World Bank Workshop for Enhancing Climate/Disaster - Resilient Renewable Energy Distributed Power System

Session 1:
”Experience in Sendai Microgrid Operational Experience in the aftermath of Tohoku Earthquake”

2019/09/10

New Energy and Industrial Technology Development Organization
Smart Community Department
Technical Officer

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Hotel Yak & Yetu
September 10 – 11, 2019

About NEDO

What's NEDO

- NEDO plays an important role in Japan's economic and industrial policies as one of the largest public research and development management organizations. It has the two basic missions of addressing energy and global environmental problems and enhancing industrial technology.
- NEDO coordinates and integrates the technological capabilities and research abilities of industry, academia, and government instead of employing its own researchers. It also promotes the development of innovative and high-risk technologies. NEDO aims to contribute to the resolution of social issues and market creation by demonstrating and promoting practical applications of such technologies.

NEDO's Missions

- **Addressing energy and global environmental problems**
- **Enhancing industrial technology**

About NEDO

Role of NEDO

In its technology development management, NEDO formulates project plans and establishes project implementation frameworks by combining the capabilities of industry, academia, and government, including public solicitations of project participants. NEDO carries out research and development projects and set targets based on changes in social conditions in order to achieve maximum results.

Position of NEDO

About NEDO

NEDO History

In the 1970s, the world experienced two oil crises. To improve Japan's energy diversification, NEDO was established in 1980 to help usher in energy conservation and new energy technologies. In 1988, NEDO added research and development of industrial technology to its activities. Today, it uses its role as a research and development management organization to boost innovation and promote research and development on energy, environmental technology, and industrial technology.

- 1980 **New Energy Development Organization established**
- 1988 **Research and development on industrial technology added. Name changed to New Energy and Industrial Technology Development Organization**
- 1996 Integration with Coal Mine Damage Agency. Coal mine damage compensation program added
- 2003 **Incorporated Administrative Agency New Energy and Industrial Technology Development Organization established under the Act on the New Energy and Industrial Technology Development Organization**
- 2006 Kyoto Mechanisms Credit Acquisition Program added
- 2007 Transitional operations related to coal mine damage recovery completed
- 2012 Coal and geothermal operations transferred to Japan Oil, Gas and Metals National Corporation
- 2014 Technology Strategy Center established
- 2015 **Status changed from incorporated administrative agency to national research and development agency**
- 2016 Kyoto Mechanisms Credit Acquisition Program discontinued

1986
Experiments on a large-scale grid-connected photovoltaic power system started for the first time on Rokko Island in Hyogo Prefecture

2012
Commercial model demonstration hydrogen station constructed

About NEDO

FY2018 Budget

1.45 billion US dollars

(FY2018 tentative budget)

NEDO aims to address energy and global environmental problems and raise the level of industrial technology through integrated management of technological development. This ranges from the discovery of technology seeds to the promotion of mid- to long-term projects and support for practical application.

* As only an outline of NEDO's activities is given below, individual budget amounts do not add up to the total.

Energy Systems (481 million US dollars)

- System provision technology
- Energy storage technology such as batteries
- Technology related to hydrogen production, storage, transport, and use
- Renewable energy technology

Industrial Technology (444 million US dollars)

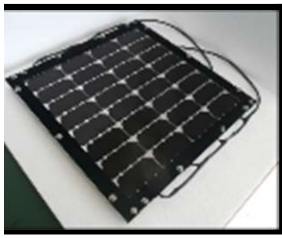
- Robot and AI technology
- IoT, electronics, and information technology
- Manufacturing technology
- Materials and nanotechnology
- Biotechnology

Energy Conservation and Environment (407 million US dollars)

- Technology to harness unutilized thermal energy
- Environmentally-friendly steel manufacturing technology
- Development of high-efficiency coal-fired power generation technology
- Technology related to sequestration of CO_2
- Fluorocarbon recovery technology
- 3R technology, including resource screening and metal refining technology
- International demonstrations, Joint Crediting Mechanism activities, and others

New Industry Creation and Discovery of Technology Seeds (53.6 million US dollars)

- Fostering technology-based startups
- Promotion of open innovation



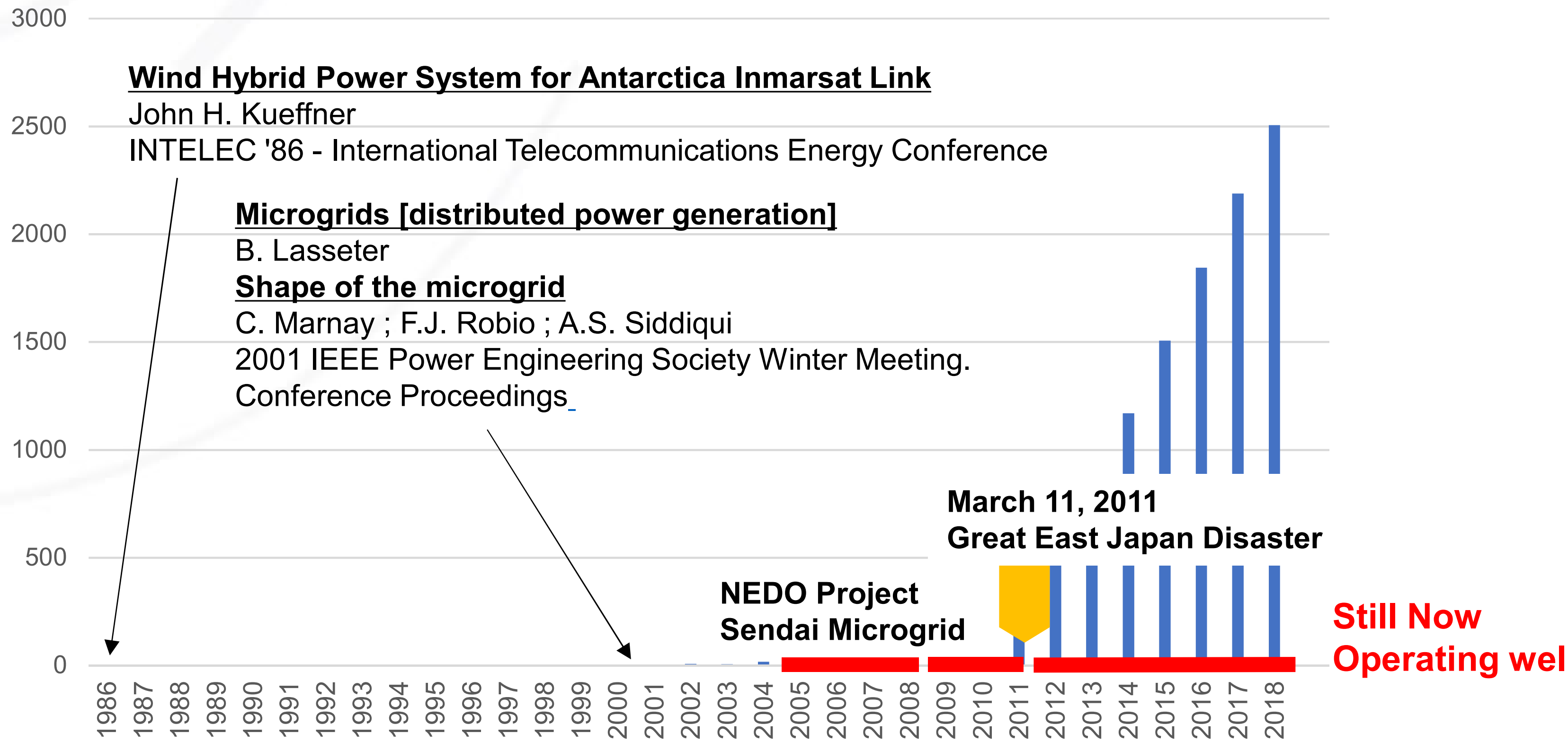



What this graph shows?

IEEE Xplore Digital Library, Search Resutls

Displaying results 1-25 of 12,270 for "Microgrid + power + system"

Filters Applied: 1986 - 2018, Conferences (9,754), Journals (2,292), Magazines (131), Early Access Articles (56), Standards (19), Books (15), and Courses (3).



What is Microgrid?

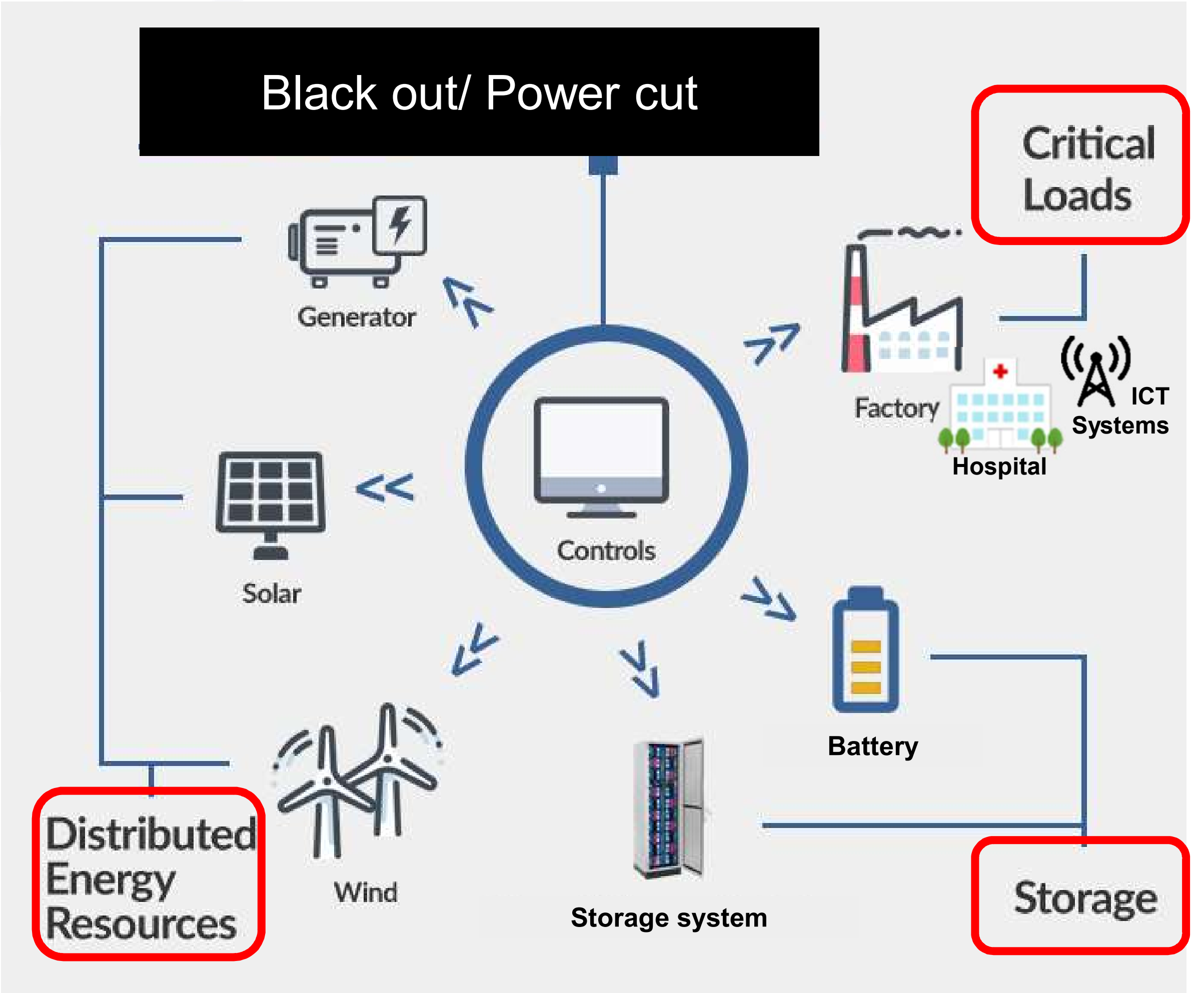
Microgrid Definitions

- **U.S. Department of Energy Microgrid Exchange Group:**
  - A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

- **CIGRÉ C6.22 Working Group, Microgrid Evolution Roadmap:**
  - Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while is landed.

