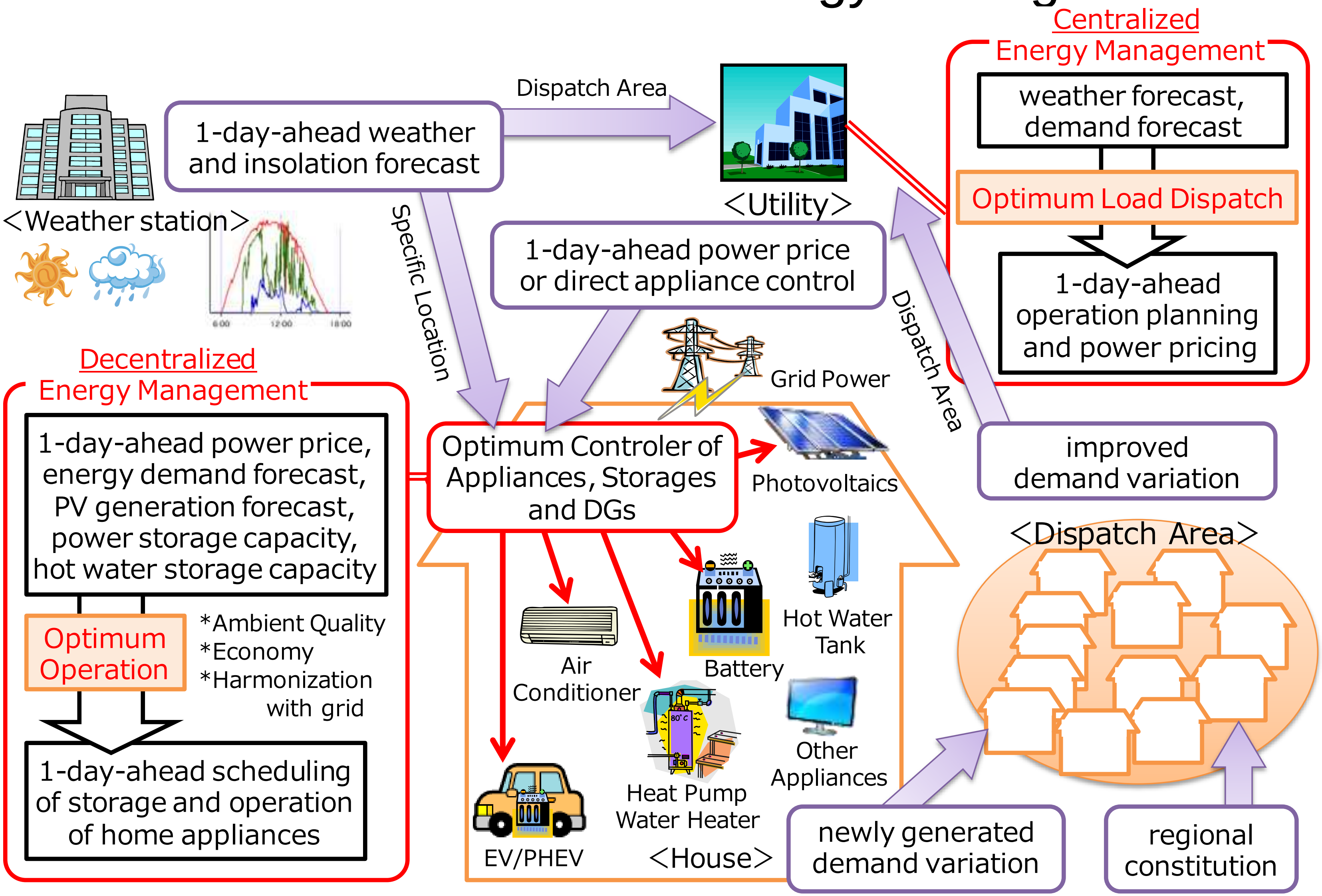
HEMS: Home Energy Management System

BEMS: Building Energy Management System

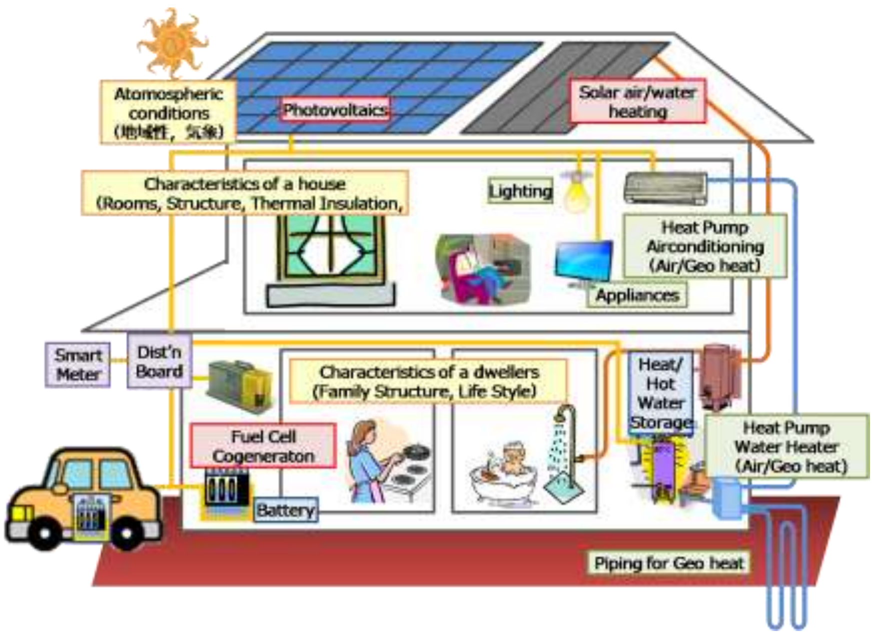
- ✓ Area EMS will be effective to enhance the autonomic control capability of demand side with more resources.
- ✓ Area EMS enables harmonized operation between network (centralized EMS) and demand (de-centralized EMSs) to enhance total system quality.



Renewable Energy Deployment and Centralized/Decentralized Energy Management

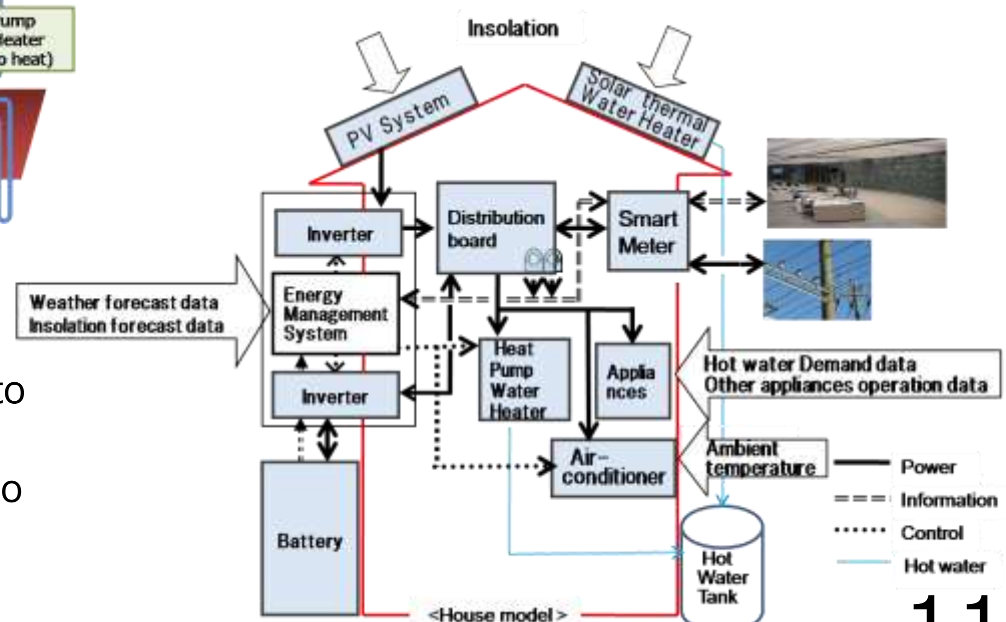


A blueprint for future housings and communities

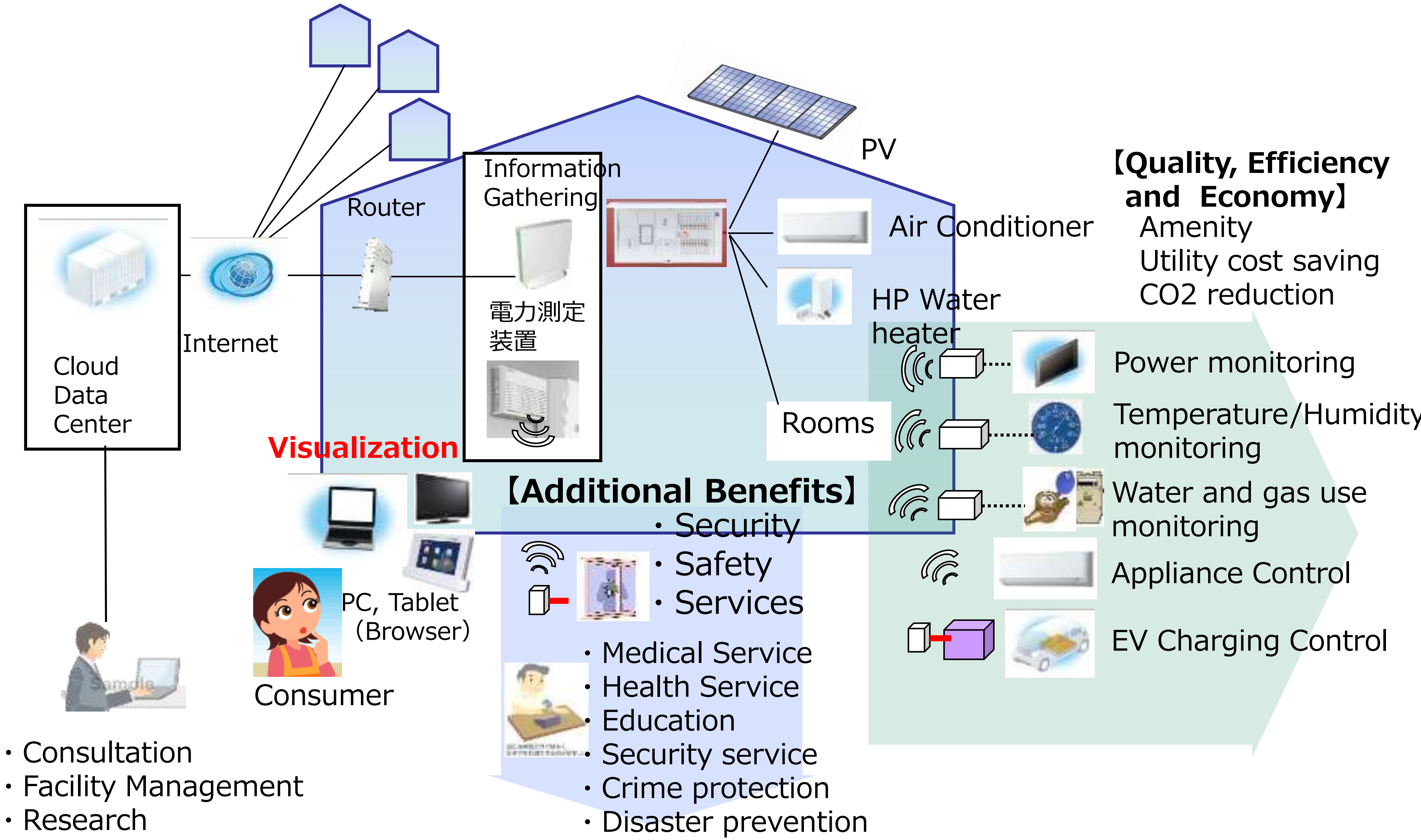


- Functional cooperation with grid, in addition to energy saving and comfort
- Maximum use of PV, solar heat, geothermal and aero thermal heat
- Standardization and low pricing of distributed energy management and household information technology are key

- Handling a variety of environmental conditions and household compositions
- Quick establishment of awareness of how to optimally combine diverse technologies
- Quick establishment of awareness in how to manage the overall operation of devices



Beyond Energy: HEMS's Future



Expansion of Scope of Smart Grid

- An existing Power System is structured by generation, transmission, distribution and in-active demands with uni-directional power flows.
- The increase of controllable distributed loads, generations, EVs and batteries has been activating the demands and make the power flows bi-directional.
- The harmonization of centralized/decentralized energy management will increase the flexibility to accommodate carbon-free and low carbon energy supply.
- The demand activation brings about availability of new data and information which enables new energy services, new energy-related and non-energy-related services, and new products.
- However, the information and data for new services and products requires higher specification with a new ICT infrastructure than original energy requirements.

Harmonization of Centralized/Decentralized Energy Management

for Energy System Integration

1. What is a smart grid?
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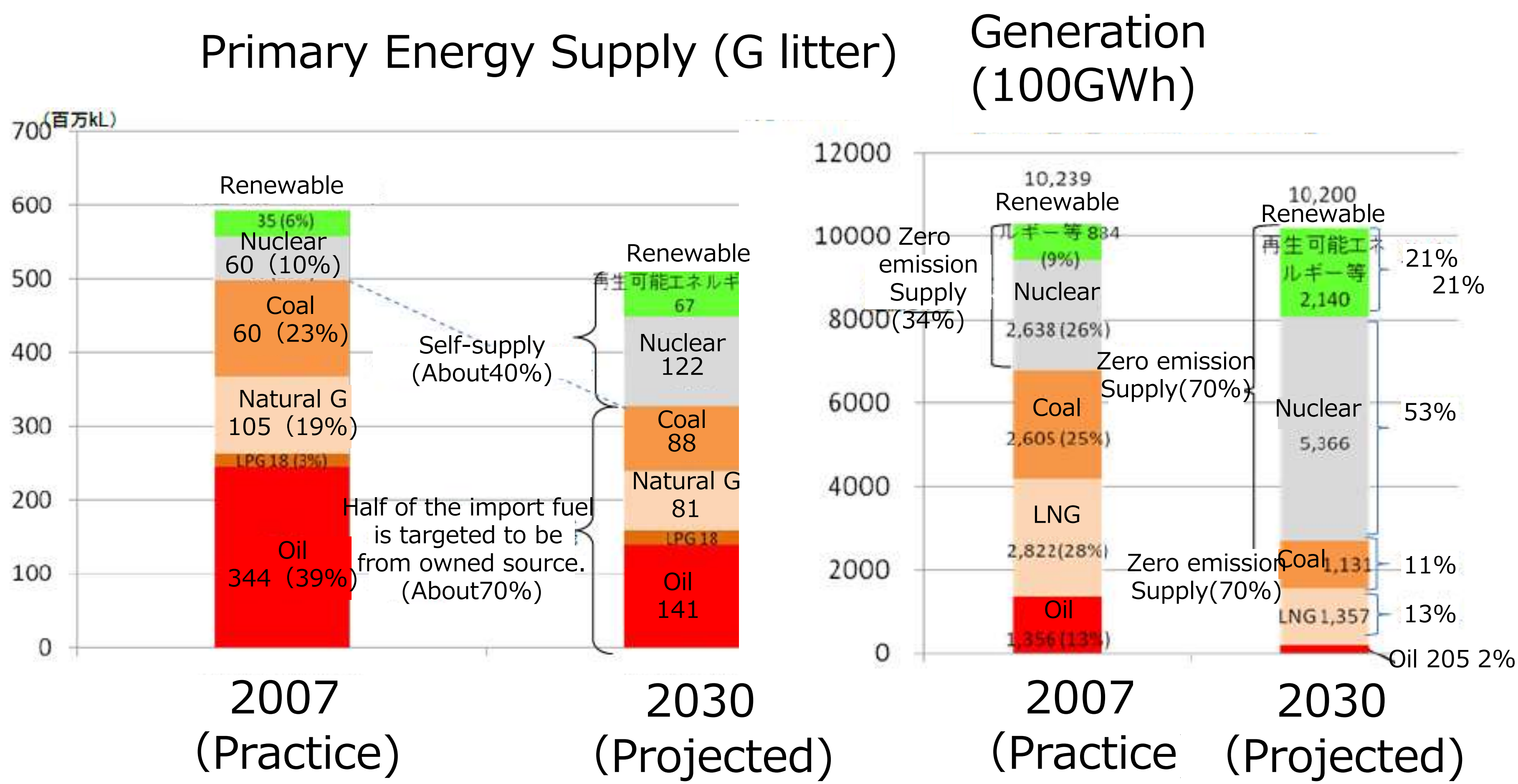
Japan's Energy Supply Prospect in 2030(METI 2010.6)

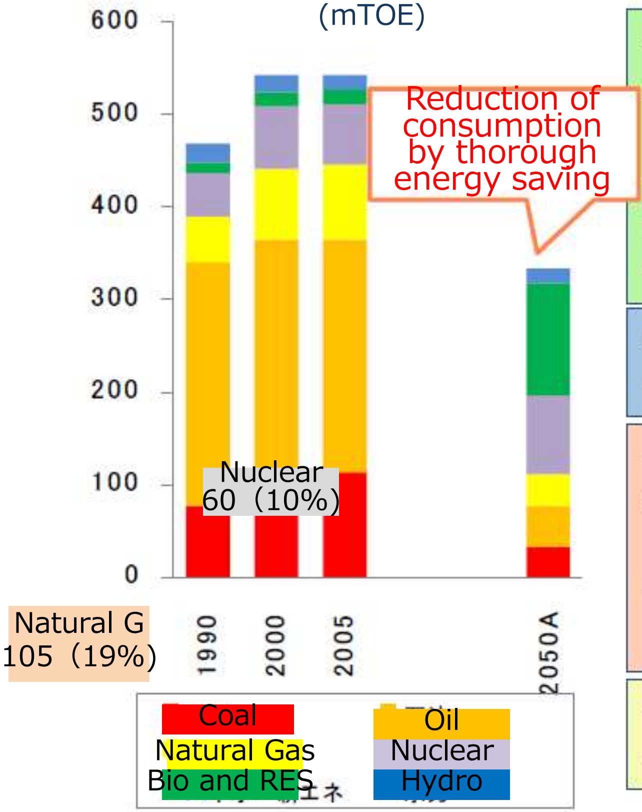


Japan's Energy Supply Prospect in 2050 (MOE 2010.6)

Case Study for CO2 80% Reduction in 2050 (Scenario A: Supply Side)

- The share of zero-emission energy (ex. PV, Wind, Nuclear) is from 20% to 70%.
- The consumption of fossil fuel is reduced from 450 mTOE to 110 mTOE.
- The CO2 emission from fossil fuel power plant will be treated by CCS.