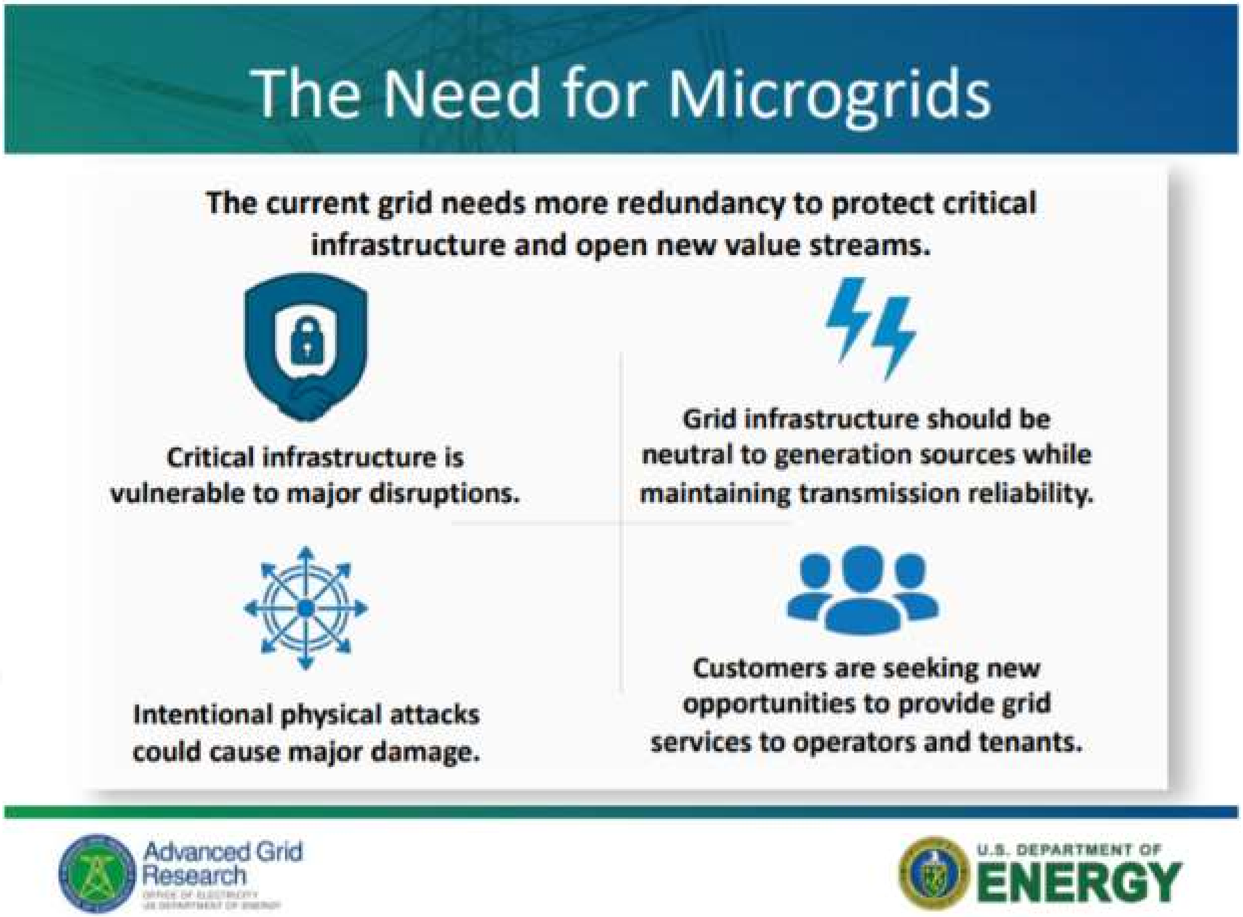
Source:
https://building-microgrid.lbl.gov/microgrid-definitions

Typical Microgrid Configuration



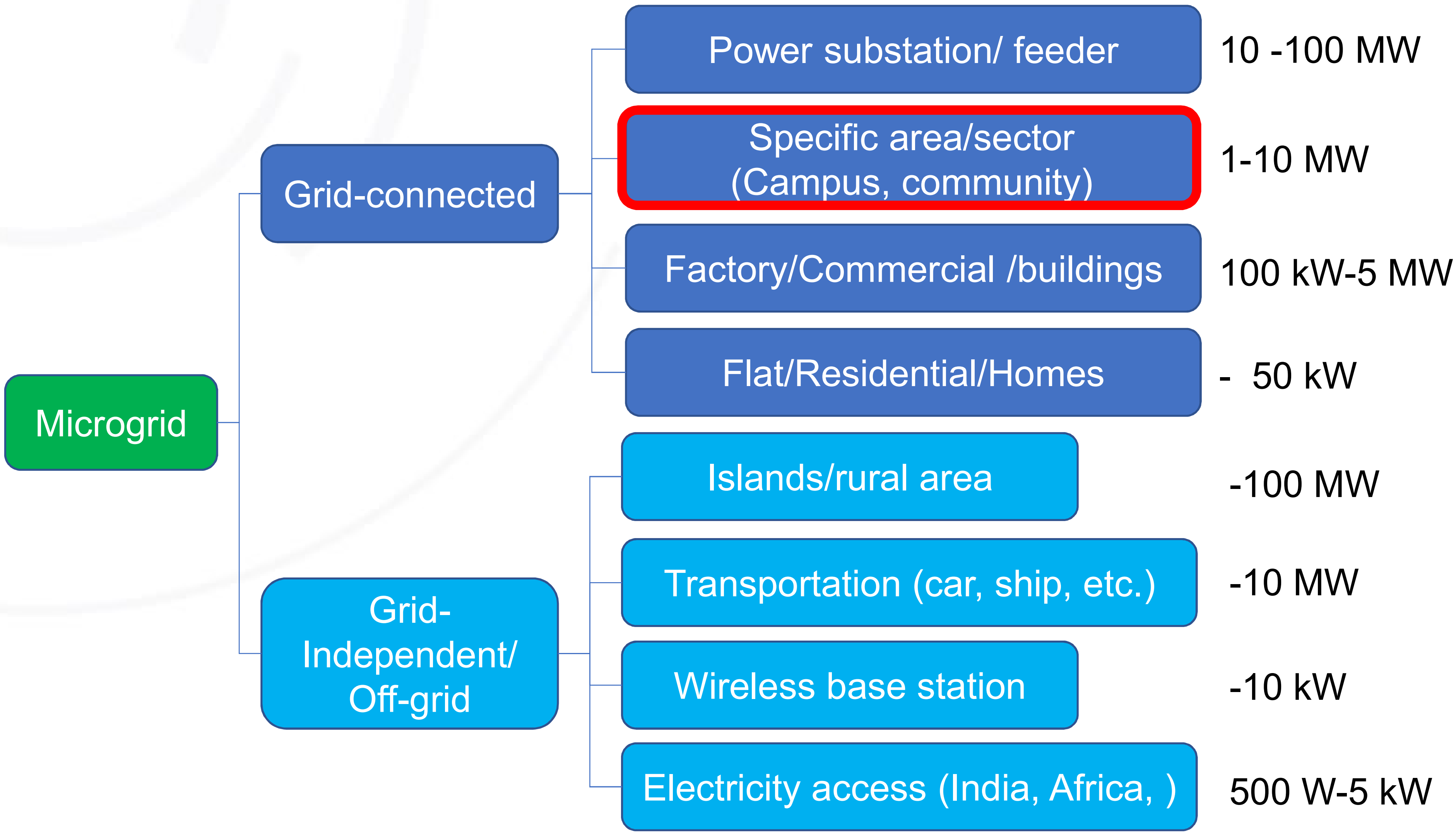
Need for Microgrids, Why Microgrid is so expected?

Micrograms Poised to Dramatically Change Energy Landscape



Source: Dan Ton, Microgrid R&D Program at the U.S. DOE,
2019 Symposium on Microgrids Fort Collins, August 2019

Category of Microgrid (example)



The Sendai Microgrid from LBNL/DOE Web Site, USA

BERKELEY LAB

MICROGRIDS AT BERKELEY LAB

GRID INTEGRATION GROUP • ENERGY STORAGE AND DISTRIBUTED RESOURCES DIVISION

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- About Microgrids
- Microgrid Definitions
- Types of Microgrids
- Examples of Microgrids
  - Fort Carson
  - Mesa del Sol
  - Santa Rita Jail
  - Sendai Microgrid
  - Huatacondo
  - Hartley Bay
  - New York University
  - Borrego Springs
  - Fort Collins

The Sendai Microgrid

Perhaps the **most well-known microgrid demonstration** on this planet, The Sendai Microgrid Project was one of the four major New Energy and Industrial Technology Development Organization (NEDO) ones carried out in Japan between 2005 and 2008. After some upgrades, this project is still fully operational.

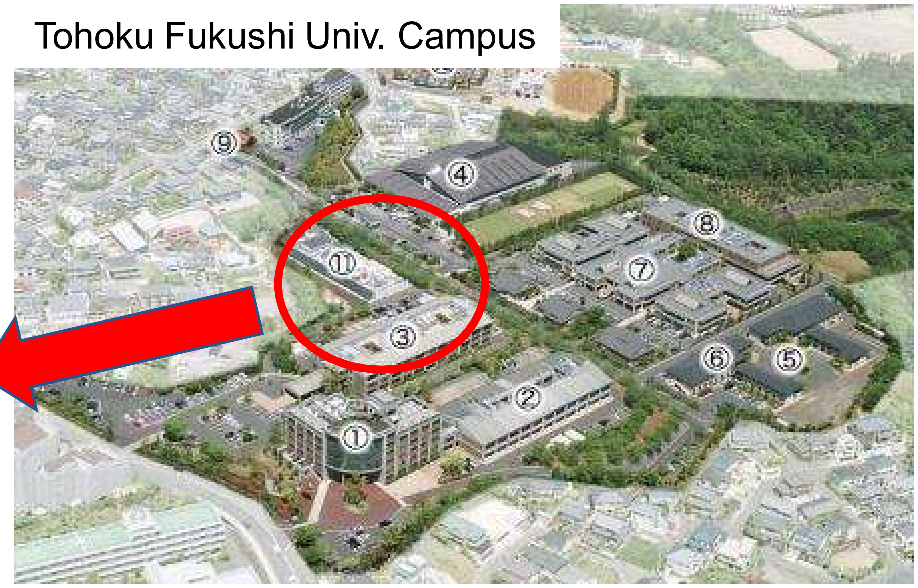
While already highly successful, the project achieved microgrid superstardom because of its **excellent performance during the 2011 earthquake and tsunami**. Following a service loss of a few hours, its engine generators were started and the microgrid supplied the teaching hospital of Tohuku Fukushi University, on whose campus it is located, with both power and heat for the duration of the two-day blackout.

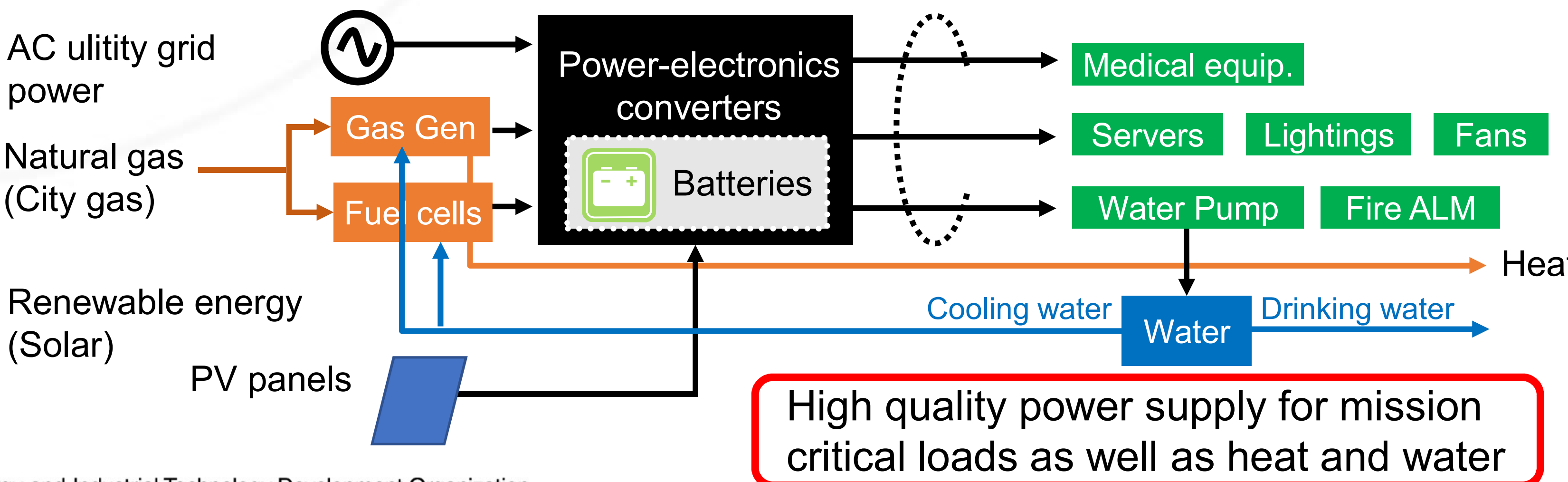
The energy center contains **two 350 kW natural gas fired gensets, 50 kW of PV, and modest battery storage**. Another notable feature of this project are the six varying levels of power quality supplied on various circuits. One of them is a direct DC circuit that supplies the control room, in which all devices, including data racks, are DC to avoid disturbance propagation.

The Sendai Microgrid (PJ: FY2005 – 2008)

1 mega-watt Microgrid System, Energy Center

Tohoku Fukushi Univ. Campus





Background of Sendai Microgrid Project

➢Trends on electricity and customer need in Japan

- Deregulation and liberalization of the electric power market
- Contribution to environmental protection
- Practical use of distributed power supply
- Increase in customer demand for high power quality (PQ)

and so on…

Studies on "an ideal power supply network system for Japan" have been conducted

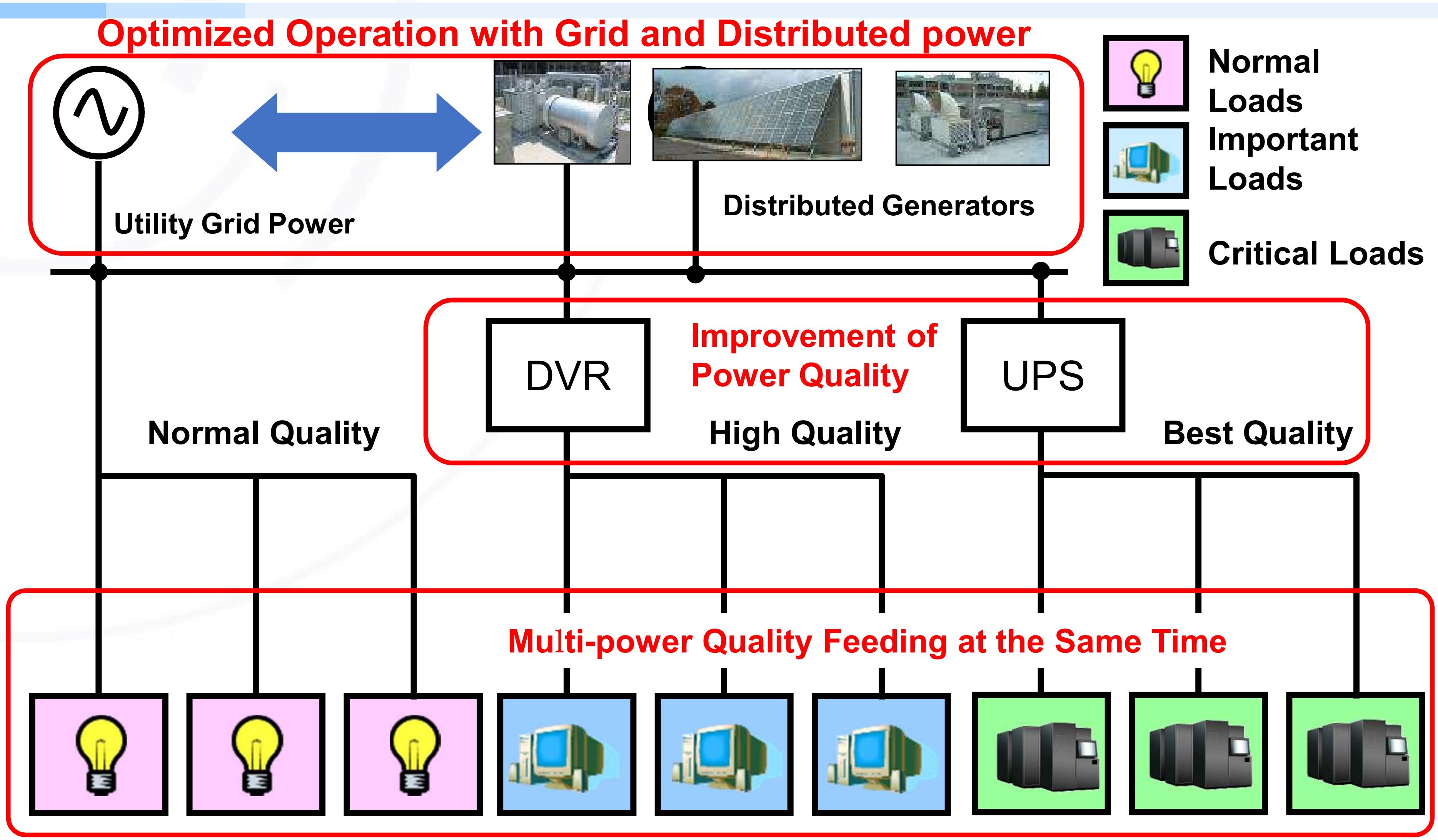
⬇

Multi Power Quality Microgrid (MPQM)
By Sendai Microgrid Project

Goals of NEDO Sendai Project

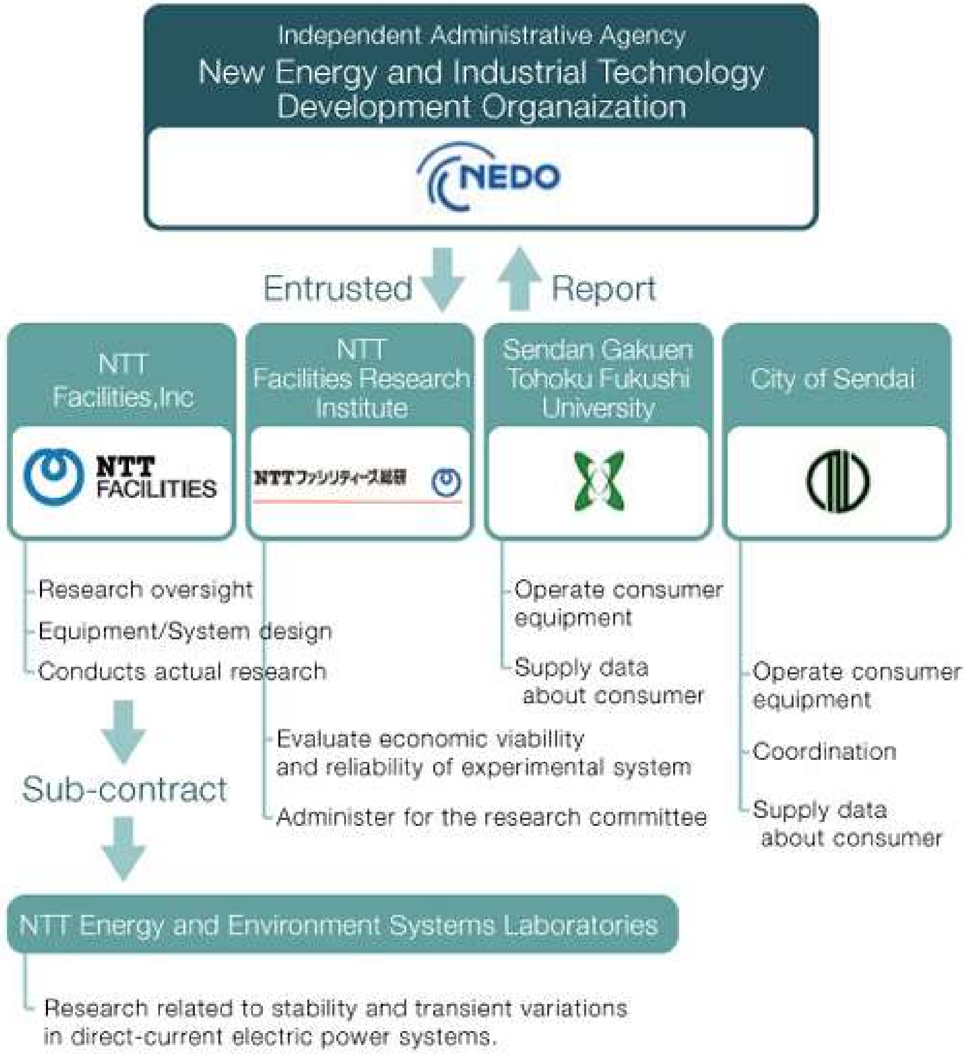
- Optimized operation between the grid power and distributed generators
- Development of a new power plant for multiple power quality level feedings
- Field operation for real customers in some areas
- Verification of the power plant's reliability, stability, and security