Primary Energy Supply (mTOE)



<Image of Supply mix>

＜再生可能エネルギー＞
- 太陽光発電の導入量は2005年のおよそ120倍（ほとんど全ての住宅・建築物に太陽熱/太陽光発電が設置）。
- 洋上にも陸上と同程度の風力発電が設置・稼働。
- バイオマスは輸入も含めて供給量を確保。
- 水力は現状維持程度。

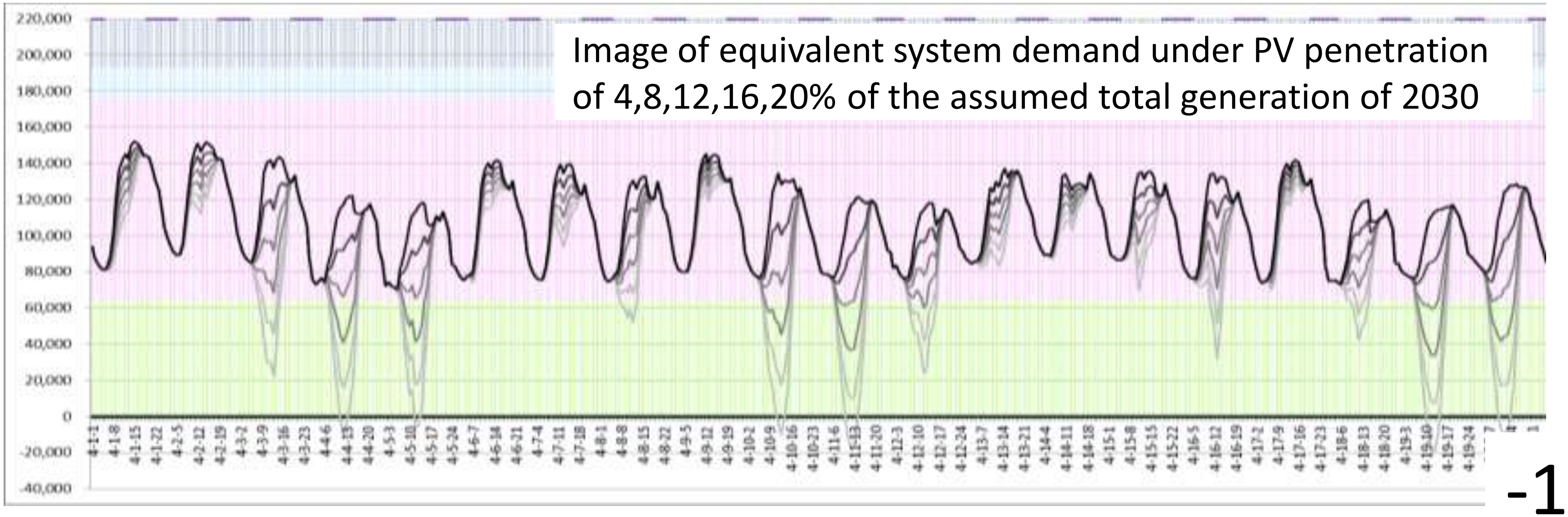
＜原子力＞
- 原子力の発電容量は現状水準を維持。

＜石炭・石油・天然ガス＞
- 運輸部門や産業部門の効率改善・燃料転換により、石油の消費量は大幅に低下。
- 天然ガスは産業部門におけるシェア拡大も、省エネや民生部門における電化の影響等により消費量は半減。

＜CCS＞
- 火力発電所で排出されたCO2はほぼ回収され、地中等に隔離。

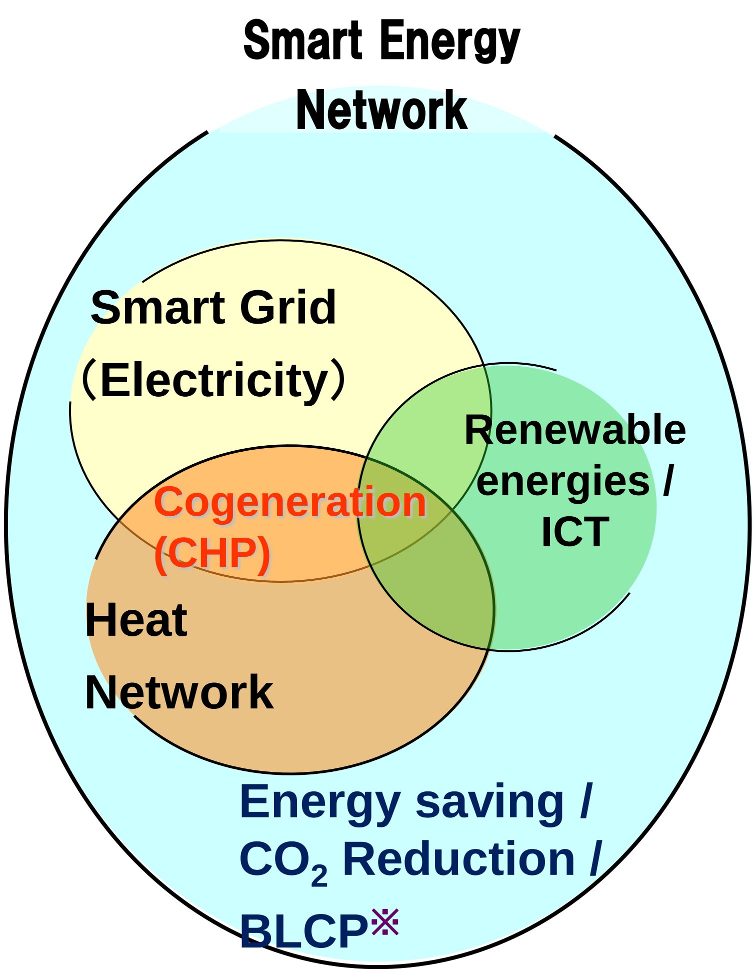
The Implication by an Extreme Case

- The utilization of renewable energy, when introduced in the shape of variable power generation, the issue of demand-supply balance becomes more difficult to fix as the penetration level increases.
- The countermeasures for the issues are more sophisticated operation of the existing and application of new technologies in operation and asset portfolio in a series of steps.
- Renewable generation forecast and flexible operation of power system generators are important.

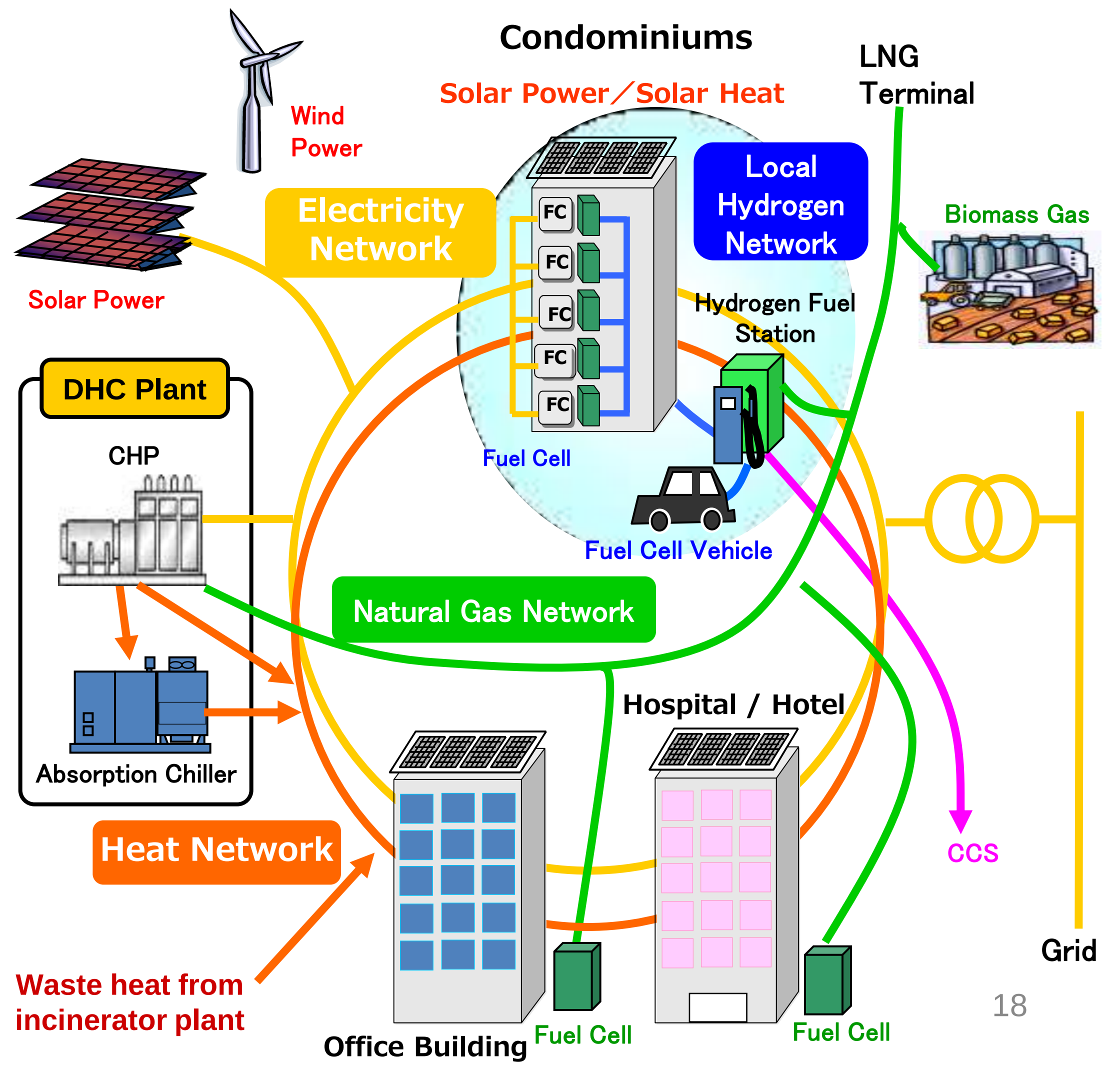


Concept of Smart Energy Network in Japan

- Smart networks of electricity, heat, renewables and natural gas
- Integration of central and distributed systems, and all clean energy technologies
- Increasing efficiency, flexibility, security, reliability and quality



※Business and Living Continuity Plan



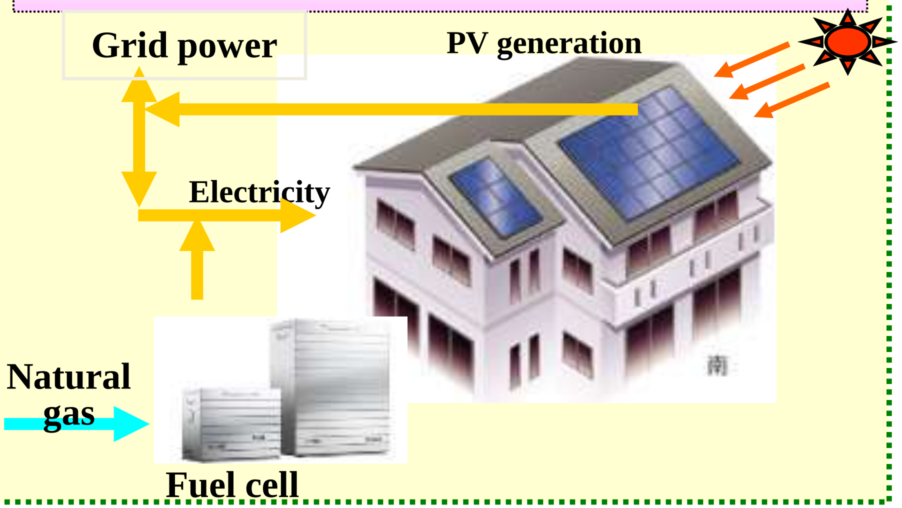
Combination of renewable energies and Fuel Cell

Installing Microgeneration (PV + Fuel Cell) for residential use

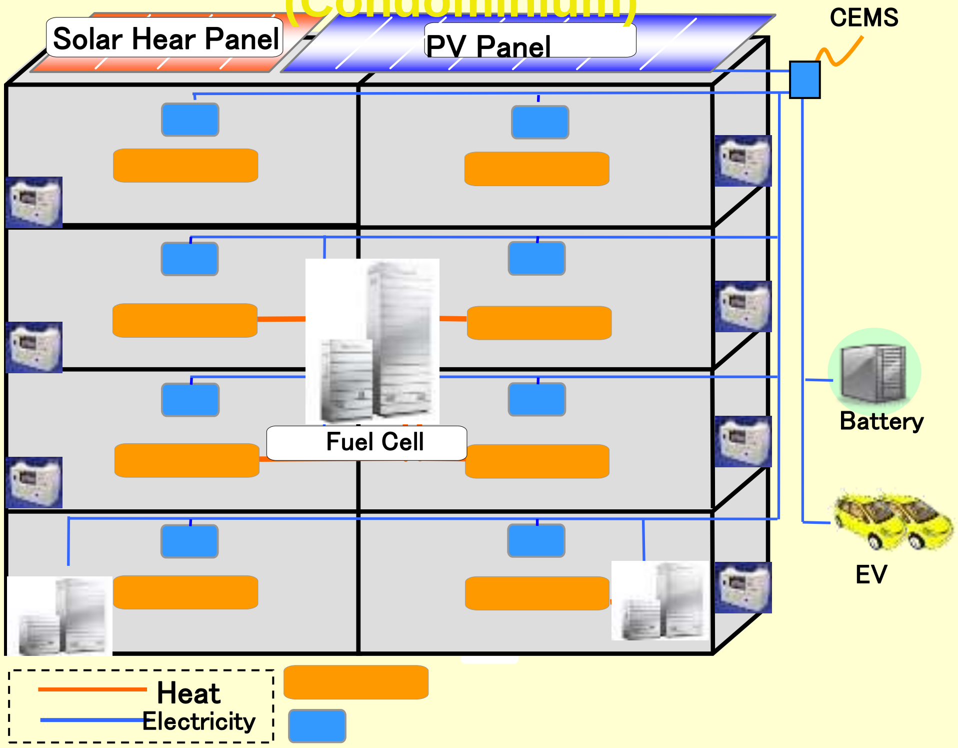
- In the individual house (PEFC) : Commercial at present
- In the condominium (PEFC) : Field Test from 2012
- In the condominium (SOFC) : Future

1. Fuel Cell + PV (House)

The best mixture; Fuel cells compensate the output instability of PV cells.



2. Fuel Cells + PV (Condominium)



Maximum Optimization of Energy System

The wider the optimization area, the more the optimization, from a house, community, a power system, interconnected power system in Japan and to the world.

However, there exist:

1) Technological constraints: distribution system, transmission system, an interconnection between power systems

2) Institutional constraints: codes for integration, transmission system rules, interconnection and operation rules

3) Security constraints: centralized control of millions of demands affects stability of energy system and security of each demand. Safety structure require some constraints on optimization.

Due to the constraints and other specific purposes, there are possibilities of distributed energy managements, in a cluster of demands, such as a house, a community, a group of EVs and others.

Energy can be distributed not only by electricity, but also by thermal energy, fuels and others.

We need to return to the essentials what we need is not energy itself but services such as comfortable temperature, humidity, brightness, and motions.

Integration of Energy System

The Energy system integration is essential for the structural change of energy in developed and emerging countries.

The drivers:

1)Socio economic condition such as population and economic development

2)Recognition of constraints of natural resources and environment

3)Recognition of economy, stability, security and sustainability

4)Various technologies of supply, deliver, end use

Important viewpoints :

1)Combination with new values

Ex.: EV navigation +Charging Service +Harmonization w/ Power system

Generation forecast + Weather forecast + Power System operation

2) Investment on New Energy Infrastructures

Ex.: Gen. Plants, Transmission and Distribution, pipe lines of gas and heat

3) Investment on existing energy infrastructure for new requirements

4) New products

5) Standards and institutional systems

Strategies for Energy system integration

- Visioning a long-term evolution of markets
  - ✓ To incorporate substantial changes such as values, lifestyle, and social system
    →Lowering carbon, energy saving
  - ✓ To incorporate innovation of technology (including sectors where company itself is not a leader)
    →Cost reduction of renewable energy and energy storage technologies
  - ✓ To assume situations in several future years
    →ex. CO_2 emission target of Japan and others in 2020, 2030, and 2050
- Identify key technologies that drive competitiveness in a future market
  - ✓ To incorporate new evaluation indicators and ways of thinking
    →New value in supply/demand adjustment relating to changes in output of renewable energy and in energy storage
  - ✓ Not to adhere to things that are highly dependent upon today's markets, systems, etc.
    →Possible change of energy prices, taxes, standards and criteria
  - ✓ To identify Progress in a long-term and uncertain market
    → ICT, energy storage, energy management, and generation forecasts
- Formulating plans of business, investment and technology development plans
  - Progressive redeployment of assets for manufacturing equipment
    →Policies for energy mix, energy networks, operating methods, and IT
  - ✓ Distribution of resources and personnel development based on long-term perspective
    →Technology development, human capacity development
  - ✓ Ensure robustness versus long-term uncertainty