Concept of Sendai Microgrid



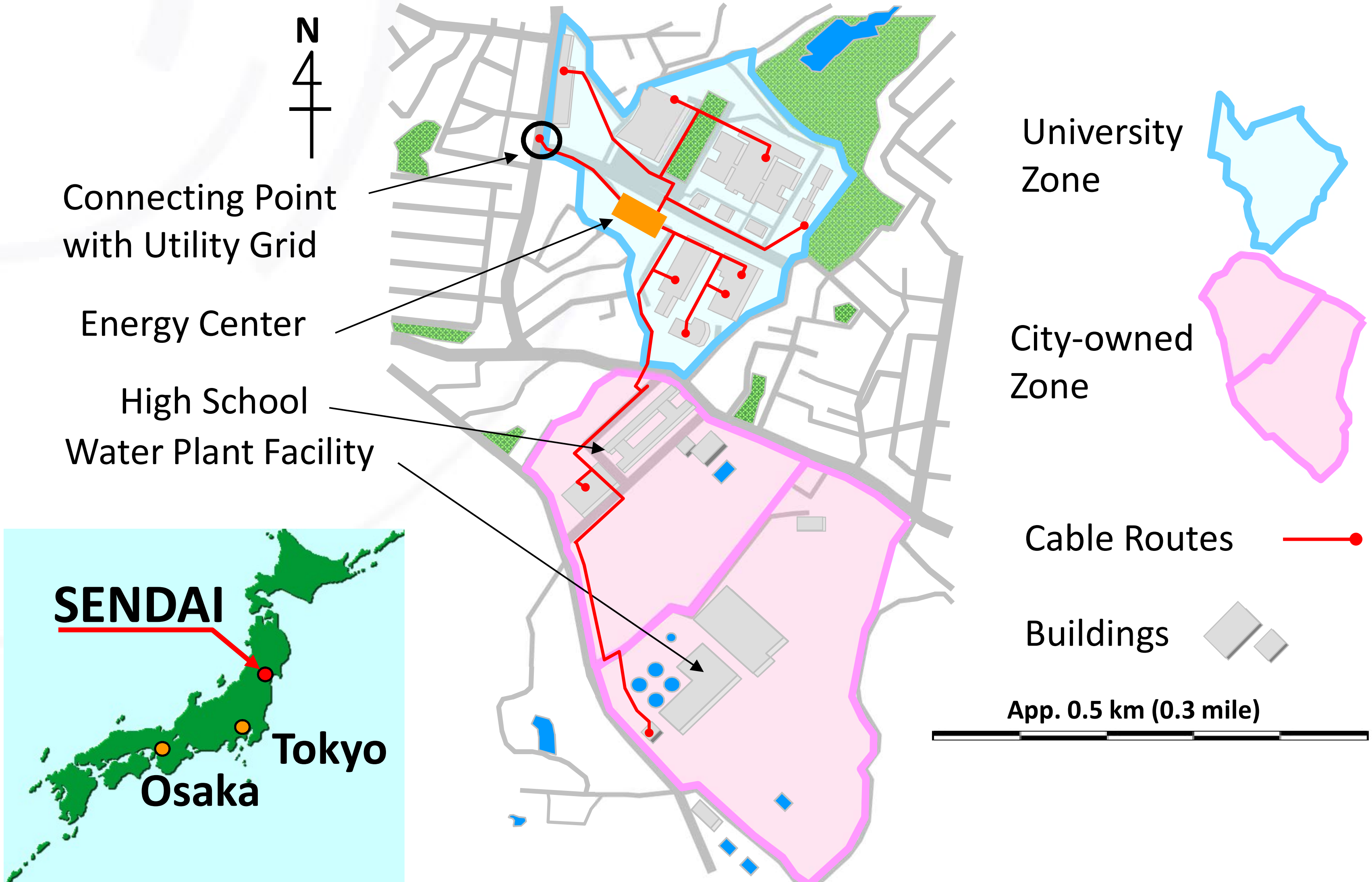
Project Organization

Project Period
2005 – 2008
(4 years)

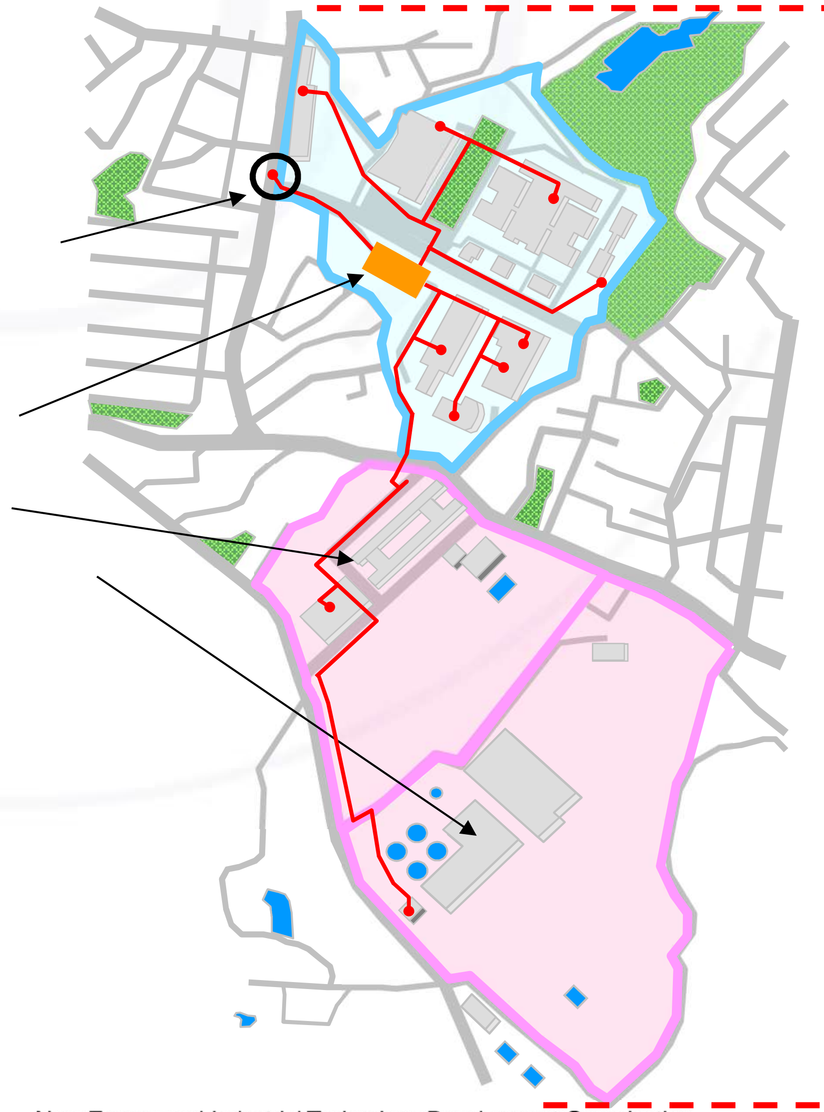


Technical Advisory committee

Map of Field Demonstration Area



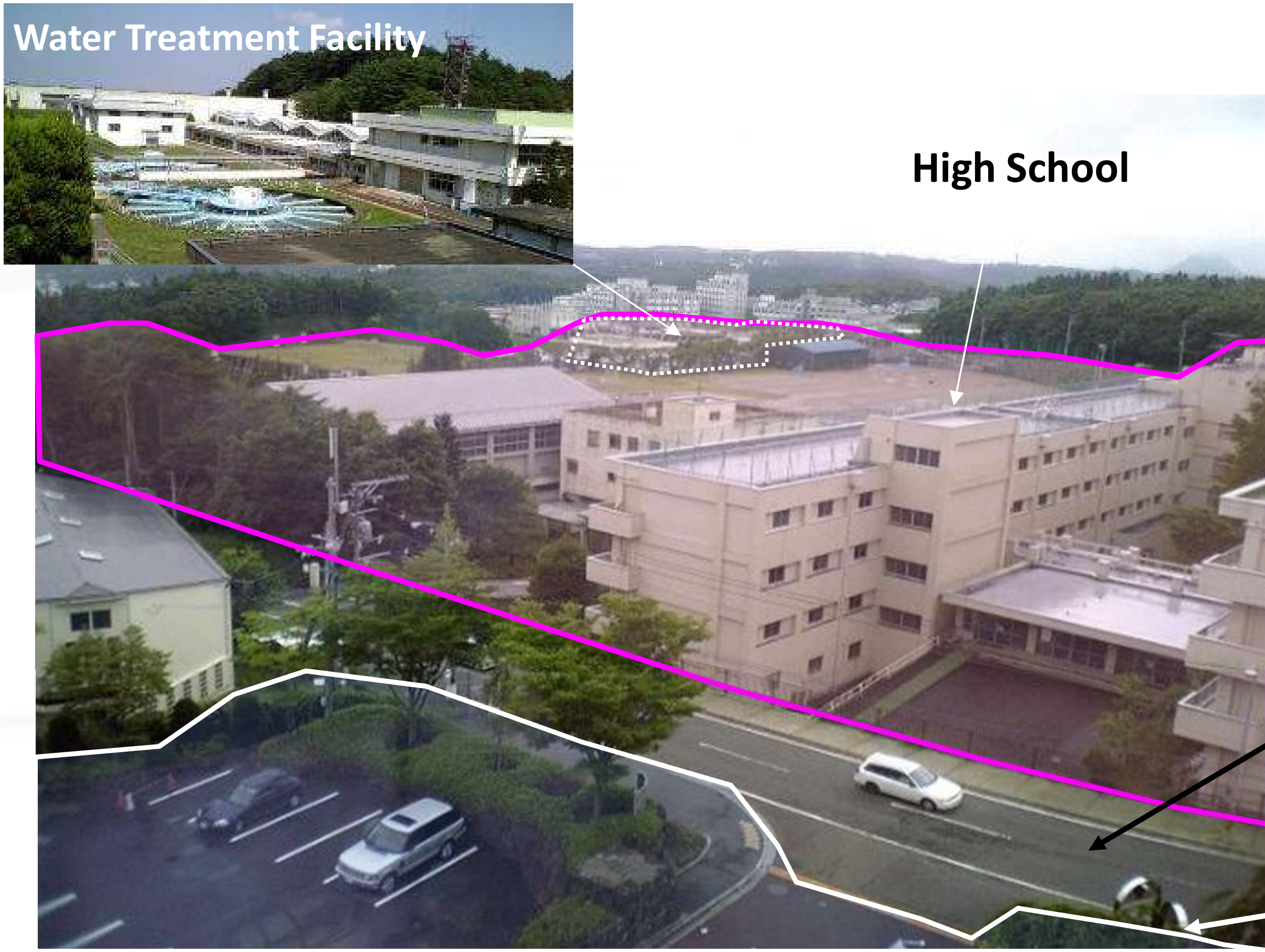
Site Comparison
Sendai Microgrid Demonstration Area and Kathmandu



University Zone

Source: Tohoku Fukushi Univ. Web Site

City-Owned Zone



Defined Power Quality Levels

Requirements	Category				
	DC Power	AC Power			
		Level A	*Level B1*	*Level B2*	*Level B3*
Interruption	**NI**	**NI**	**Less than 15 ms**	**Less than 15 ms**	**Less than 15 ms**
Voltage Dip	Y	Y	Y	Y	Y
Outage	Y	Y	Y	Y*	-
Voltage Fluctuations	Y	Y	-	-	-
Voltage Harmonics	Y	Y	-	-	-
Voltage Unbalance	N/A	Y	-	-	-
Frequency Variation	N/A	Y	-	-	-

Note:
NI: No Interruption, Y: With compensation
-: Without compensation, *: When Gas engine sets generated

Kinds of Load

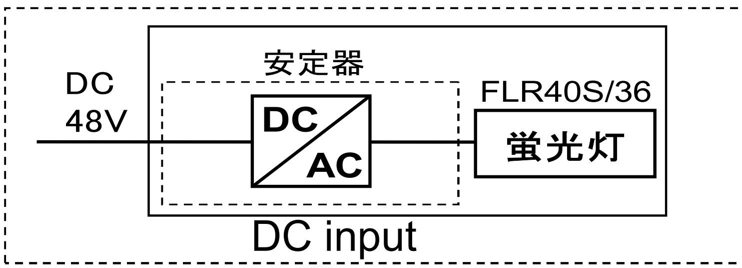
Levels	Capacity of Converters	Consumers (Load)	Zone
Level A	200 kVA	Clinic (MRIs) Laboratory (servers)	University
Level B1	20 kVA	Nursing Care Facilities (lighting, PCs)	University
Level B2	600 kVA	High School (lighting, PCs, elevators) Water plant (induction motors)	City-owned
Level B3	200 kVA	Nursing Care Facilities (lighting, clinic equipment)	University
DC	20 kW	Energy Center (300 Vdc and 48 Vdc) (servers, lighting, fans)	University
Normal Quality	N/A	Nursing Care Facilities Training Center Dormitories	University
Level C	~ 10 kW	Hospital (Emergency power)	University

Critical 48 VDC loads in Energy Center

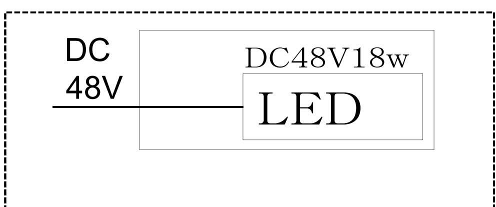
DC Fluorescent lighting

Fluorescent lamp ballast (Nextek, Made in USA)

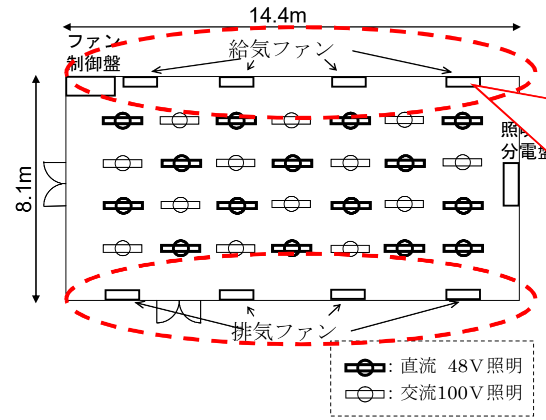
Lamp is a standard product.



DC LED lighting



DC Ventilation Fan



DC Servers from USA

HP dc-input（BL20P）

Sendai Microgrid Control System

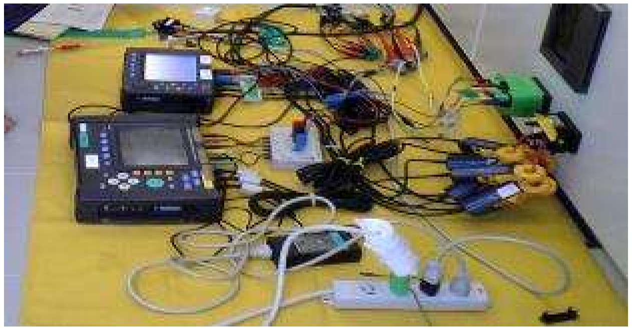
Construction (1)

Construction (2)

Construction (3)

Field test, Aug. 25 – 26, 2007

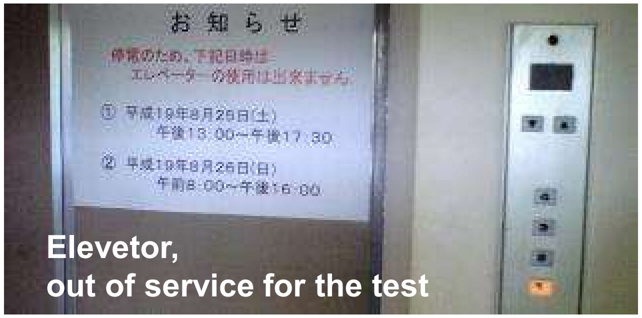
Meeting before the field test



Power quality meters and instruments

Operators for the test

Monitoring in out site



Elevetor,
out of service for the test

Water supply facility

Evolution of the Sendai Microgrid

NEDO

3Q 2005 Start — 1Q 2008 Finish — March 11, 2011

1st step

NEDO Demonstration (Power Supply) Launched

2nd step

Ongoing Operation (Energy Supply)

3rd step

Change Operation Policy Changed

Today

Replace fuel cells Deploy more PV panels, etc.

Future?

Design/development → Construction → Demo

・Hospital opened
・Heat recovery and quality level-C added

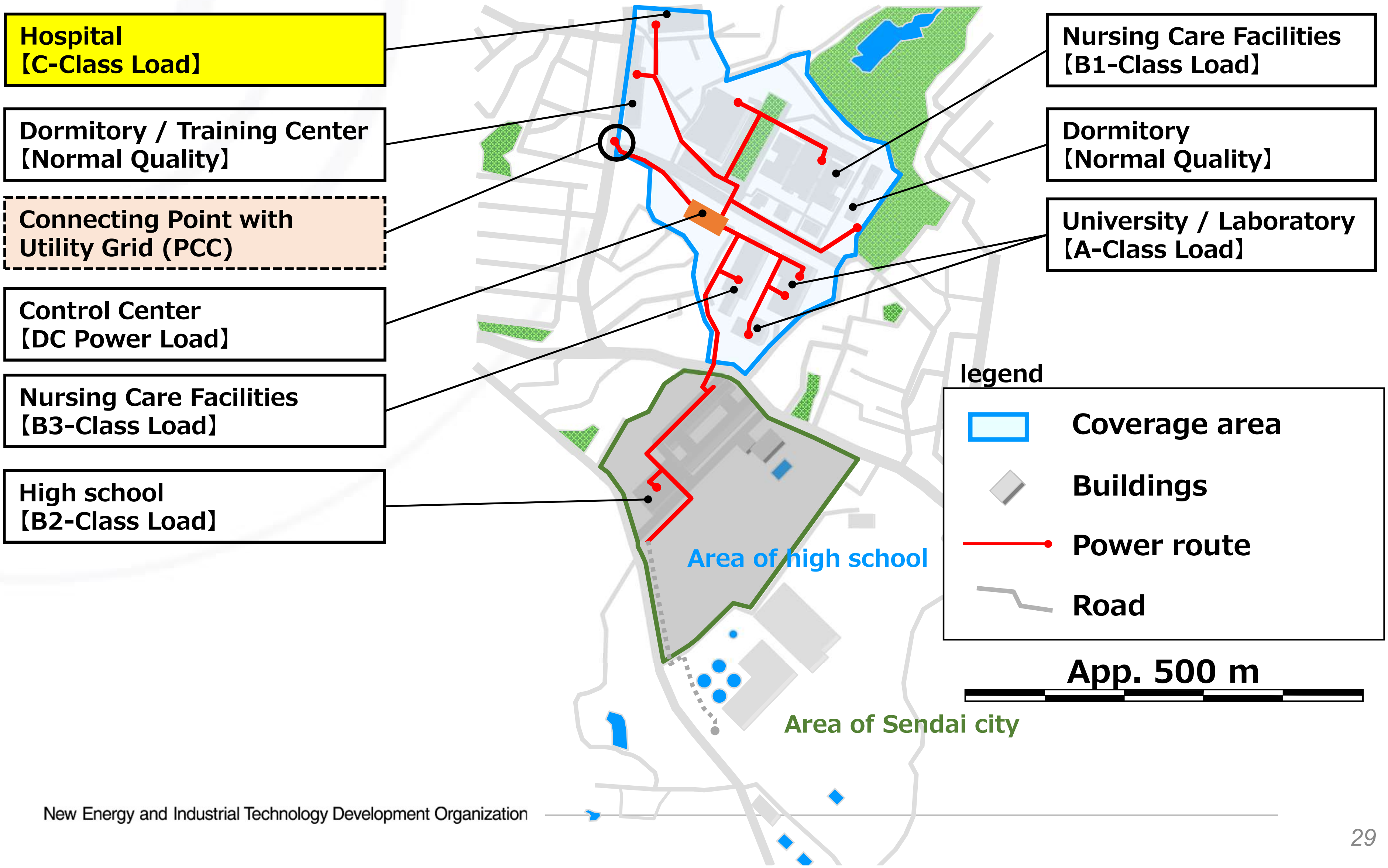
•Quality level B2 stopped
•City zone disconnected
•DVR removed
•MCFC removed
•GE operation policy changed