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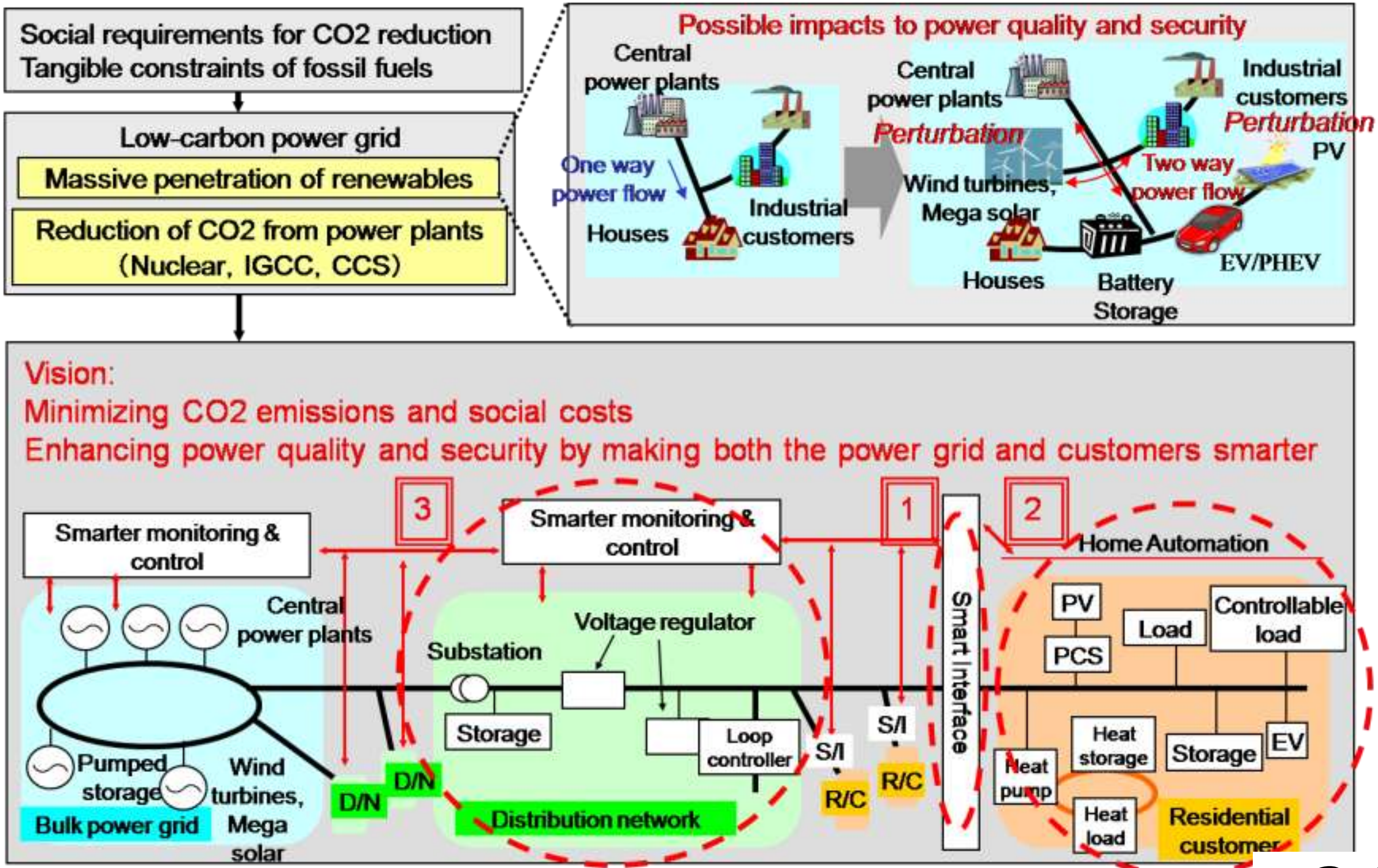
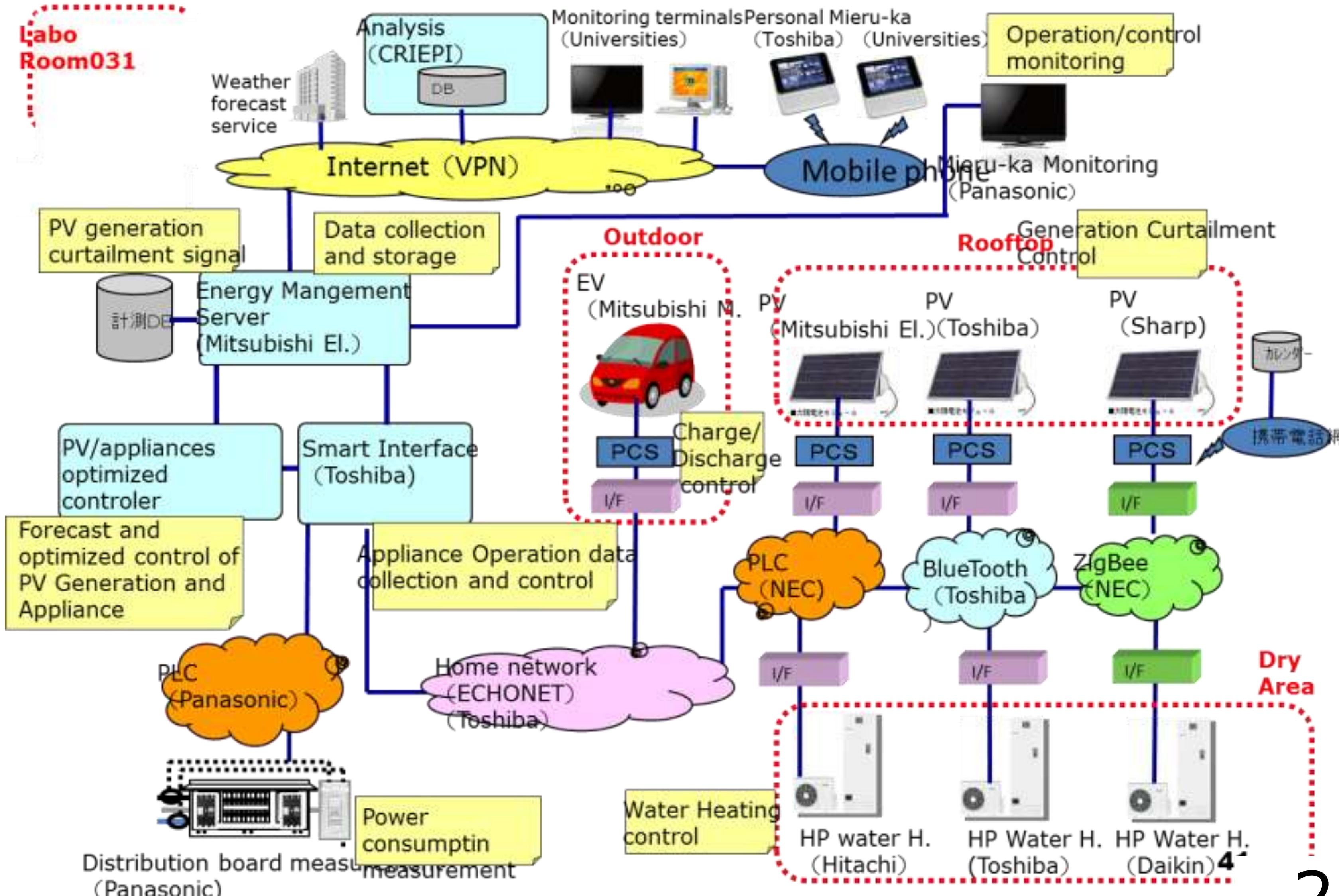
Smart Grid Demonstration Test by Power Utilities (2010 – 2012)

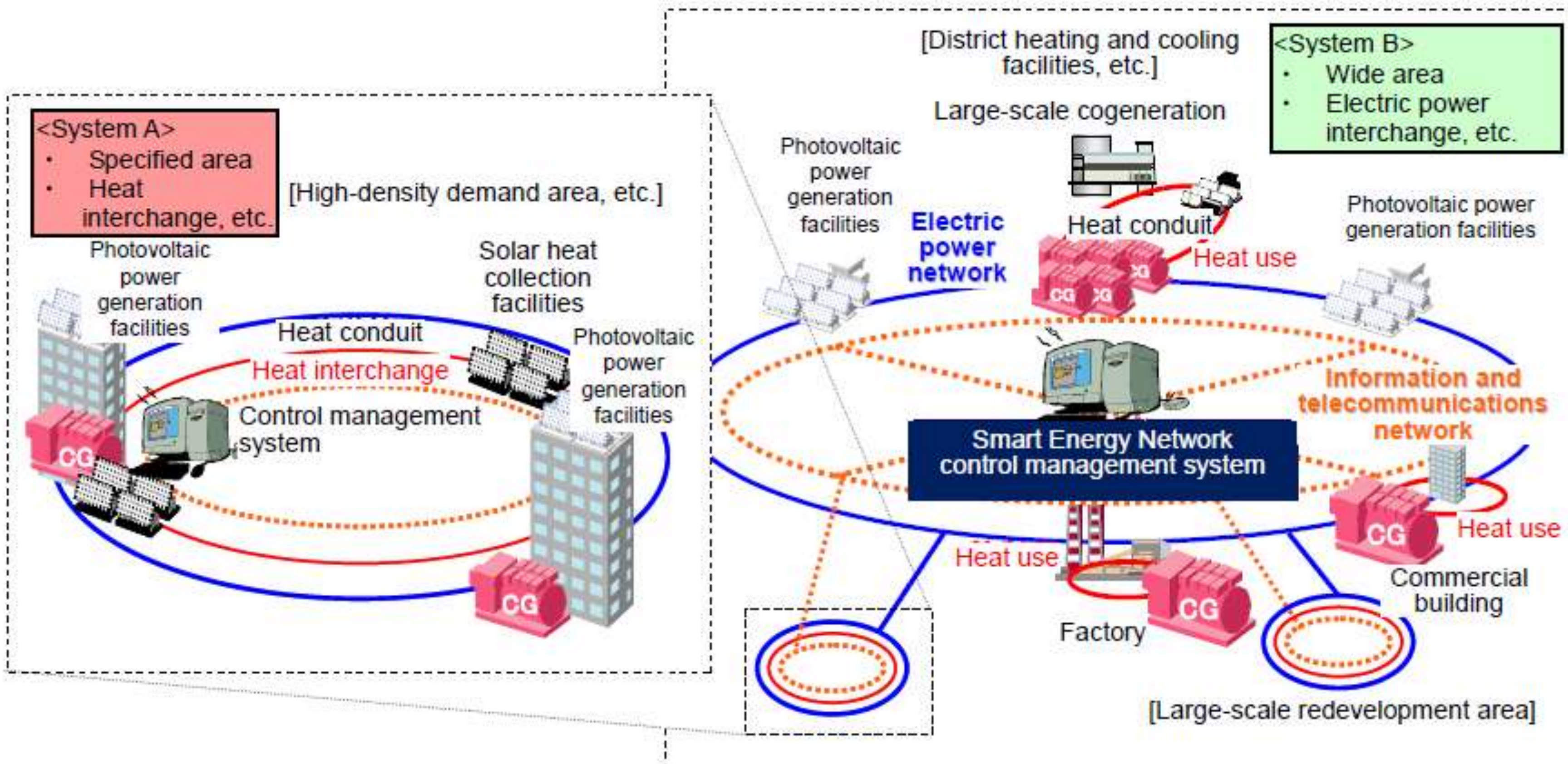


METI's Smart Grid Demonstration Test (2010-2012) House Details



Smart Energy Network Demonstration Project by Gas utilities (2010 –)

Optimum distributed energy management of cogeneration and PV for the best use of power and heat utilizing ICT technologies



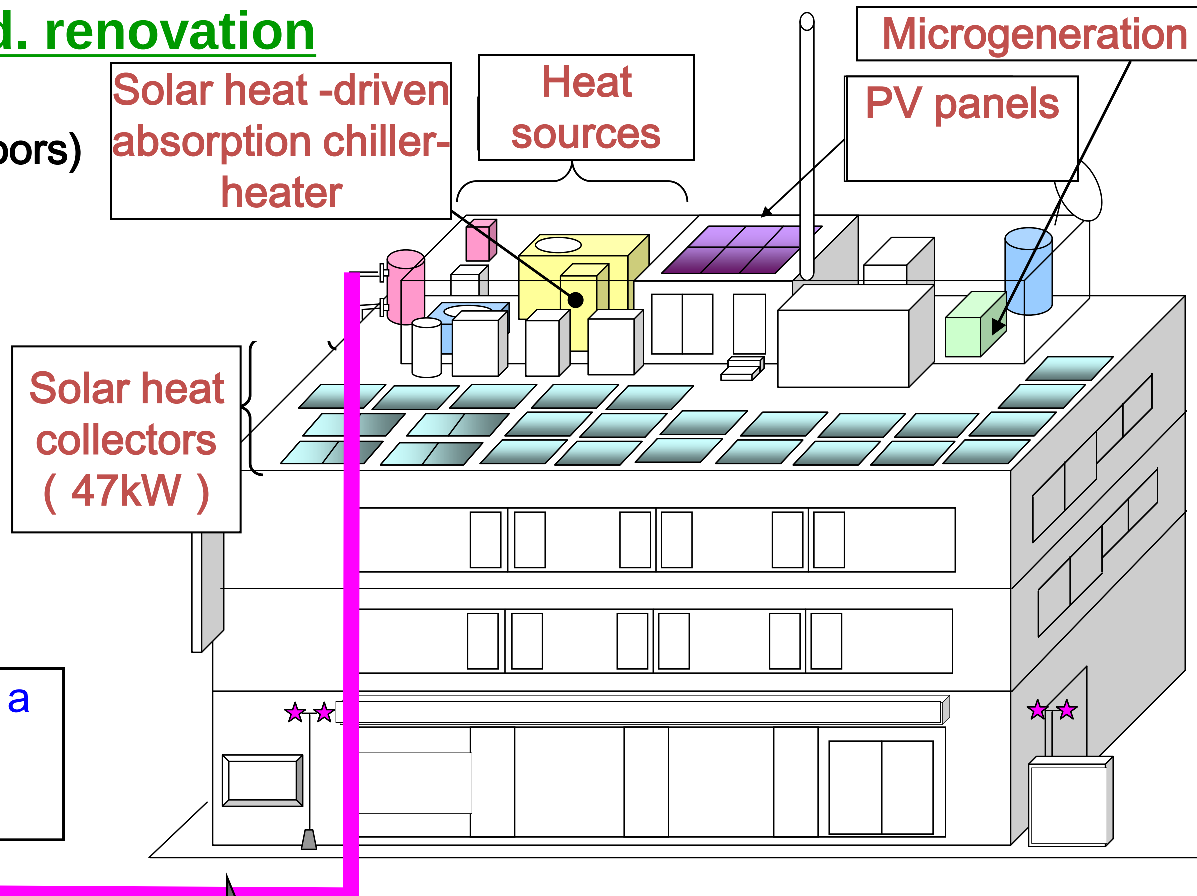
CG: Cogeneration

Demonstration of Solar Cooling and Hot Water Supply System in Japan

●Tokyo Gas Kumagaya bld. renovation

Built:1984

Floor area: Approx. 1,400 m² (3floors)



Supplying Solar heated water to a neighboring hotel
Pumping power is from PVs

- •Utilize solar heat for cooling, heating and hot water supply
- •Replacement of old equipment