•Installation PAFC 100 kW in July 2011

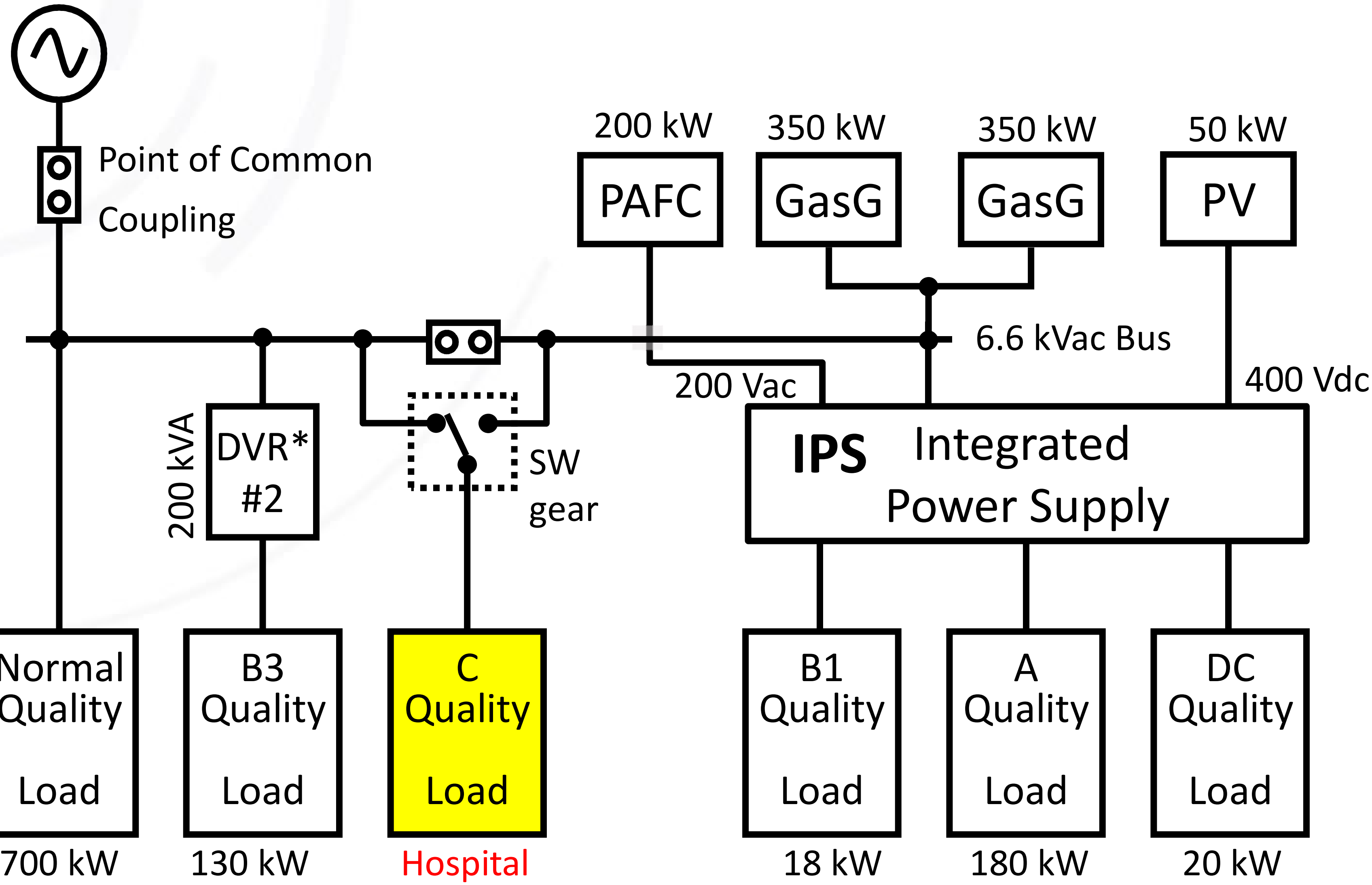
•Addition of PV panels 160 kW

Evolution from Electric Power to Energy Supply System, and Going Green

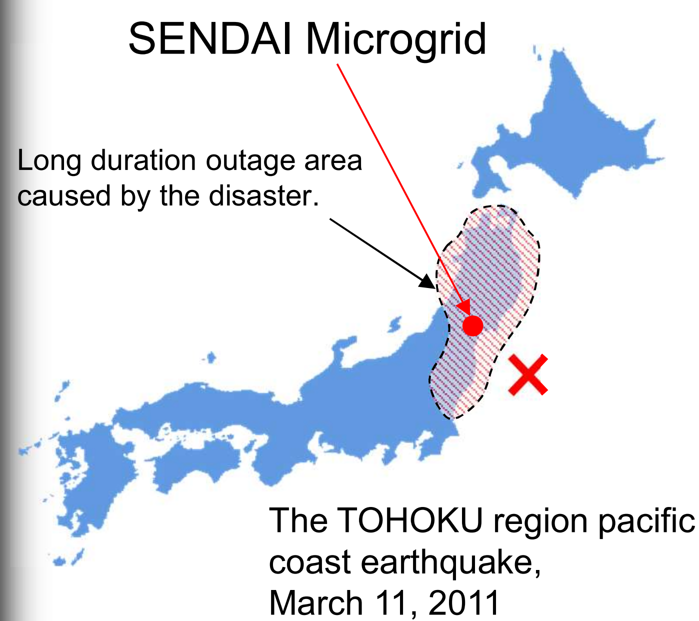
Started supplying electricity and heat to the newly established hospital



"Power Quality Level-C" for New Hospital



A Microgrid That Wouldn't Quit, "March 11, 2011"



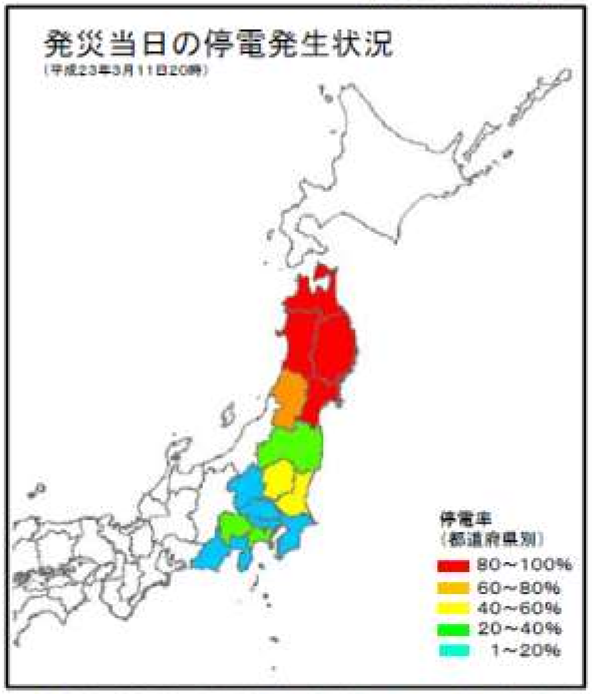
Source: http://spectrum.ieee.org/energy/the-smarter-grid/a-microgrid-that-wouldnt-quit/0

The Great East Japan Earthquake, March 11, 2011

Wide-area power outages in the Tohoku and Kanto areas

ライフライン被害
電力

発災当日の停電発生状況(3月11日20時)



東北電力管内

都道府県	停電戸数	停電率(※)
青森県	900, 000	99%
岩手県	770, 000	95%
秋田県	660, 000	98%
宮城県	1, 370, 000	96%
山形県	510, 000	74%
福島県	270, 000	22%

東京電力管内

都道府県	停電戸数	停電率(※)
東京都	102, 665	1%
神奈川県	1, 277, 705	24%
栃木県	567, 925	43%
千葉県	346, 489	9%
埼玉県	342, 878	8%
群馬県	225, 524	17%
茨城県	823, 404	42%
山梨県	145, 009	22%
静岡県(富士川以東)	113, 051	13%

(※)東北電力の停電率＝停電戸数/需要家戸数×100%で算出　需要家戸数は経済産業省提供資料による。
東京電力の停電率＝停電戸数/契約口数×100%で算出　契約口数は東京電力資料「平成22年度数表でみる東京電力」による。

(出典)
停電戸数：東北電力HP「東北地方太平洋沖地震に関する、停電情報」http://www.tohoku-epco.co.jp/emergency/9/index.html　東京電力HP「東北地方太平洋沖地震による影響などについて」
http://www.tepco.co.jp/cc/press/index-j.html

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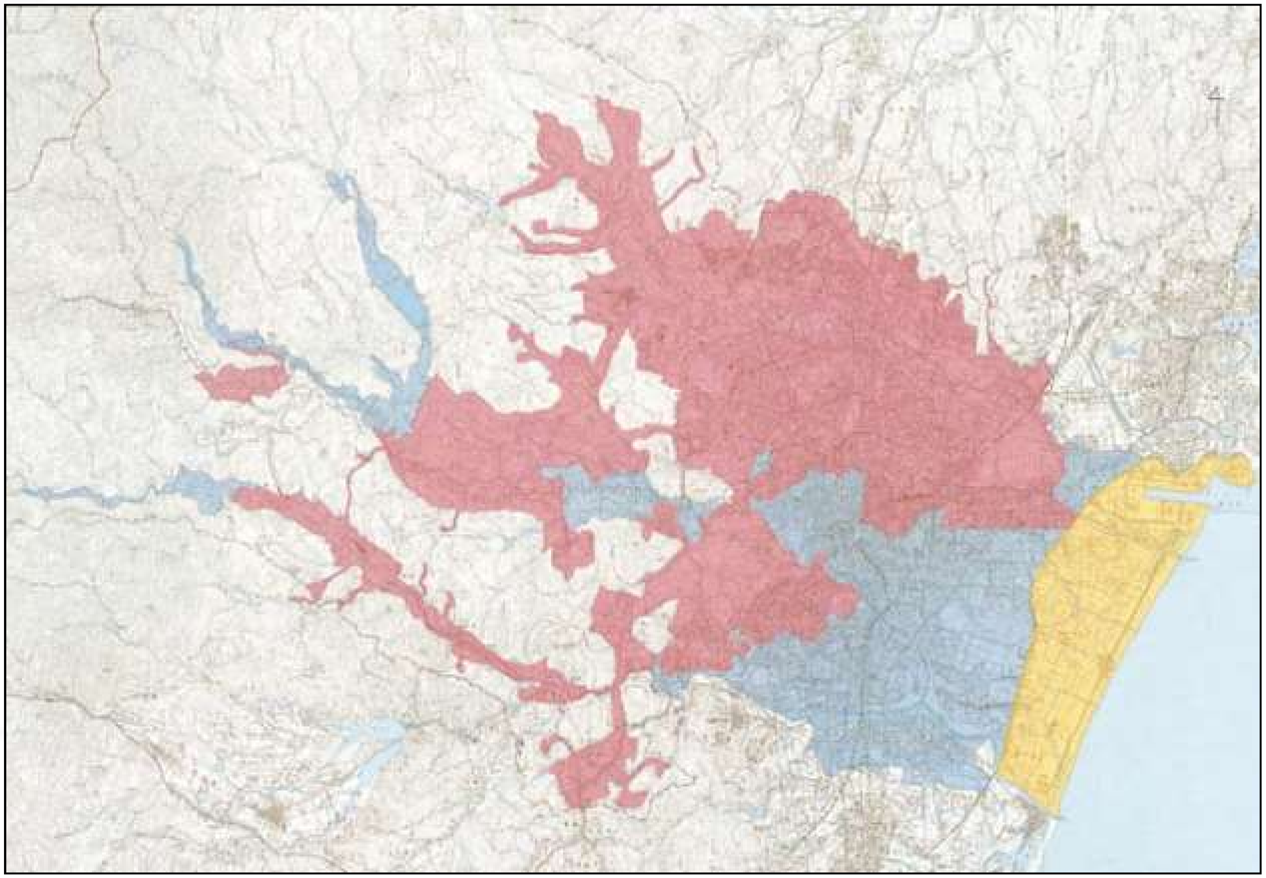
東北地方太平洋沖地震を教訓とした
地震・津波対策に関する専門調査会
報告
参考図表集
平成23年9月28日
中央防災会議
東北地方太平洋沖地震を教訓とした
地震・津波対策に関する専門調査会

Interruption of Water Service in Sendai

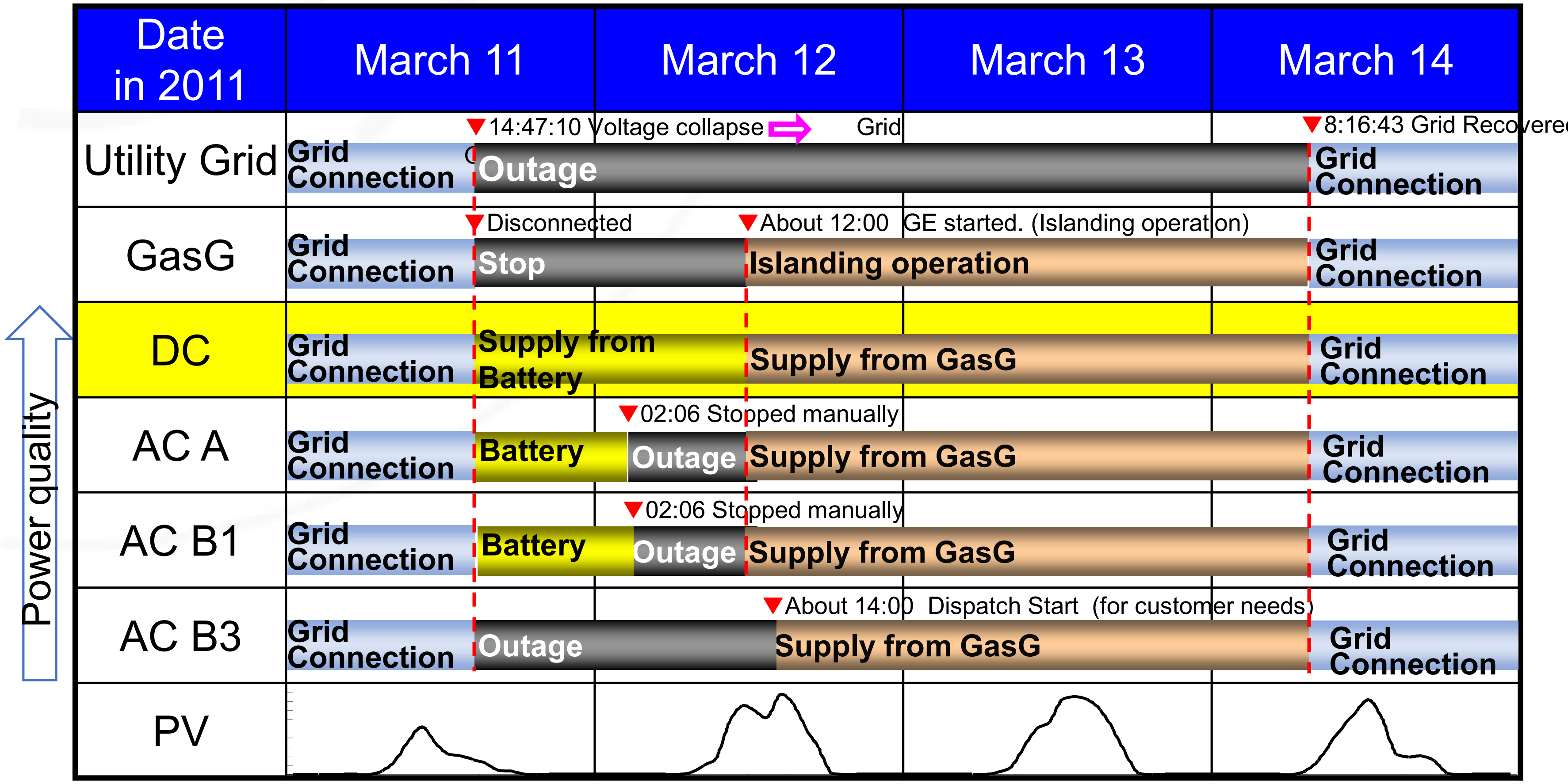


After March 11, 2011

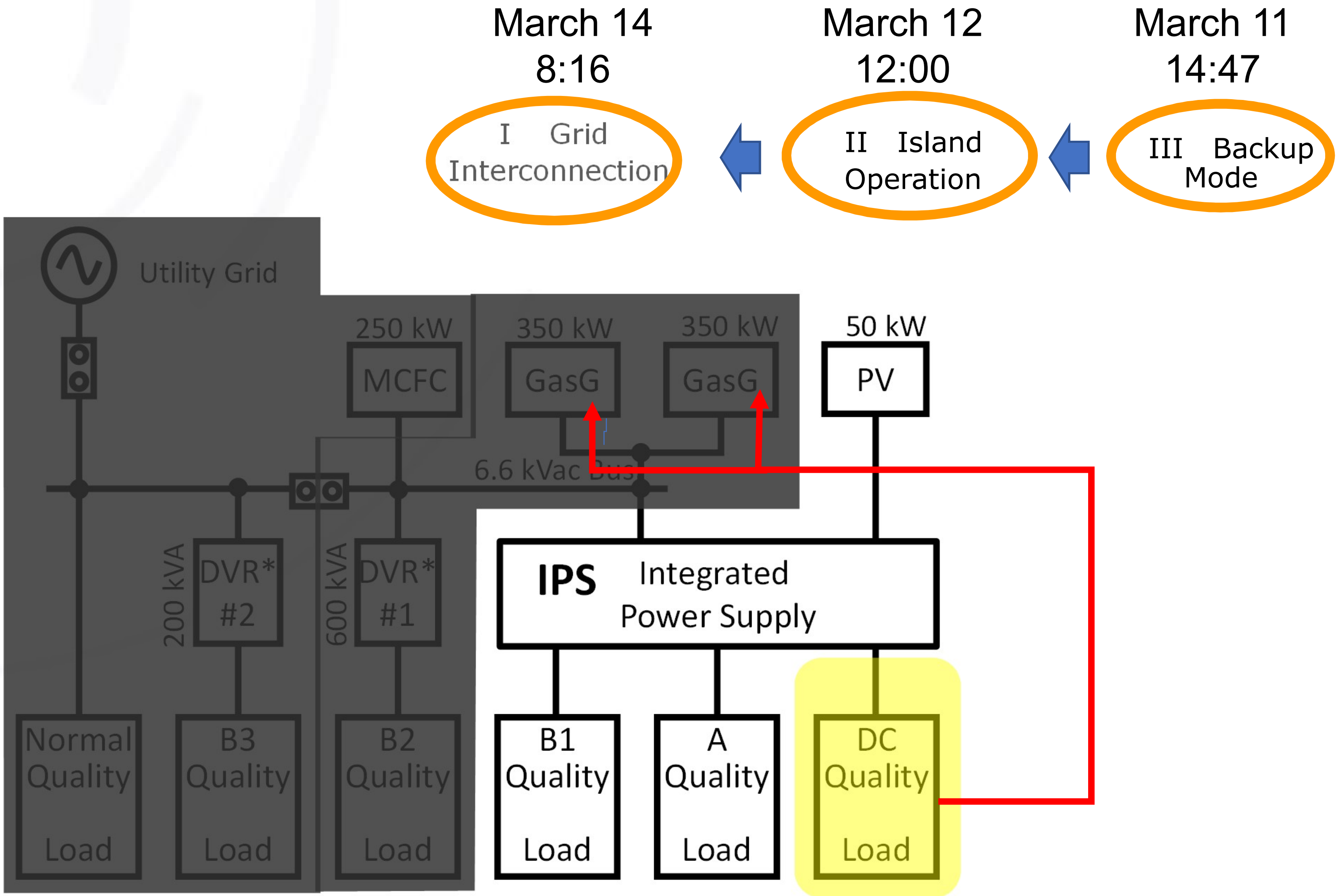
Red: No Service
Blue: w/o Damage
Yellow: Damaged by Tsunami