32% Primary energy reduction

29% CO_2 reduction

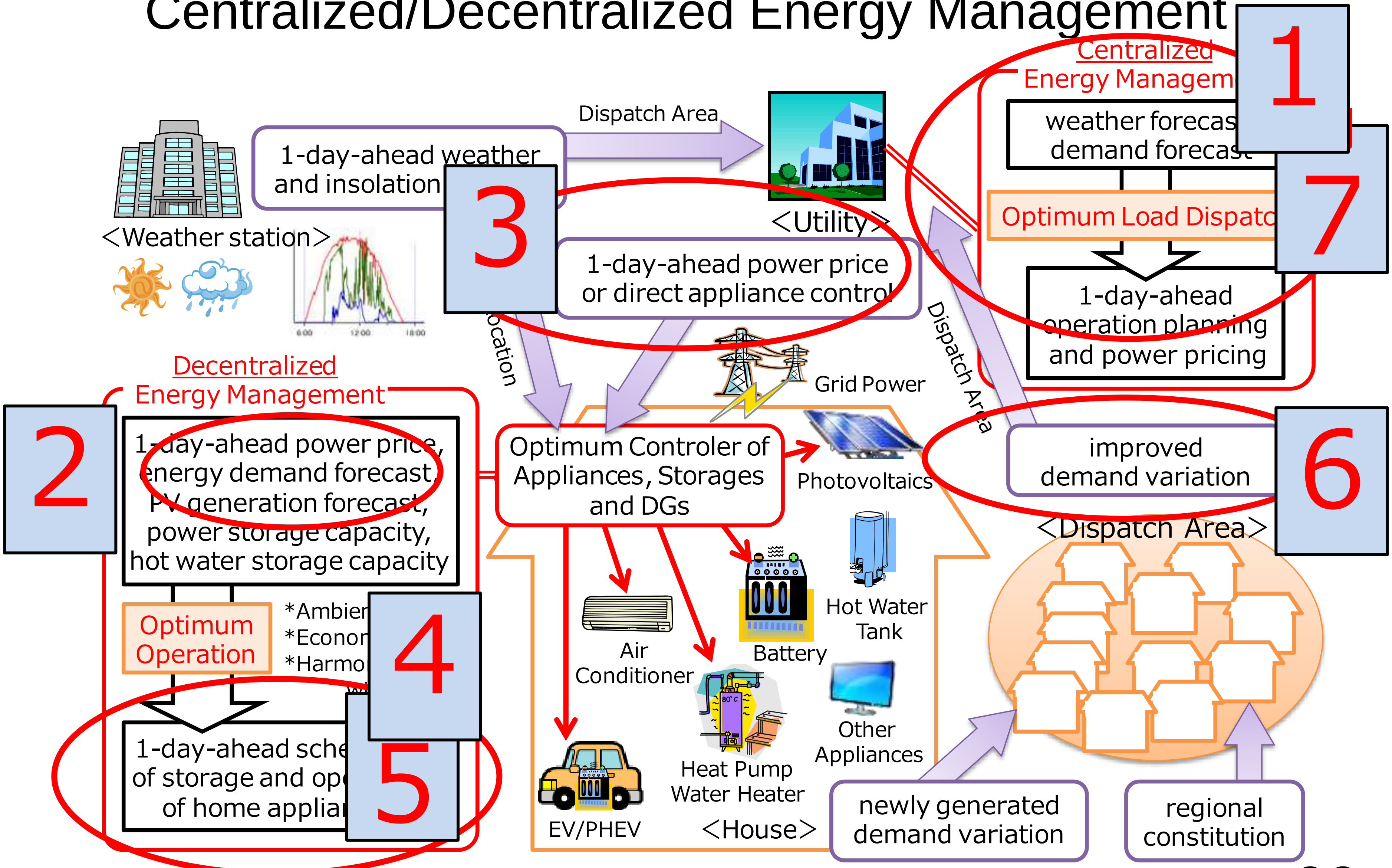
Our Researches

January, 2011

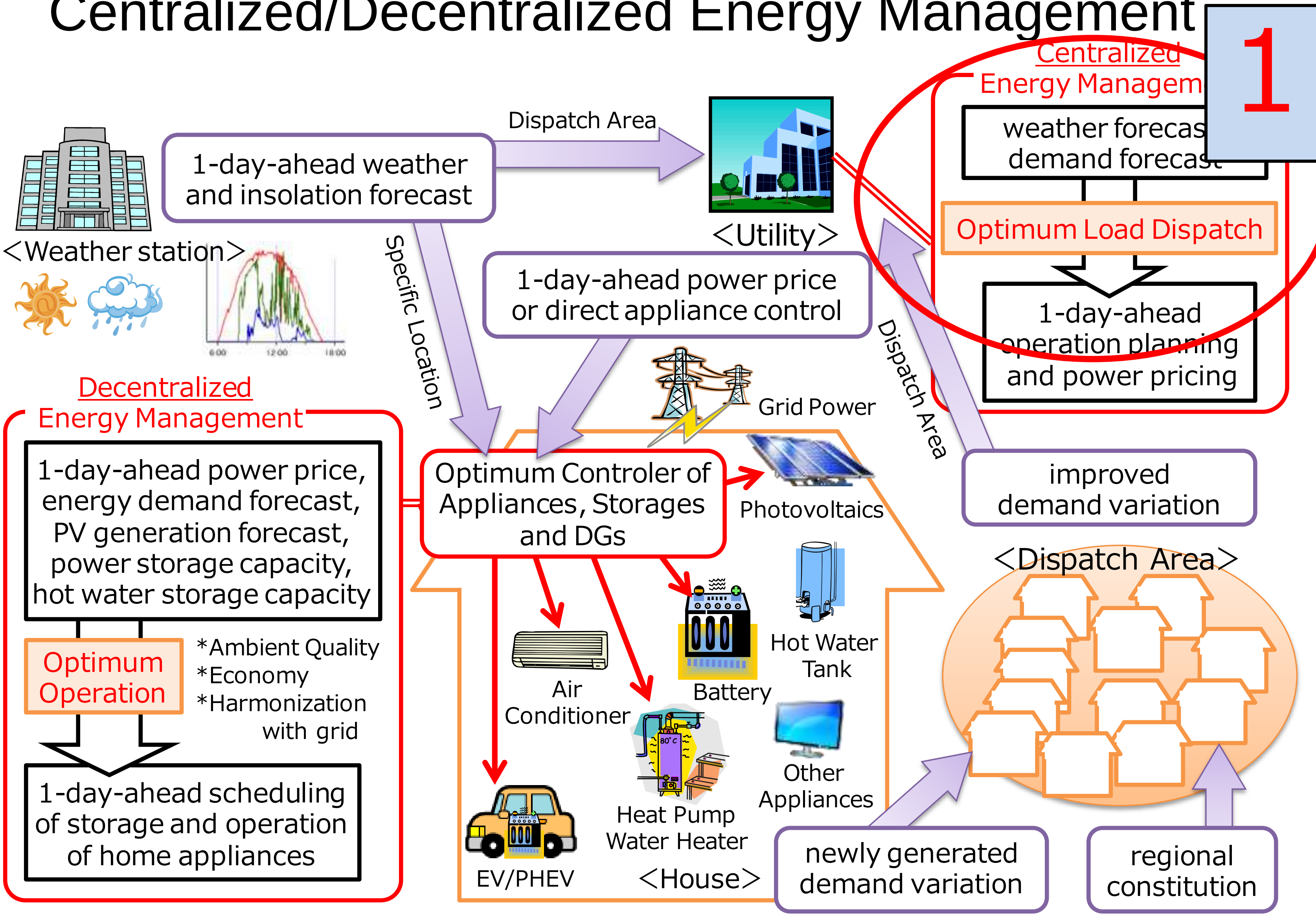
Ogimoto Lab, Iwafune Lab

Energy Engineering Collaborative Research Center (CEE)
Institute of Industrial Science
The University of Tokyo

Renewable Energy Deployment and Centralized/Decentralized Energy Management



Renewable Energy Deployment and Centralized/Decentralized Energy Management



Long Term Load Forecast: Background and Objectives

1

- Change of Demand
  - Energy efficiency Technology
  - New demand technology (Heat pump Water Heater, PHEV/EV)
  - Energy storage technology(Batteries, Hot water tank)

- Penetration of renewable energy
  - Load fluctuation by demand side variable generation
  - Variation of PV and Wind generation

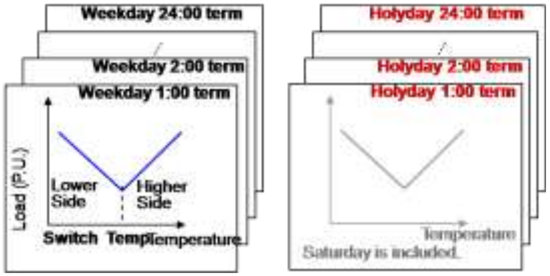
- Fossil fuel distributed generation
  - Gas engine generation, Fuel cell
  - 熱主電従運転

Requirement for load curb for long term demand-supply balance analysis and planning

福留、東、荻本、岩船：将来における電力需要曲線の想定手法, 電気学会全国大会6-161

Long term load forecast : Methodology

(1)Atmospheric temperature-load model



- Identification of weekday/holiday hourly temperature-load coefficients.
- A shape of the monthly load curbs are estimated.
- The monthly load curbs are adjusted according to experienced monthly peak loads and productions.
- The absolute value of the monthly load curbs are adjusted to the estimated annual peak load and energy production.

(2)New demand technology model (for heat pump water heater, PHEV/EV and battery)

- Estimation of deployment schedule in a power system
- Estimation of hourly kW and kWh by estimation of utilization

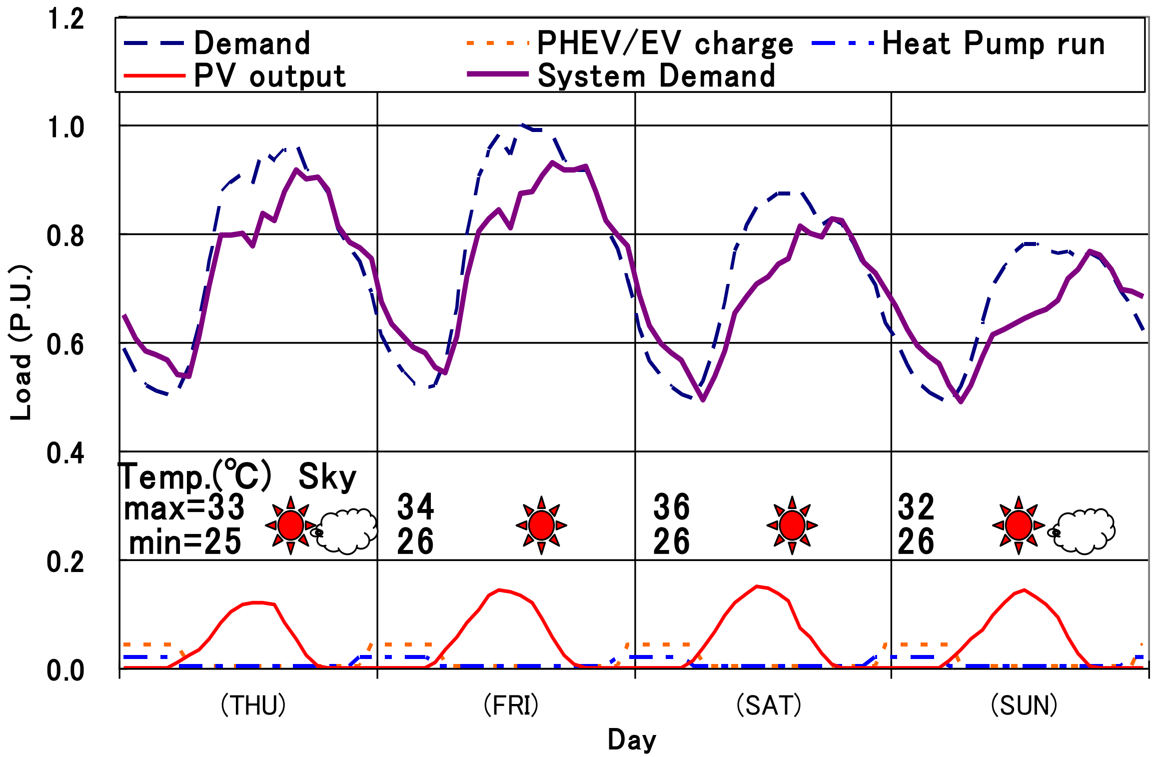
(3)PV model

- Estimation of deployment schedule in a power system
- Hourly generation of 8760 hours is estimated according to actual data of irradiation, atmospheric temperature and wind speed

福留、東、荻本、岩船：将来における電力需要曲線の想定手法, 電気学会全国大会6-161

Long term load forecast: Results

- In 2030
  – With the 5% of HPWH, 2.5% of PHEV/EV, 20% of PV (percentage of the maximum load)

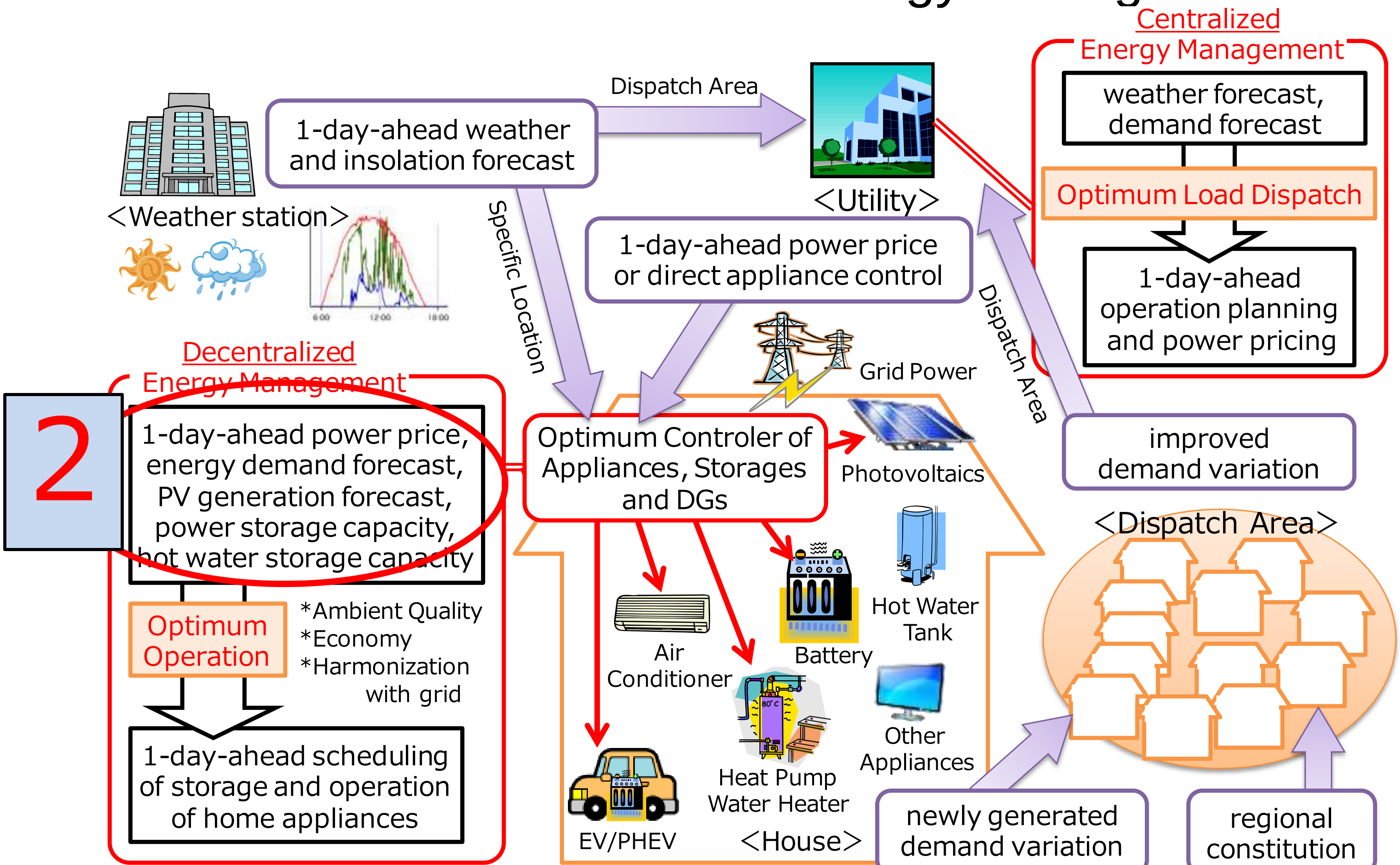


Night : bottom-up
Daytime : peak reduction
Daily peak: shifted to evening

福留、東、荻本、岩船：将来における電力需要曲線の想定手法, 電気学会全国大会6-161

Centralized/distributed Energy Management

Renewable Energy Deployment and Centralized/Decentralized Energy Management



Home demand Measurement, Analysis, forecast : Configuration

2

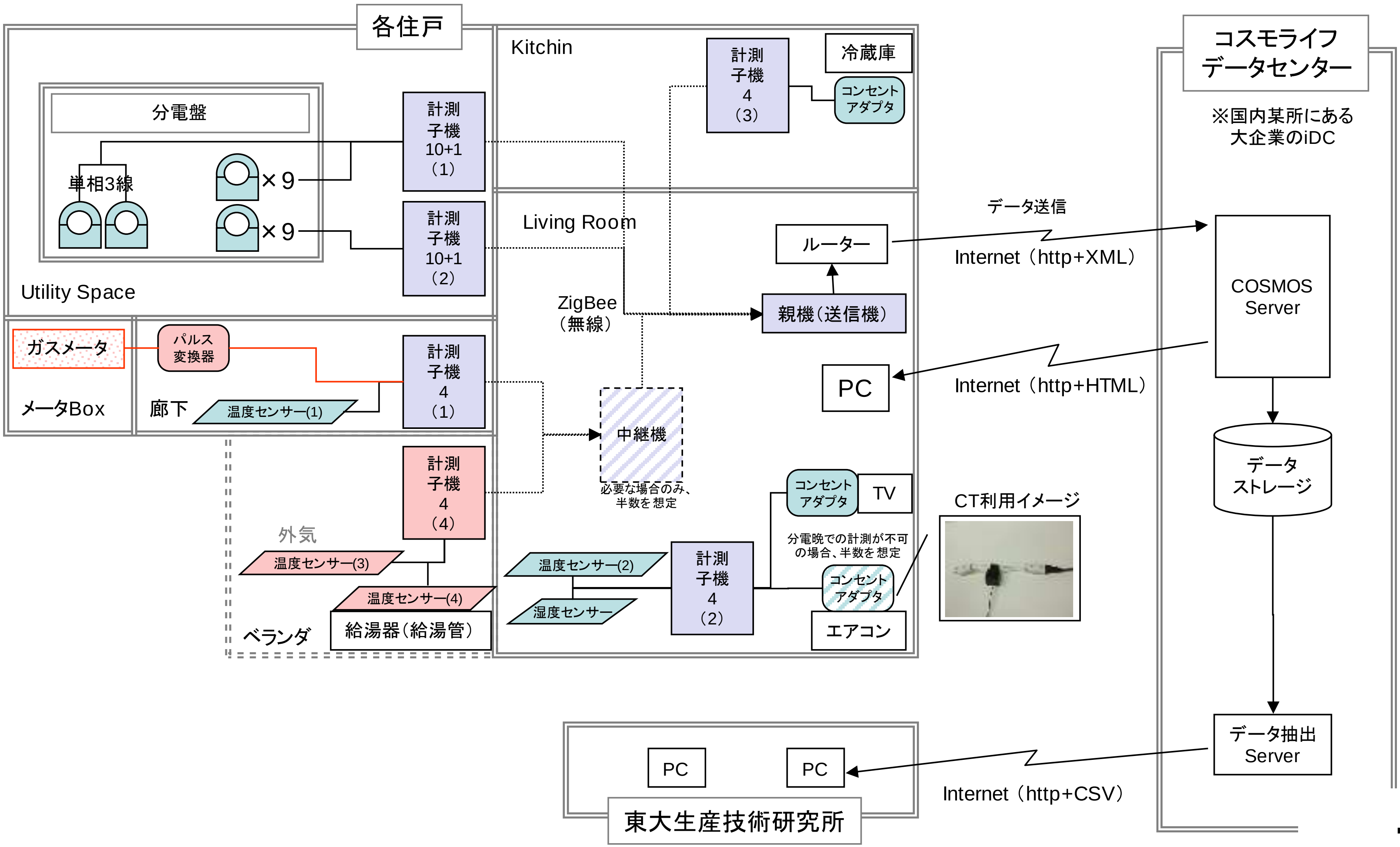
- For distributed energy management for a building, it is necessary to forecast the energy demand of the building.
- Monitoring is also effective to find energy use with little actual benefit. Energy efficiency diagnosis can be made effectively using the monitoring data.
- We are doing the following energy use data collection with 50 homes.

Homes Around 40 apartment houses and some detached houses which are located 30 km form the heart of Tokyo.

Features of the apartment houses
Space :around100m2
Habitants :1-5
Appliances : gas water heater, gas floor heater, gas oven, heat-pump air conditioner, disposer

Monitoring points : current of power distribution board by circuit, water heater current, room temperature and moisture (by minute) and gas consumption (by 5 minutes)

Home demand Measurement, Analysis, forecast : Configuration



Home demand Measurement, Analysis, forecast : Clustering of load

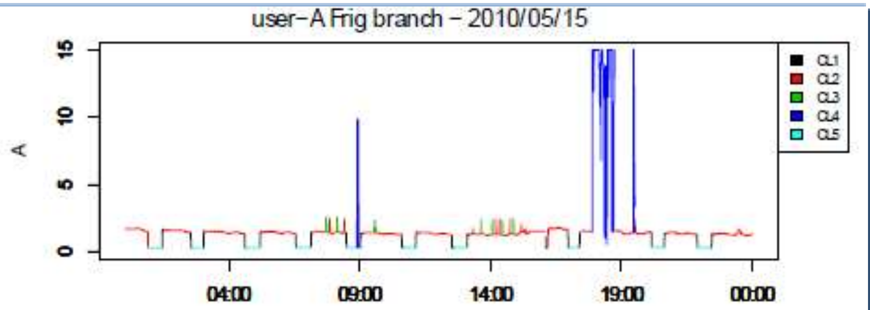


図 3　世帯 A における冷蔵庫回路電流クラスタ分解結果

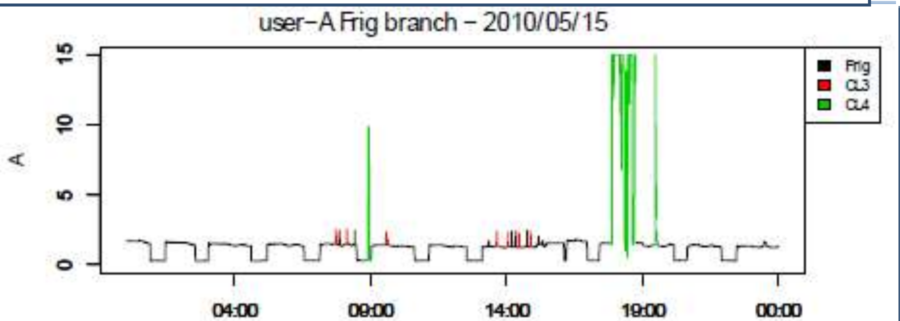


図 5　世帯 A における冷蔵庫回路電流クラスタ統合結果

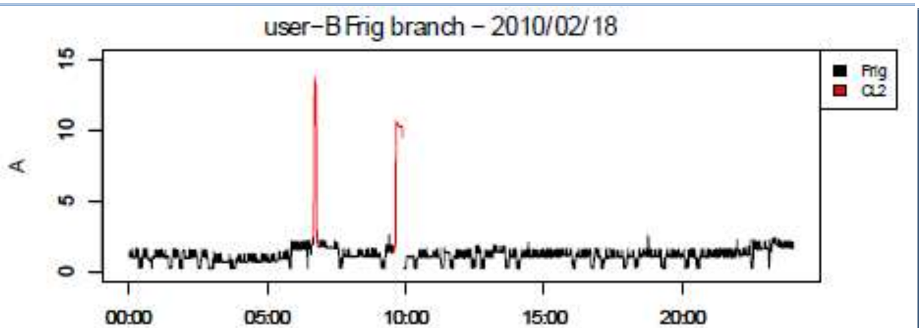


図 6　世帯 B における冷蔵庫回路電流クラスタ統合結果

In the circuits of a power distribution board of a house give the basic information of power use is available economically and reliably.

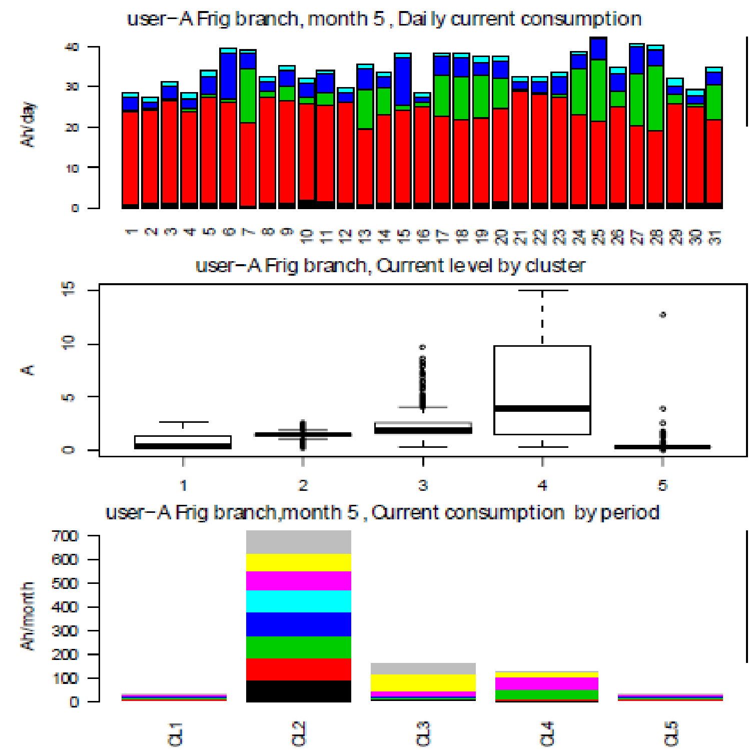
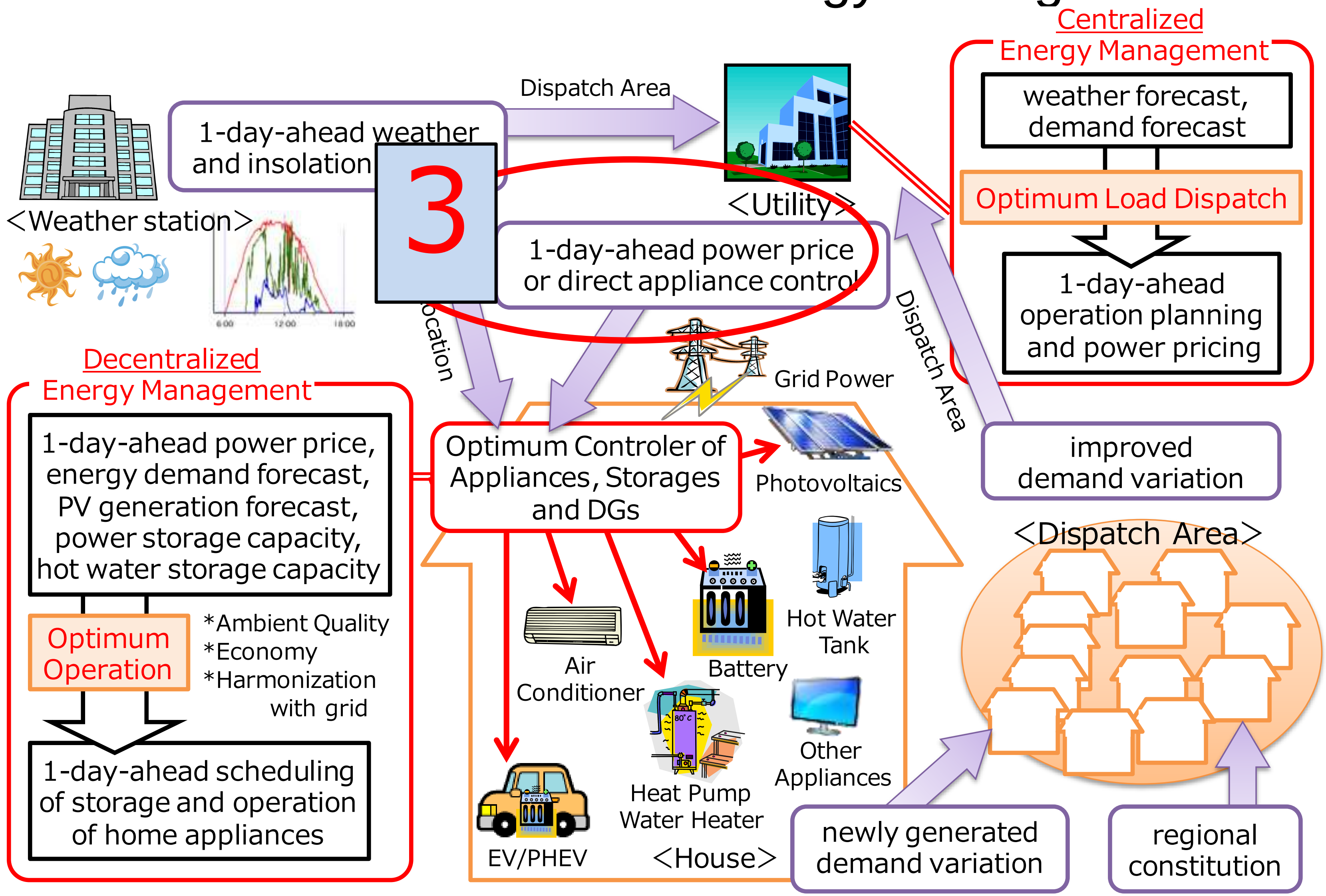


図 4　世帯 A における 2010 年 5 月冷蔵庫回路電

岩船由美子,八木田克英,荻本和彦:自己組織化マップを用いた住宅用分電盤データの用途別推計,エネルギー資源学会第28回研究発表会,,2

Renewable Energy Deployment and Centralized/Decentralized Energy Management

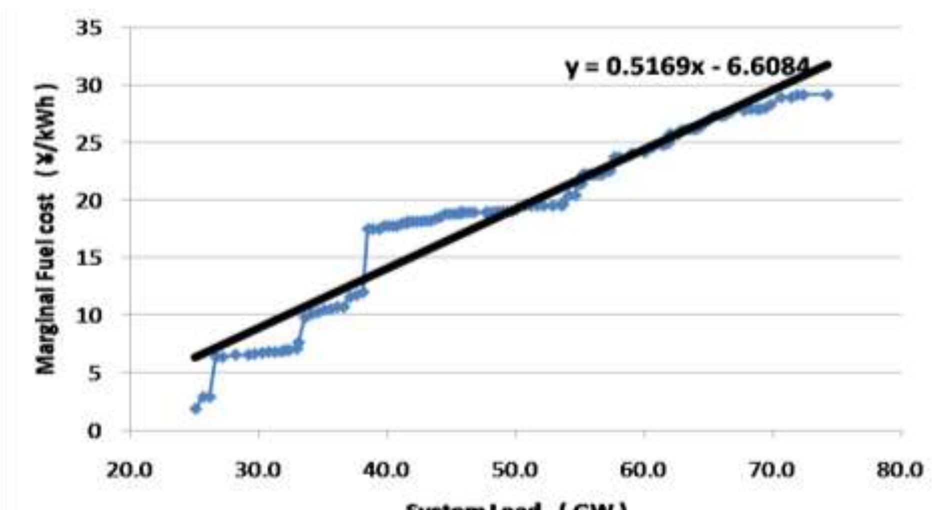


The change of system marginal production cost under PV penetration: System cost profile

✓With an assumption of fuel prices, marginal production cost profile of a power system is calculated and lined up based on technical features of each generating unit including a pumped storage unit.

✓In our study, we used the fuel prices of 169＄/bbl. for oil, 1482＄/ton for LNG and 182＄/ton for coal.

✓The production cost of a pumped storage unit is calculated assuming thermal or nuclear generation which supply pumping energy with an assumption of pumping efficiency and transmission loss.



3

荻本,片岡,池上:太陽光発電大量導入の電力系統の運用コストに与える影響試算, エネ資コン17-4, (2010)

The change of system marginal production cost under PV penetration　: Assumption of system load

✓The future power demand is estimated through 需要は、過去の需要の気温との相関モデルを用い、1998年の気温データから推定した。

✓PVの発電量は、1998年の気象データ（日射量, 気温, 風速など）から想定した。

✓新規需要としては、ヒートポンプ、PHEV/EVの需要を、導入台数と深夜割引料金の想定の元、1台あたり運転/充電電力量から、系統全体の量を算定。

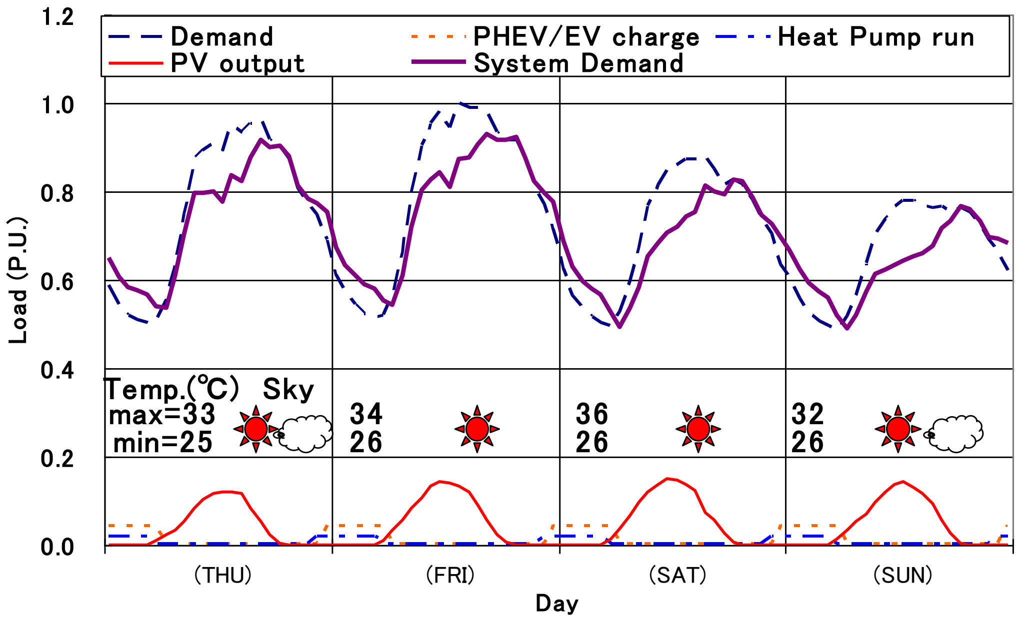


Image of an Equivalent System Load

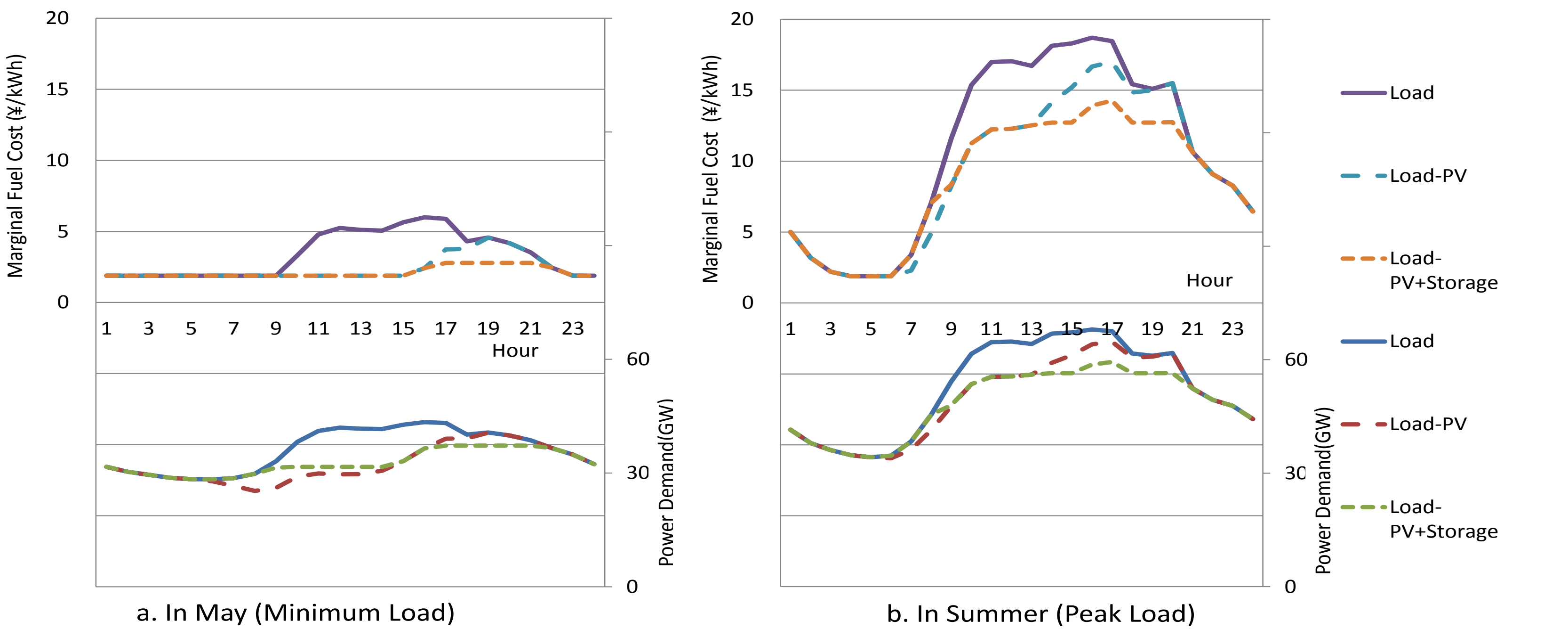
荻本,片岡,池上:太陽光発電大量導入の電力系統の運用コストに与える影響試算, エネ資コン17-4, (2010)

The change of system marginal production cost under PV penetration (in May and in August)

✓The figures show system loads of three cases (Original load, equivalent load with PV, equivalent load with PV and battery) and corresponding system marginal production costs for two seasons with minimum and maximum loads.

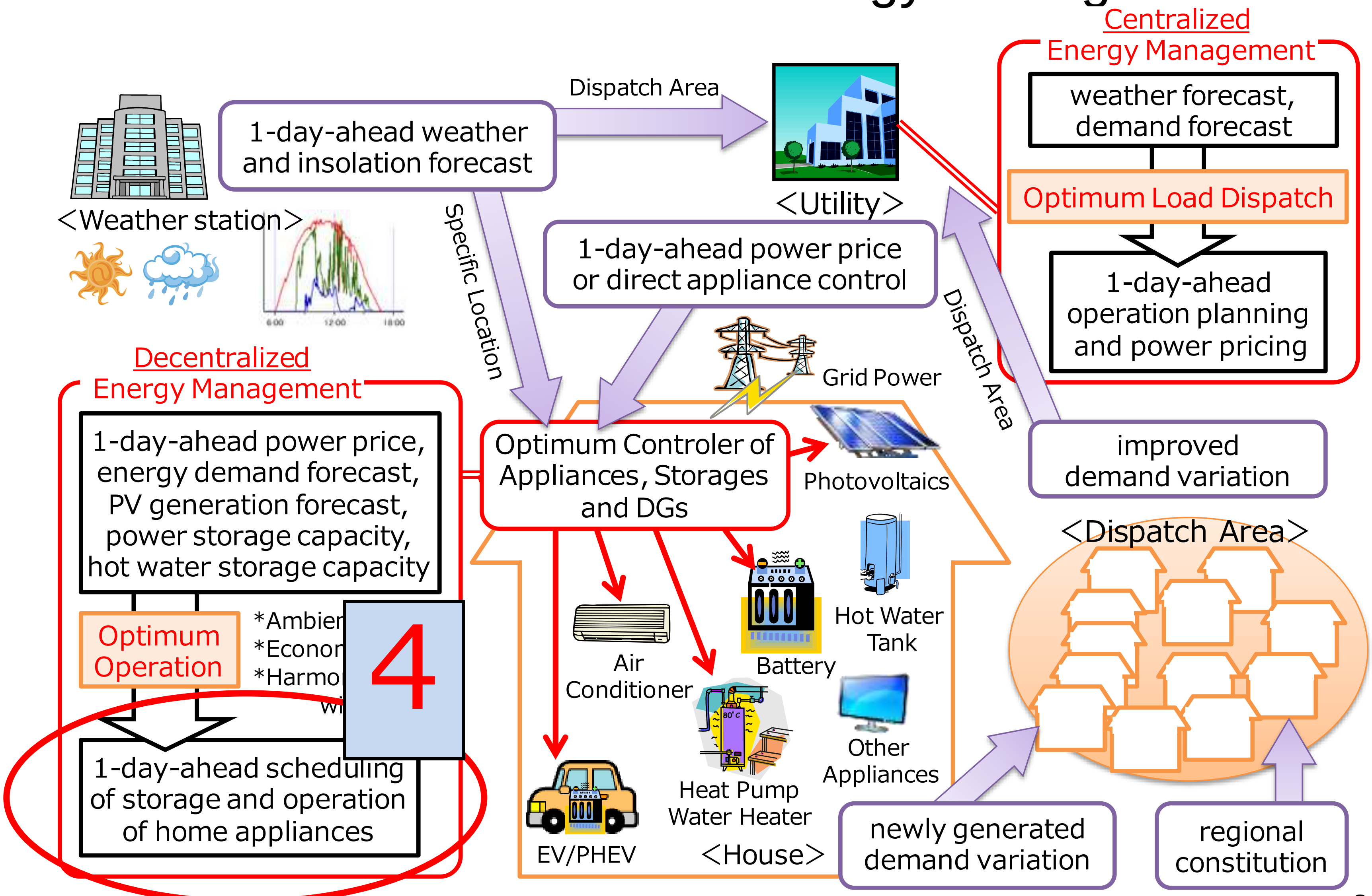
✓In the cases, 15GW PV are assumed in a power system of 60GW peak load.

✓With PV penetration, the peak of an equivalent system load moves from the daytime to the evening. The peak load in the evening is reduced with storage.



荻本,片岡,池上:太陽光発電大量導入の電力系統の運用コストに与える影響試算, エネ資コン17-4, (2010)

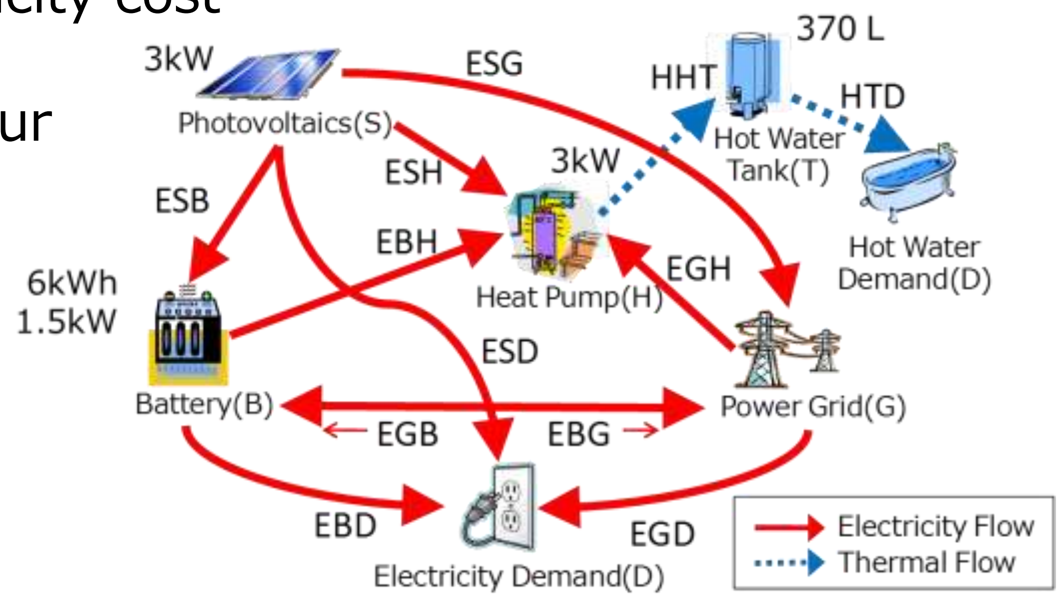
Renewable Energy Deployment and Centralized/Decentralized Energy Management



HEMS Optimum Op.: Assumption

4

- Mixed Integer Linear Programming (MILP)
  - minimize the home electricity cost
  - Time resolution of one hour
  - Target period of 2weeks
    1-14 May 2003 (Spring)
    1-14 Aug 2003 (Summer)
    1-14 Jan 2004 (Winter)



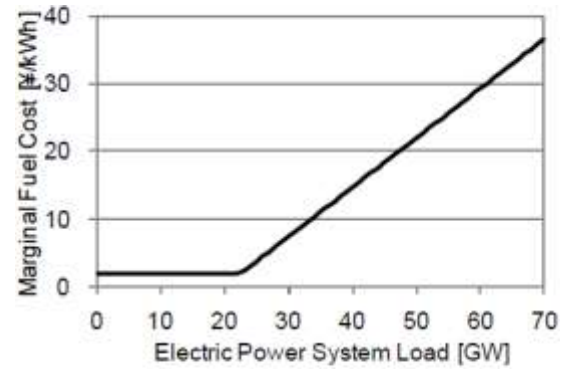
- Input data
  power demand, hot water demand, PV generation, air temp., feed-water temp., electricity prices, and performance data of appliances
- Output data
  electricity flow and thermal flow
  ⇒ operation time of Heat Pump Water Heater (HPWH)
  ⇒ charging or discharging time of Battery

HEMS Optimum Op.: Power Rate

- Current static rate "CP"

buying night (23-7 o'clock): 9.17yen/kWh
morning and evening (7-10, 17-23): 23.13yen/kWh
daytime (10-17): 28.28 or 33.37 (summer) yen/kWh

selling 48 yen/kWh



- Future dynamic rate "Vx"

buying by home

"V0" : hourly marginal fuel costs plus the fixed charge 10 yen/kWh

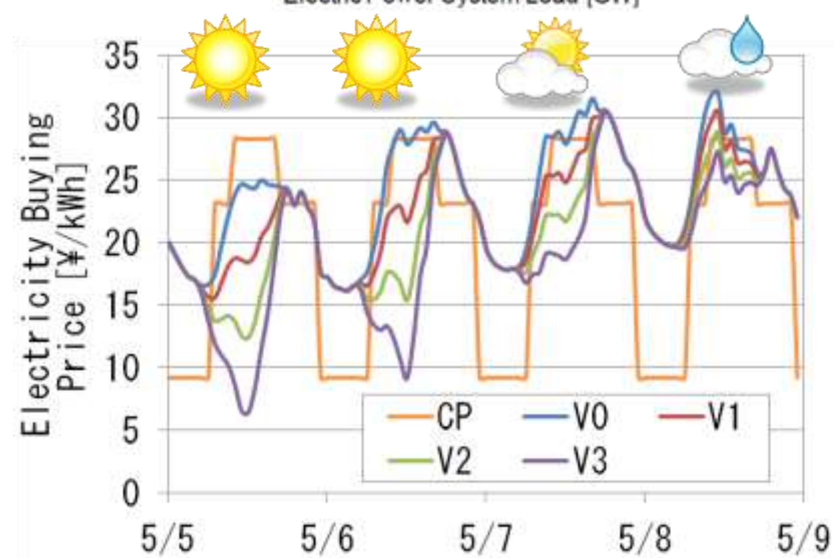
"V1" : hourly marginal fuel costs plus the fixed charge 10 yen/kWh <u>under the large PV penetration</u>

"V2": increasing the differences by 2 times

"V3": increasing the differences by 3 times

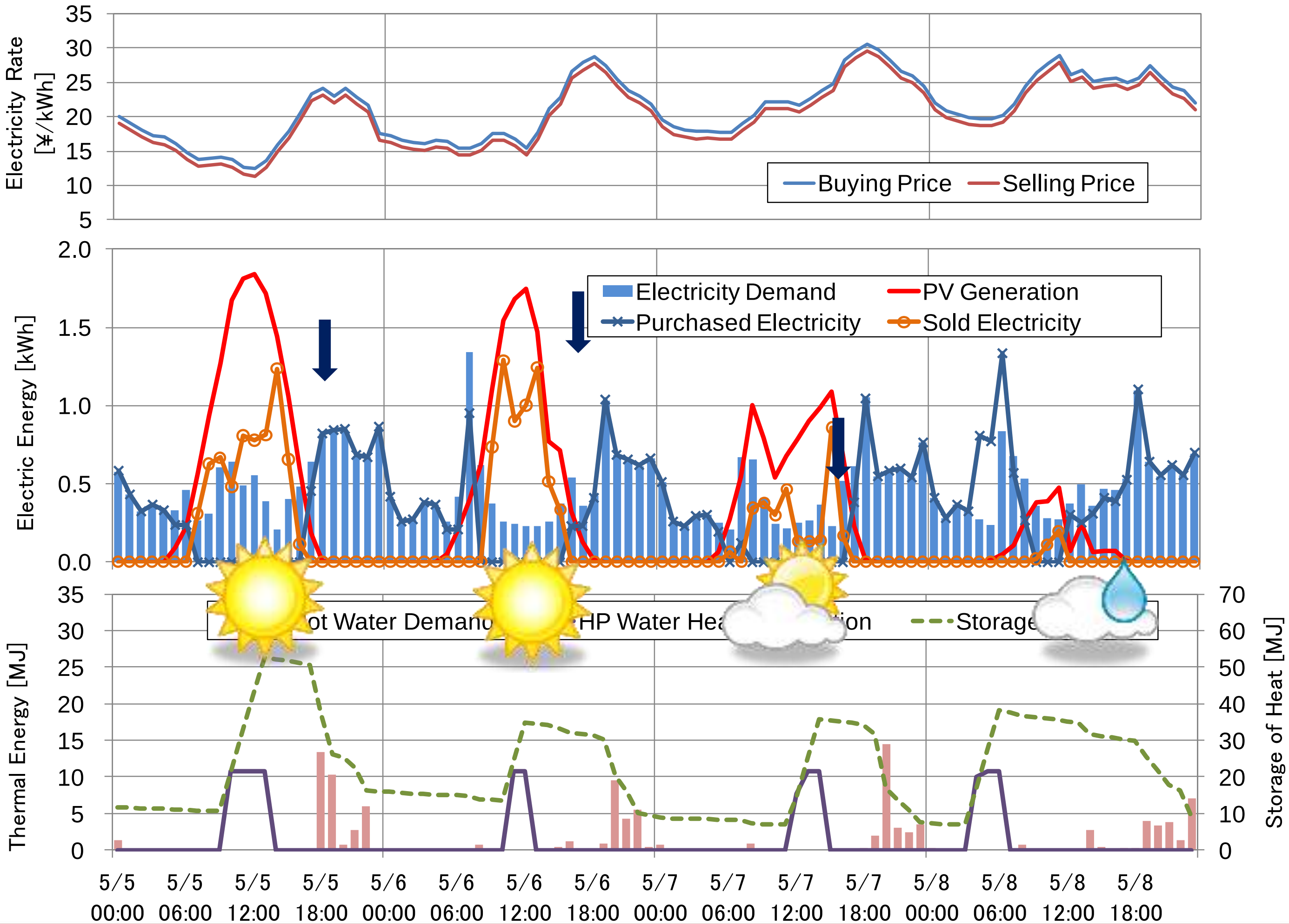
selling

1 yen/kWh below buying prices



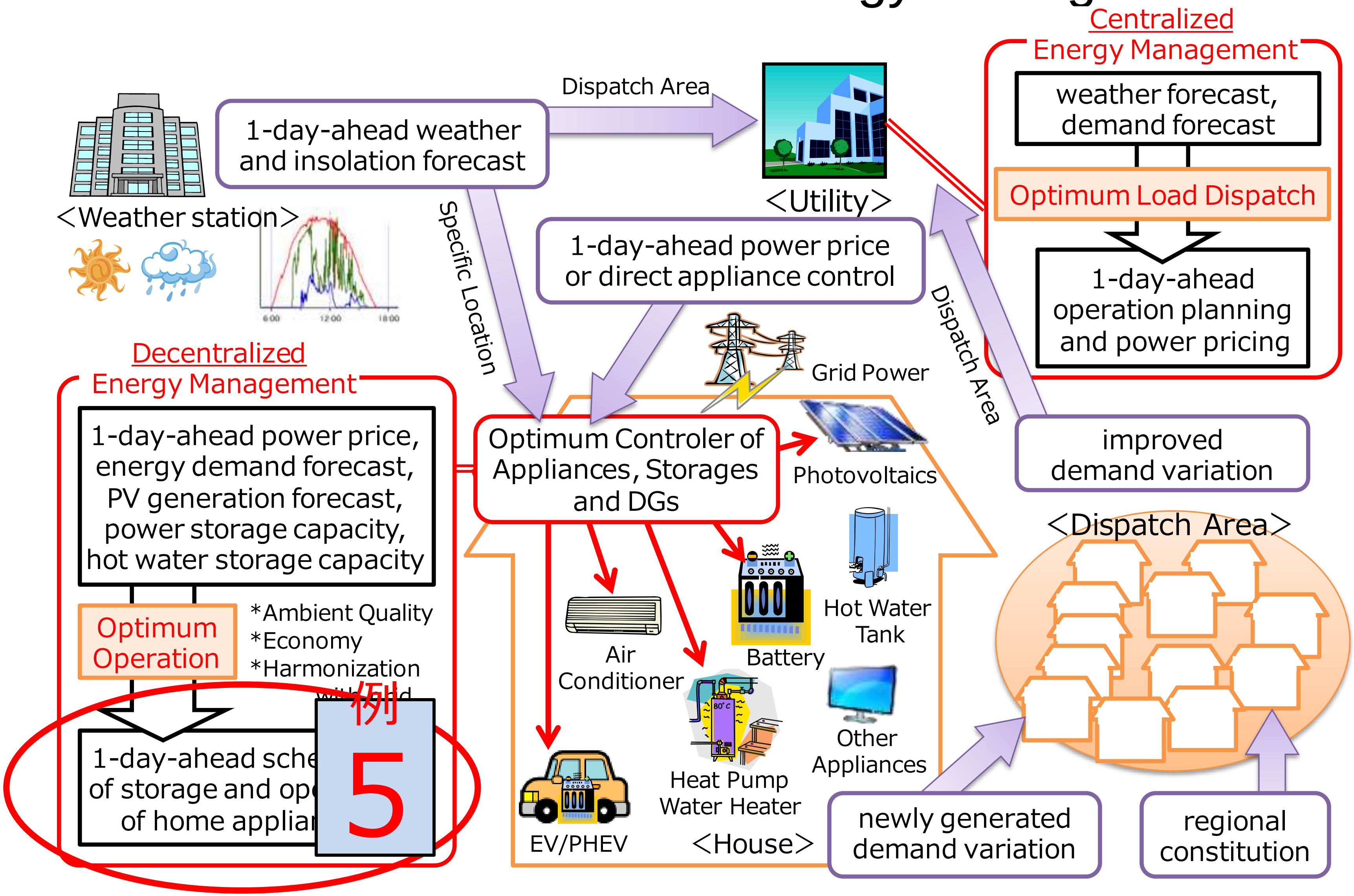
Hems Optimum Op.: Dynamic rate V2

- Optimum operation schedule with price "V2"

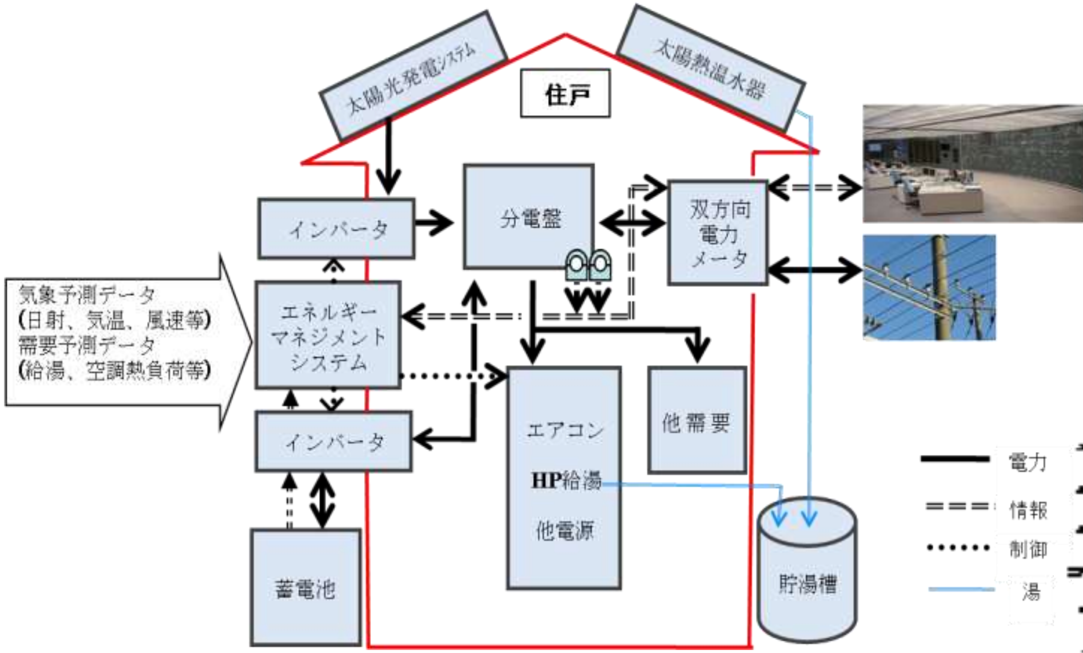


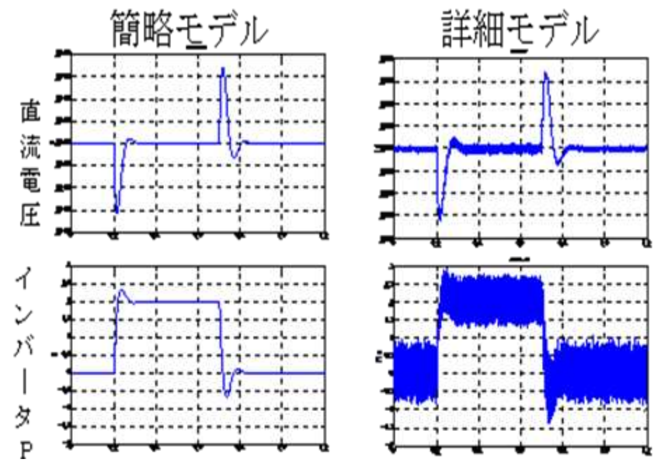
On May 7, COPs of the HPWH were improved significantly by air temperature rising about 5 to 8 degrees Celsius during the daytime.

Renewable Energy Deployment and Centralized/Decentralized Energy Management

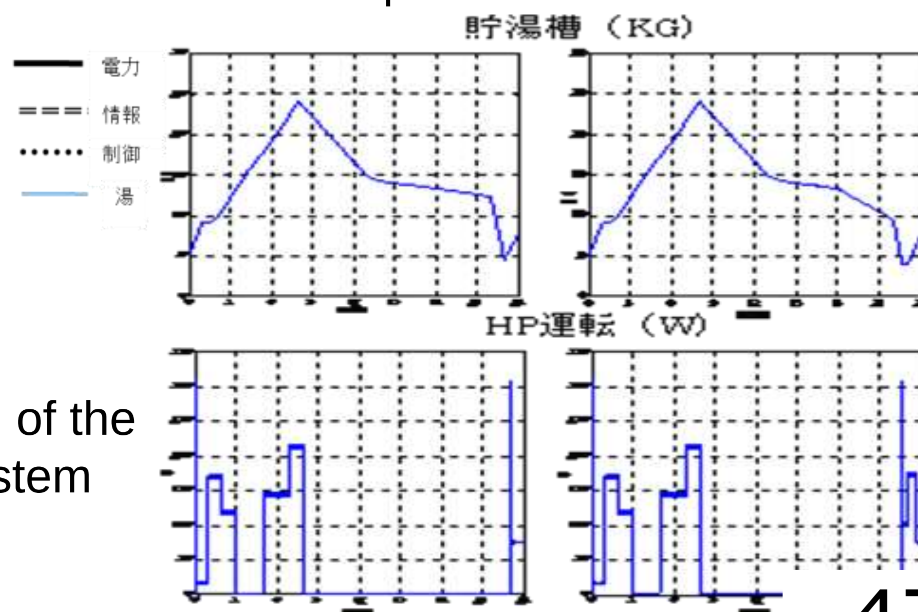


Realization of HEMS Controller Simulator using Matlab





Operation of an inverter



5

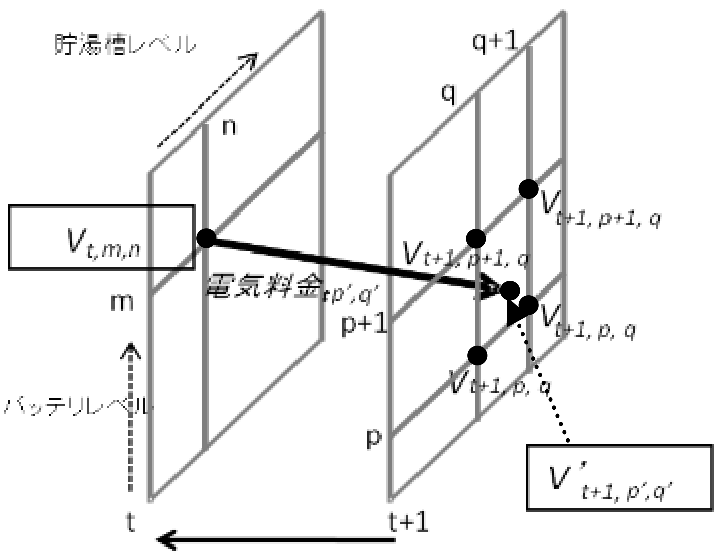
Operation of the total system

Realization of HEMS Controller Learning through Probabilistic DP

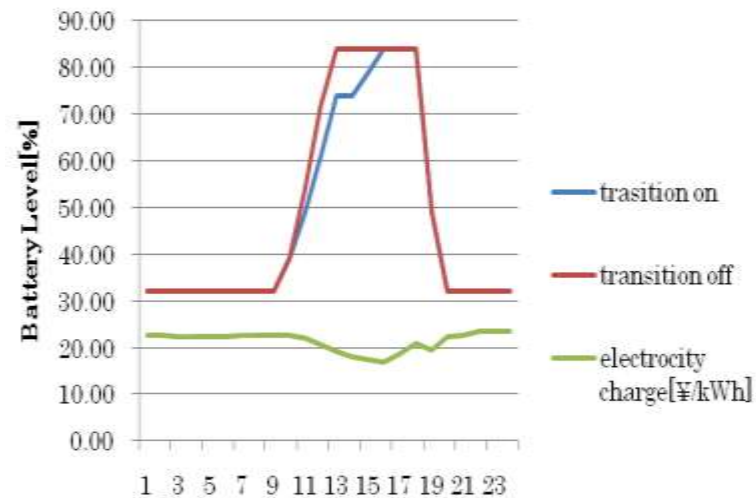
✓HEMS learns the practices of power rate, irradiation, self-demand of power and hot water

✓HEMS operates based on the learning. The frequency of the learning will be decided according to the performance of the control.

✓Irradiation and self-demand of power and hot water are modeled as probabilistic variables.



Probabilistic Dynamic Programing Methodology



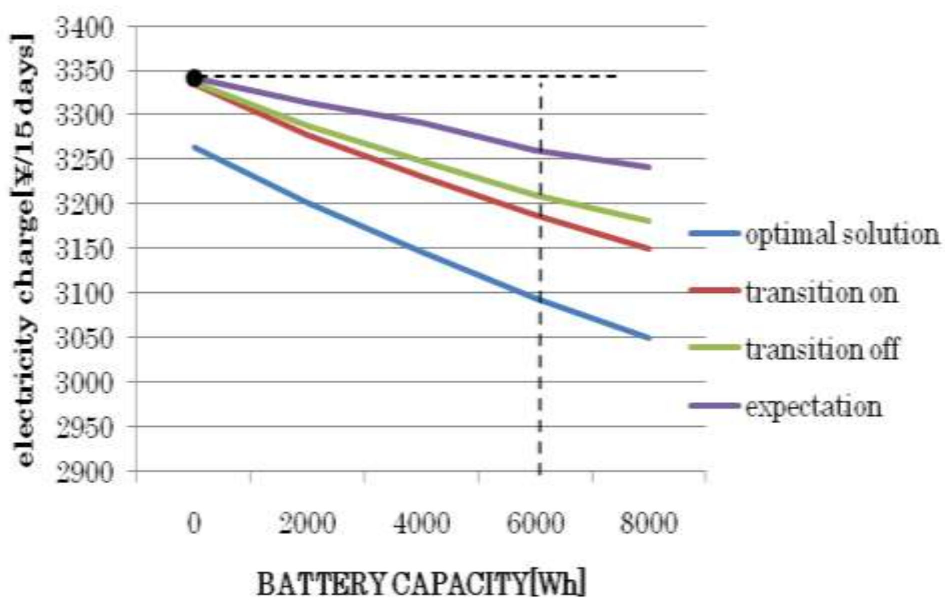
Battery operation with different control strategy

片岡,池上,荻本,土屋:家庭内需要機器の確率的DP法による運用計画, 電学全国大会 (2011)

Realization of HEMS Controller
Performance of the proposed model

✓As the learning method is enhanced, HEMS was successful to reduce the total power cost which got nearer to the level of a perfect knowledge model.

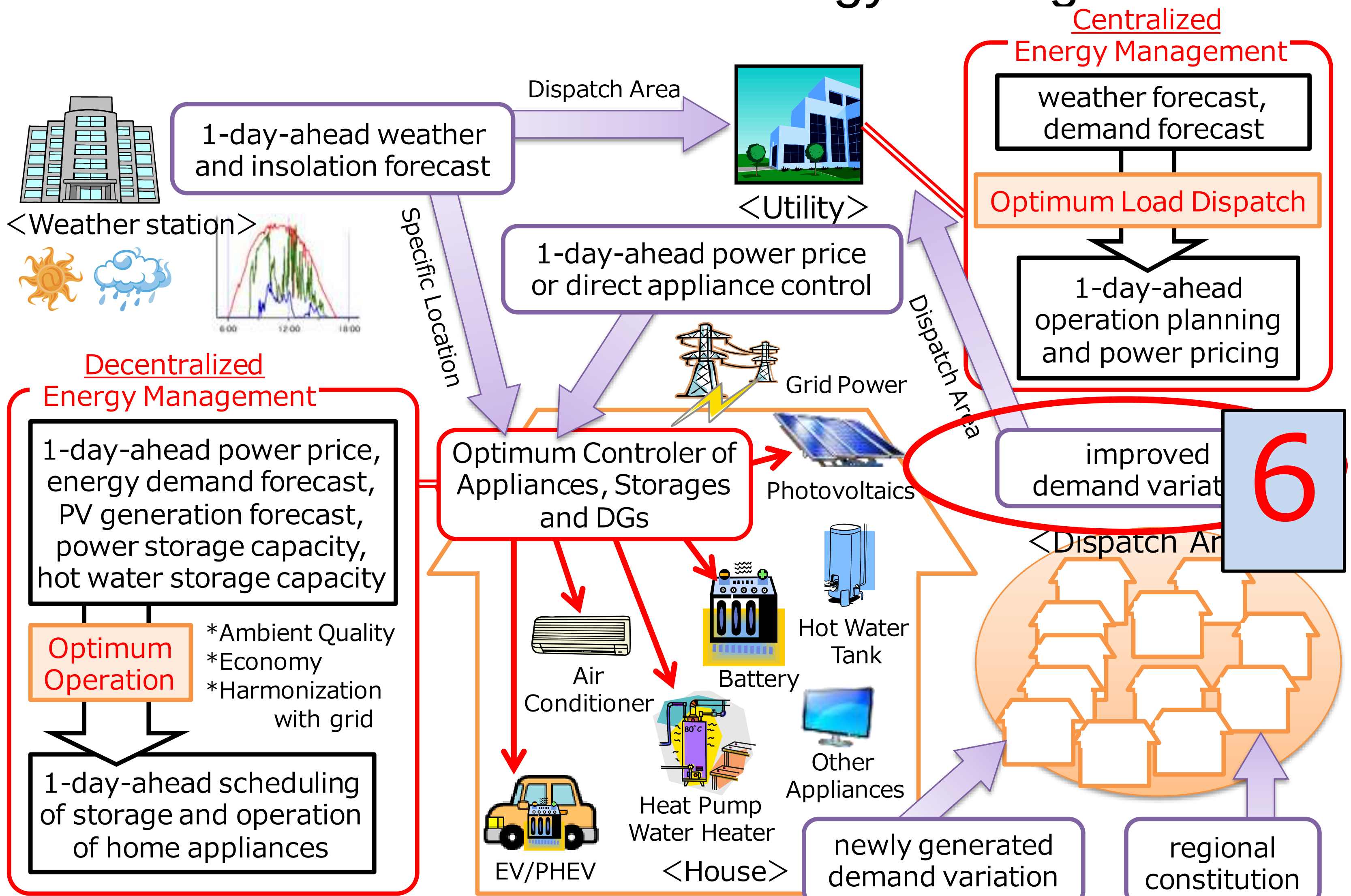
✓Although the learning model is enhanced, the load of learning and the requirement of memory storage increases, we are considering the controller is realistic commercially based on the state of art of current ICT technology.



Power Tariff reduction with different battery capacities and control strategy

片岡,池上,荻本,土屋:家庭内需要機器の確率的DP法による運用計画, IEEJ Annual Meeting (2011)

Renewable Energy Deployment and Centralized/Decentralized Energy Management



System Load Reformation by HEMS: Assumption and total operation

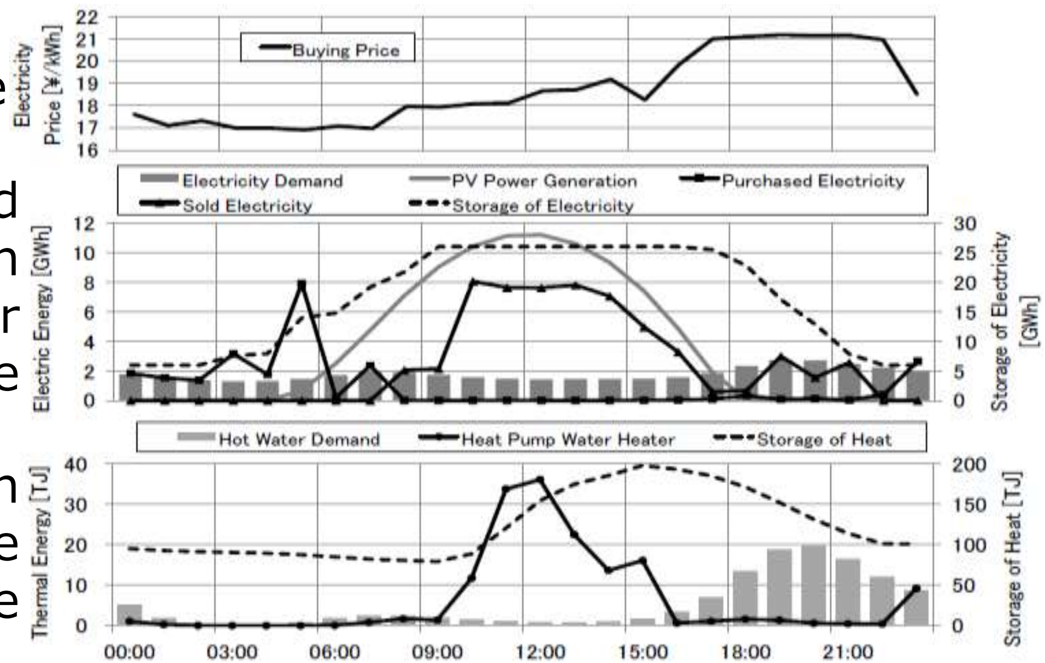
- ✓We assumed HEMS with PVs (average capacity of 3.4 kW), HPWHs (average thermal output of 4kW and hot water storage of 370/200ℓ), batteries (average capacity of 1.5 kW-6kWh) with a certain variation for 50 thousand individual homes.

- ✓Based on the latest rate curb, MILP decided the optimum operation of 50 thousand individual homes and the power demand of 5 million homes were calculated by multiplying 100, assuming 30% penetration of HMES.

Power price

Demand
PV generation
Sell/purchase of power
Charge

HP operation
Heat water storage
Hot water usage



The total power demand of 5 million homes

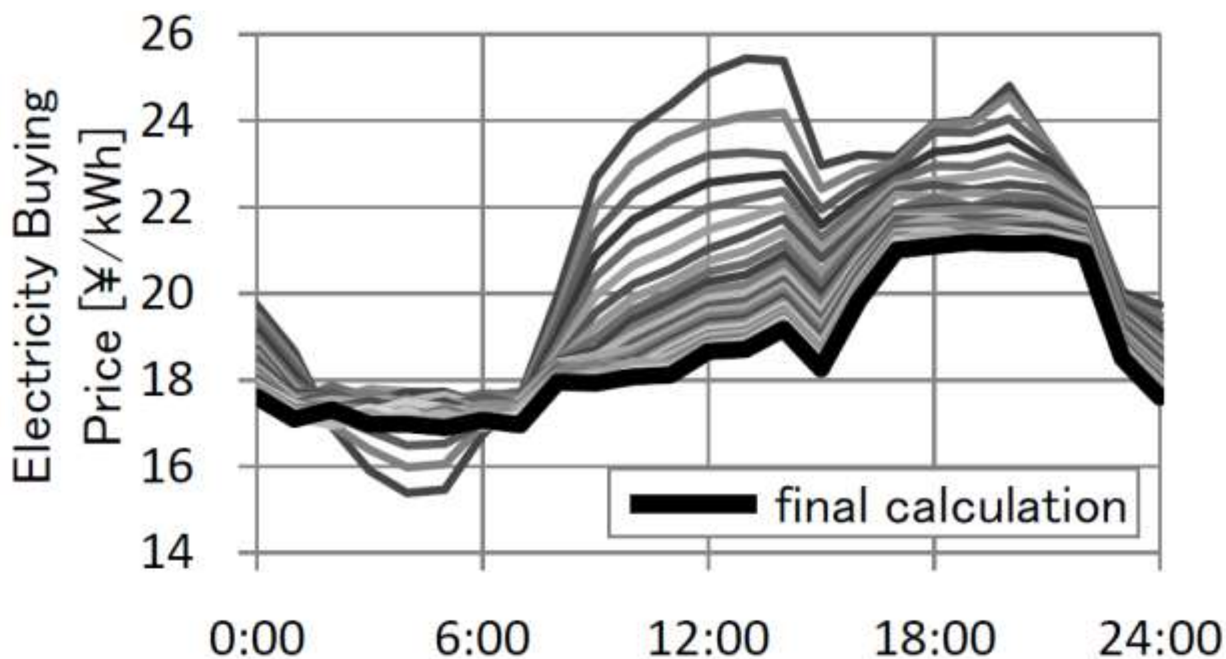
6

池上,片岡,岩船,荻本:家庭内の蓄電池とヒートポンプ給湯機による地域全体の電力需給調整力の評価, 電学全国大会 (2015)

System Load Reformation by HEMS: Change of the dynamic power rate

✓Based on the latest demand optimized by HEMS, the total power system load with an original annual peak 60GW was modified.

✓As the revision of the power system load was modified, the hourly power rate was revised. And the process was iterated 30 times.

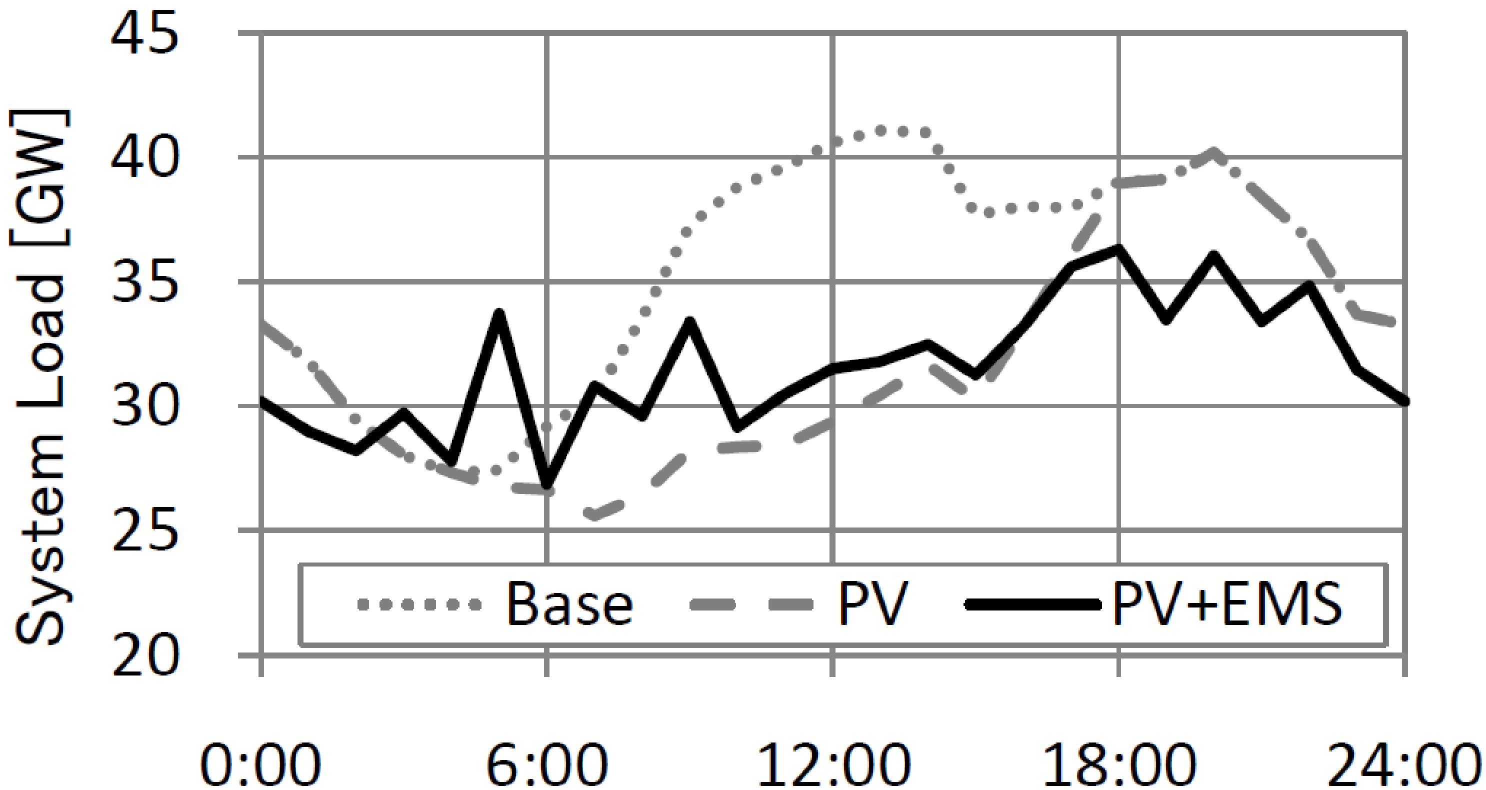


Convergence of power rate under 30 iterations

池上,片岡,岩船,荻本:家庭内の蓄電池とヒートポンプ給湯機による地域全体の電力需給調整力の評価, 電学全国大会 (2011)

System Load Reformation by HEMS: Change of the system load

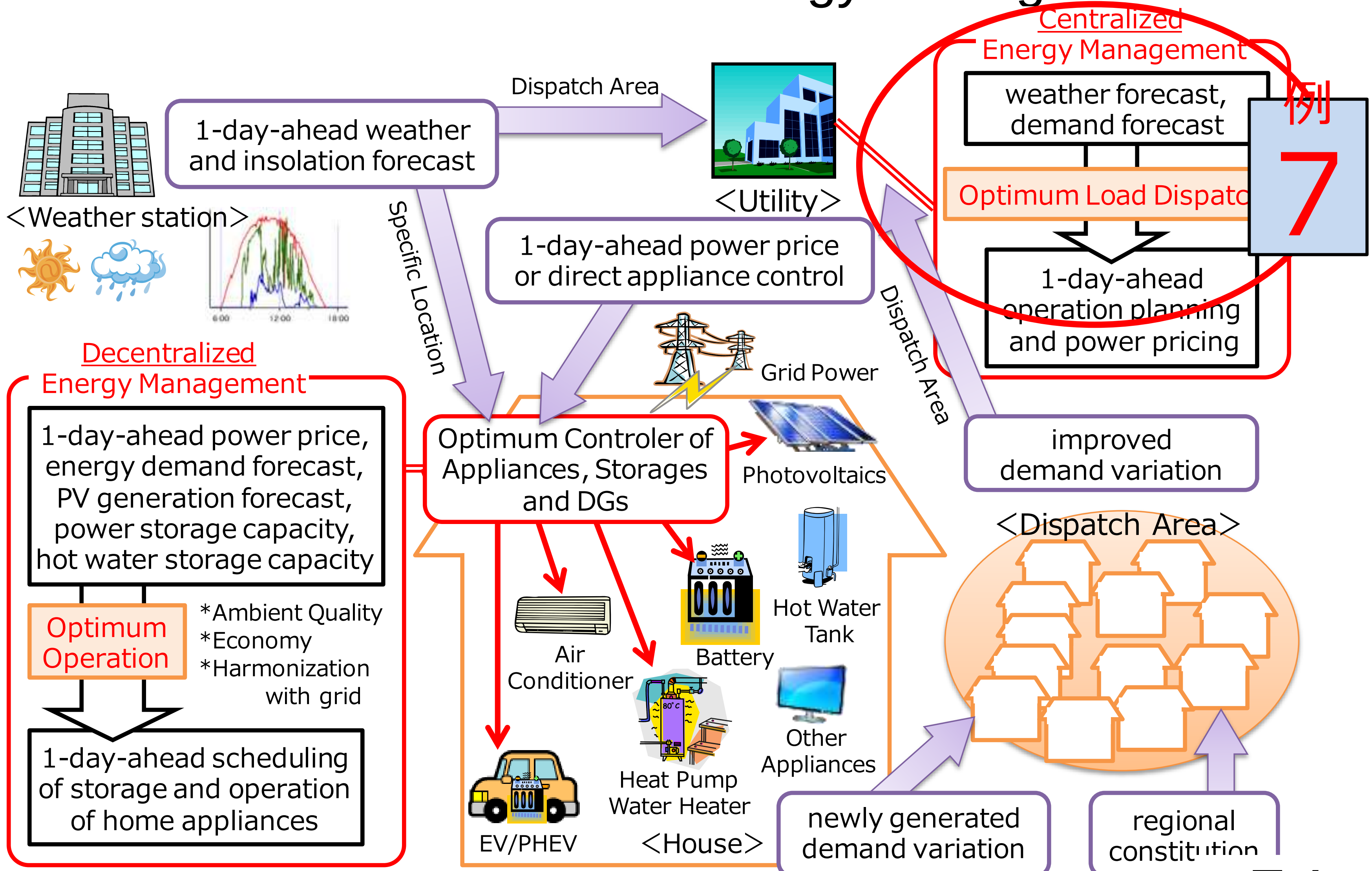
✓As a result of iteration of 30 times, the total system demand was flattened. The system peak load was reduced form 40.2GW at 20 O'clock to 36.3 GW, by 10%.



Revision of the System load（May 1st）

池上,片岡,岩船,荻本:家庭内の蓄電池とヒートポンプ給湯機による地域全体の電力需給調整力の評価, 電学全国大会 (2011)

Renewable Energy Deployment and Centralized/Decentralized Energy Management



System Operation Analysis MACRO model with direct/indirect controlled activated demand: Background and Objectives

- ✓ Day-ahead scheduling (indirect control) meets the slow and large imbalances as the Unit Commitment Scheduling does.
- ✓ Real time dispatch control (direct control) meets the medium-speed imbalances as Economic Load Dispatch control does.
- ✓ The fast balancing capability of Load Frequency Control and Governor Free Control should be secured for fast imbalances in every hour. In the operation analysis, the capability is checked in the system operation analysis based on the available capability by unit.
- ✓ Some activated demand can be estimated to offer the capability of Load Frequency Control in the future proposing reinforced ICT infrastructure.
- ✓ Some activated demand can be estimated to offer the capability of autonomous Governor Free Control using local frequency information in the future proposing the securing the layered control structure policy of s power system.

System Operation Analysis MACRO model with direct/indirect controlled activated demand: Methodology

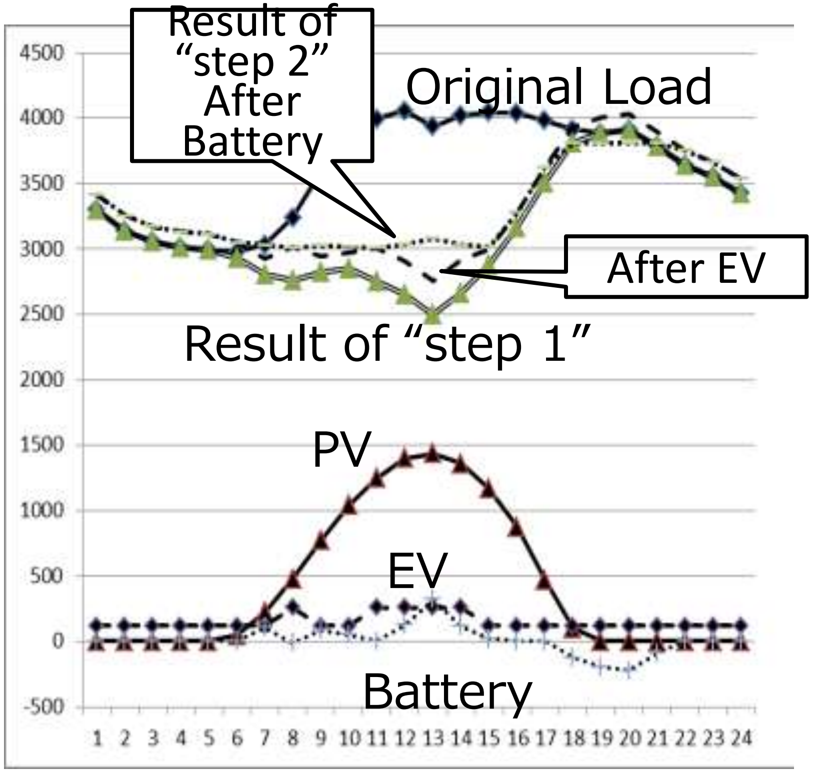
7

Steps:

1) Preparation of an equivalent system load by subtracting non-dispatchable generation such as PV and wind from the hourly original load curb.

2) Apply the indirect controlled activated demand to level the load assuming the day-ahead scheduling of HPWH, PHEV/EV charging and local battery operation including HEMS control.

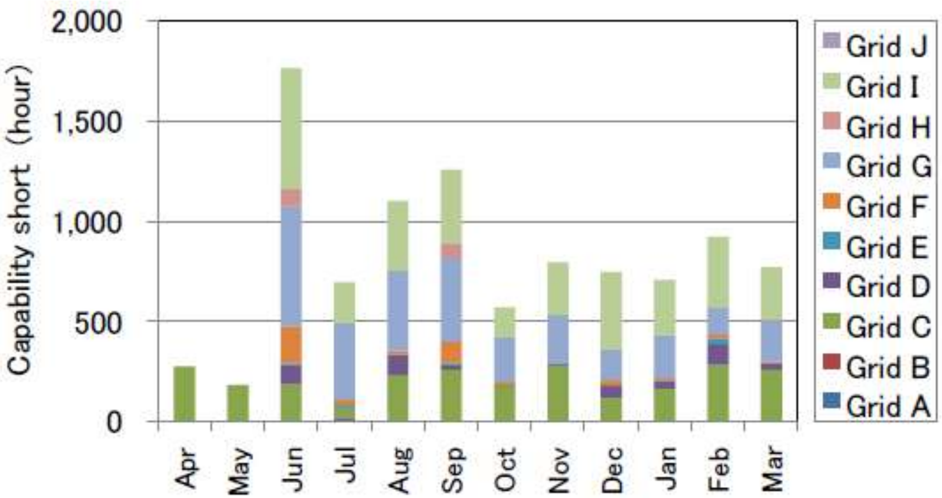
3) Based on the leveled load, the centralized energy management dispatch the load to generation unit and the direct controlled activated demand.



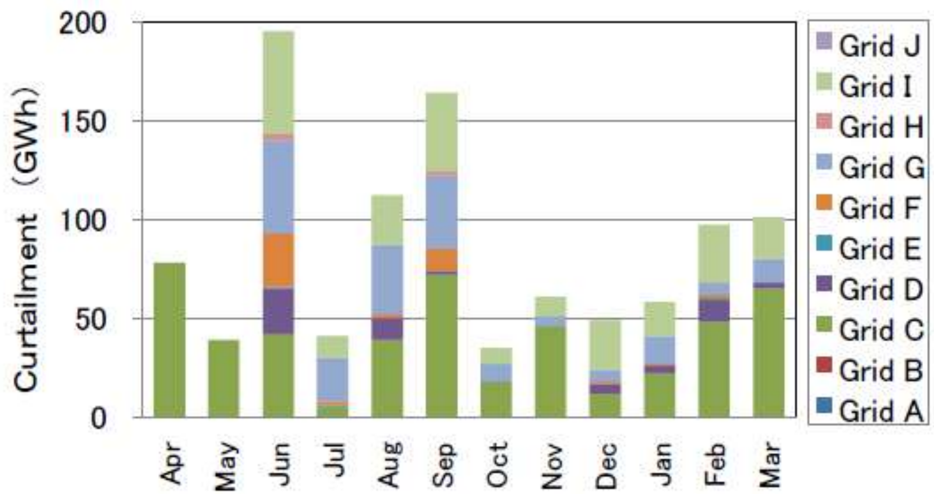
Result of "step 2" of 24 hours

System Operation Analysis MACRO model with direct/indirect controlled activated demand: Example of Results

- ✓ The analysis was made for the interconnected 9 power systems of Japan in 2030 assuming variation features of PV output and demand.
- ✓ The hours with insufficient demand-supply balancing capability were identified by month, and power system.
- ✓ The renewable energy generation curtailment was calculated to avoid the insufficiency.
- ✓ Further analysis can be made changing various planning parameters.



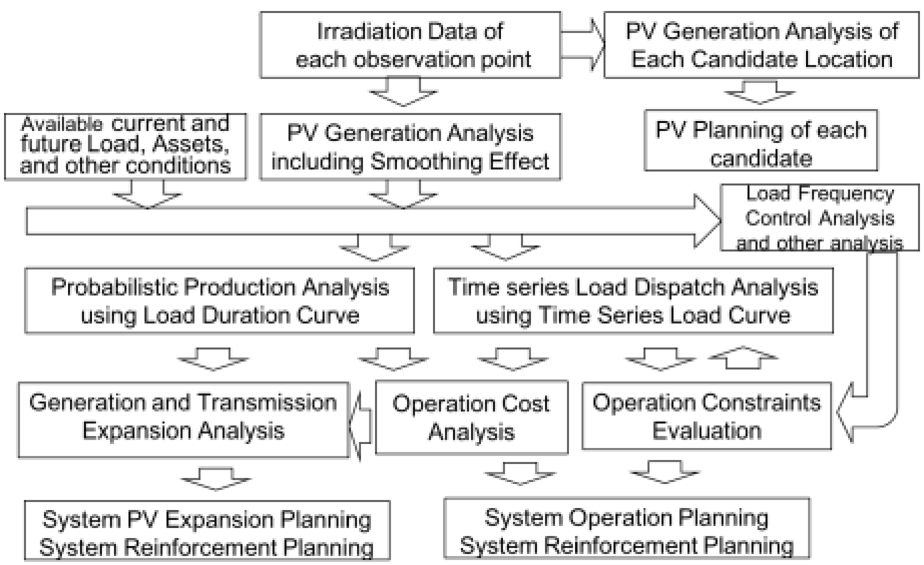
Hours with insufficient regulation Capability (With 5% load and PV variation factor)



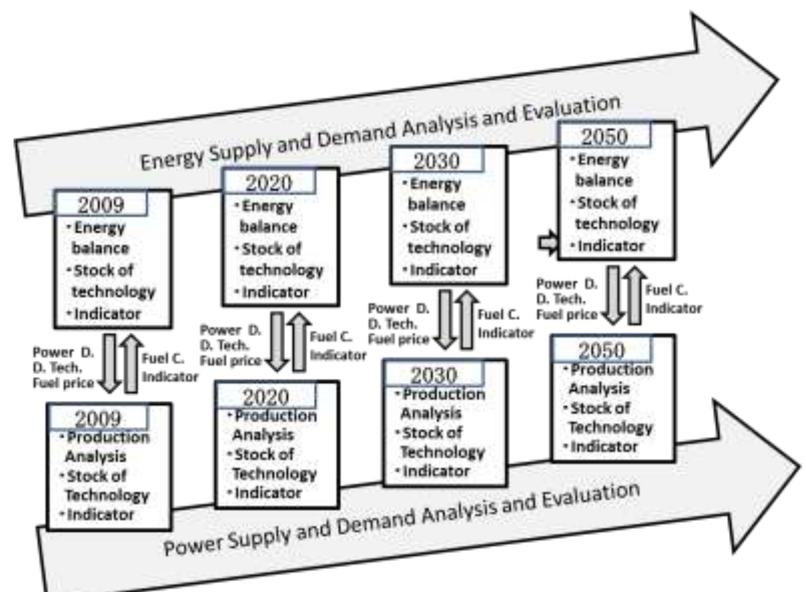
Required renewable energy generation curtailment

Long term power system planning Collaboration with Energy planning

- ✓ For the future, we need a comprehensive long-term power system planning analysis, evaluating various indicator such as economy, reliability, carbon emission and so on.
- ✓ The new technologies of supply and demand and change of life style affect the planning of a future power system.
- ✓ The collaboration with an energy model is effective because a power system model cannot generate the new power demand due to the change of life style and technology.



Total flow of power system planning



Collaboration between energy and power system models

Thank You