Condition of Supplying Power during March 11

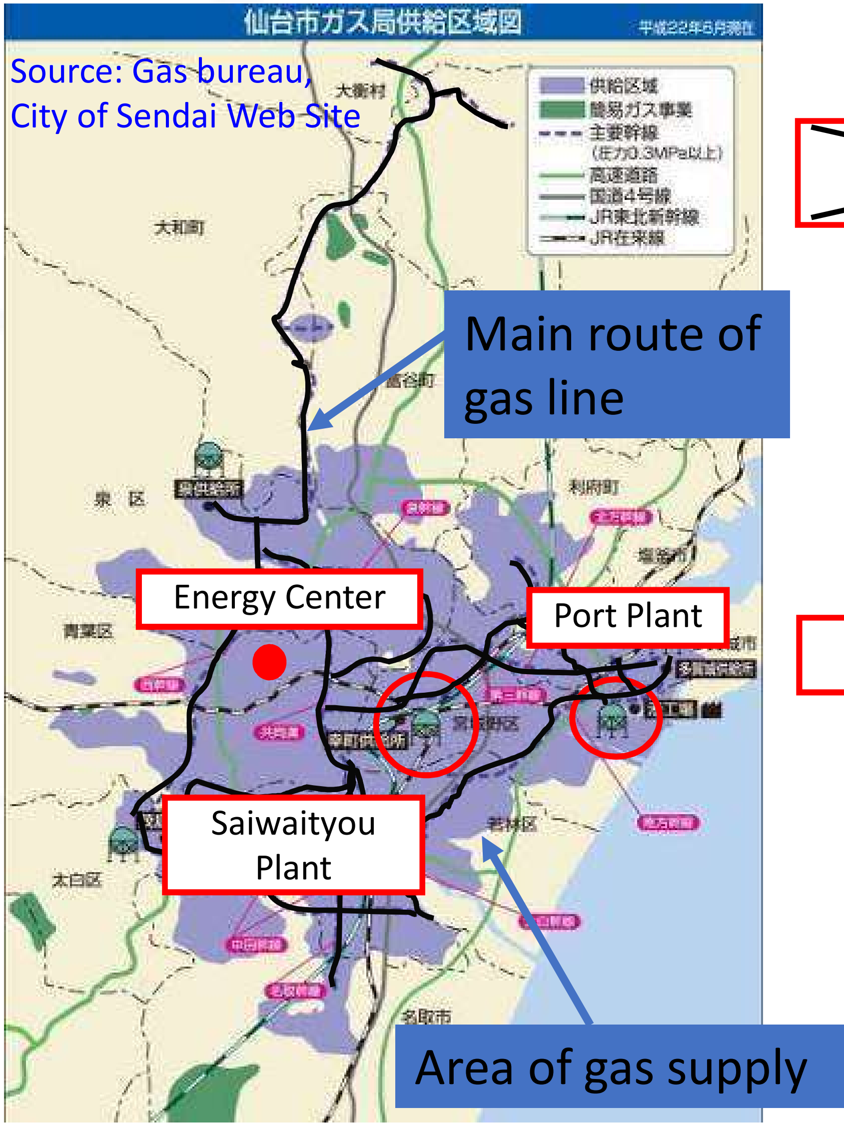
- The system continued to supply DC, A, B1without any interruptions for the batteries and the PV generation.
- GasG supplied power for 43 hours during the outage.



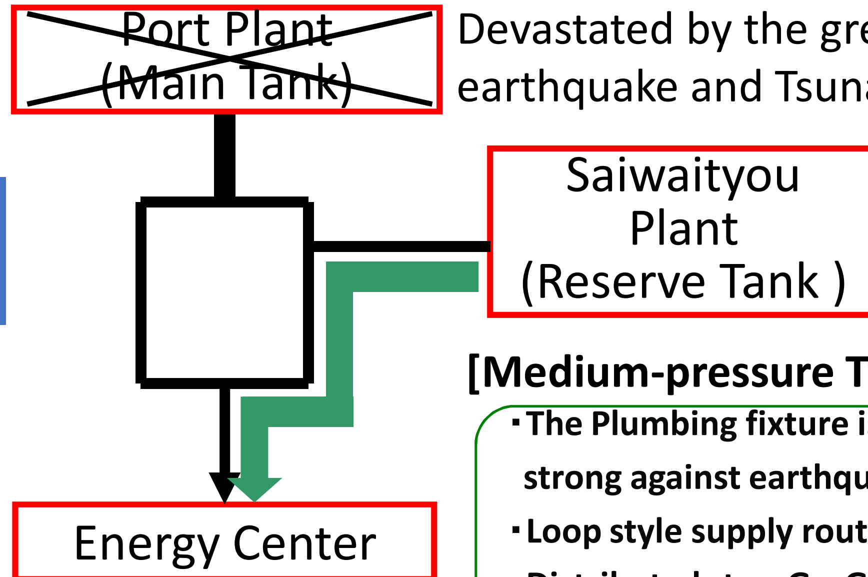
Operation After March 11 Disaster



The Condition of Gas Supply in Sendai (Medium and High-pressure Type Gas)



The outline of gas line



Devastated by the great earthquake and Tsunami.

[Medium-pressure Type Gas]

- **The Plumbing fixture is extreme strong against earthquake**
- **Loop style supply route**
- **Distributed storaGasG equipment**

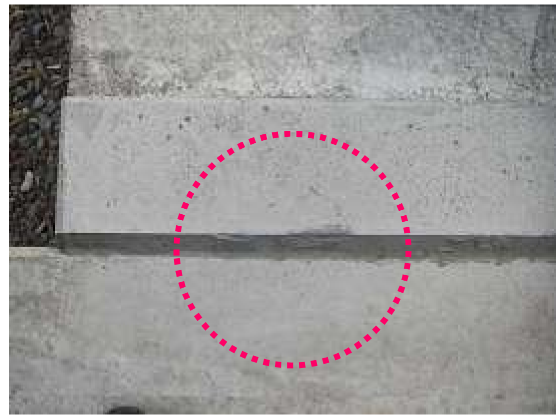
Low-pressure gas for domestic use stopped in the whole Sendai area two hours after the earthquake. Within 25days after the disaster, supply was resumed in almost the whole area.

Miner Damage in Sendai Microgrid Site

- No abnormal operation in the power system at the Energy Center.
- A few slight cracks and gaps have been discovered on the building and its foundation.

Crack on the outer wall of PQCR（Power Quality Control Room）

A gap on the noise suppression panel



Peeling off on the masonry joint of the foundation

Why did The Sendai Microgrid work well?

Strict regulations and laws for microgrid facilities in Japan (e.g.)

- **Electricity Business Act**
  - Types of electrical facilities
    - electric facilities for business use
    - electric facilities for private use
    - electric facilities for general use
  - Obligations of installers for private electrical installations
    - Maintenance of Electric Facilities for Business Use
    - Safety Regulations
    - Chief Engineers
    - Construction Plans and Inspections
  - Grid Interconnection Guideline for Ensuring of the Electric Power Quality
- **Building Standards Law**
  - “new earthquake resistance design standard” enforced in 1981
- **Fire Service Act**
  - Fire Defense Equipment, etc.

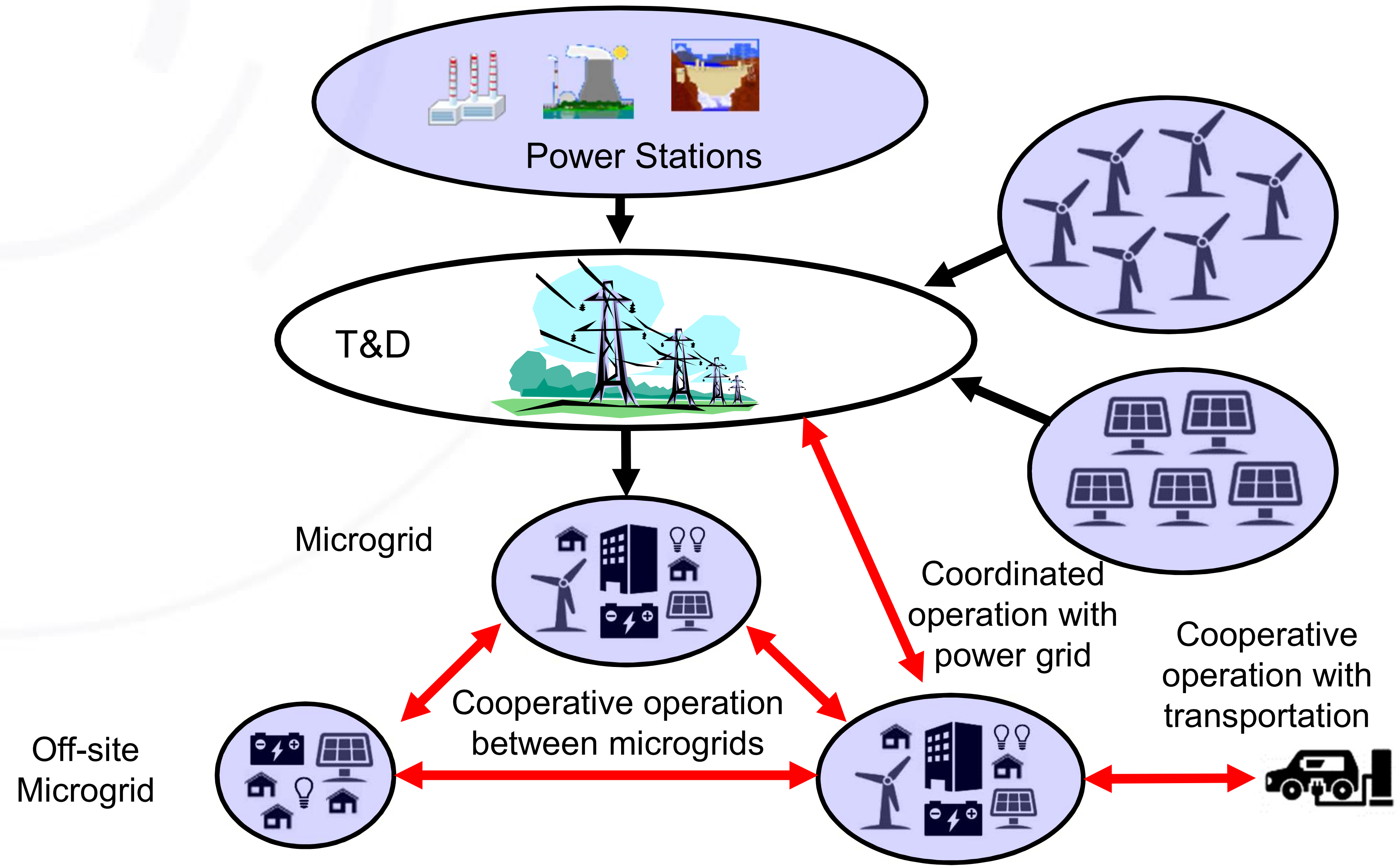
Lessons learned by NEDO demo, March 11 Disaster

- Combination of different types of energy sources is essential for higher reliability. Medium pressure gas pipe lines in Japan were very strong.
- Technologies of seamless transfer and uninterruptible power supply are key factors for microgrids.
- DC power with battery is quite reliable and effective.
- Without well-trained engineers, high-performance hardware and software are useless. Training operators and service engineers is extremely important for BCP.
- Scalability and flexibility of the microgrids will accelerate the return from the investment.

short and long term needs and solutions for enabling resilient system given recent events

- **Short time**
  - CAPEX: Who invests? Business model: Asset management, billing, etc.
  - Cost-benefit analysis
    - Maximize the value of microgrid
    - Budget is limited
  - Engineering: Tool for design (Cookie cutter)
    - Plug-in-play, flexibility of the system
      - DC power is more flexible!
- **Long time, *need to plan these changes, carefully!***
  - OPEX：Fuels, maintenance, over whole, etc.
  - Hardware performance: Aging, malfunctions, availability
  - Load management：Capacity of loads, scalability, fluctuation, change of needs
  - Personnel: Transfer, retile, education
  - Regulation/code/policy
  - Plan of Long-term operation and do drill/training/education

Evolution of microgrids



Sendai City, Green New Deal Project

Planned in FY 2012, 16 sites in Sendai city

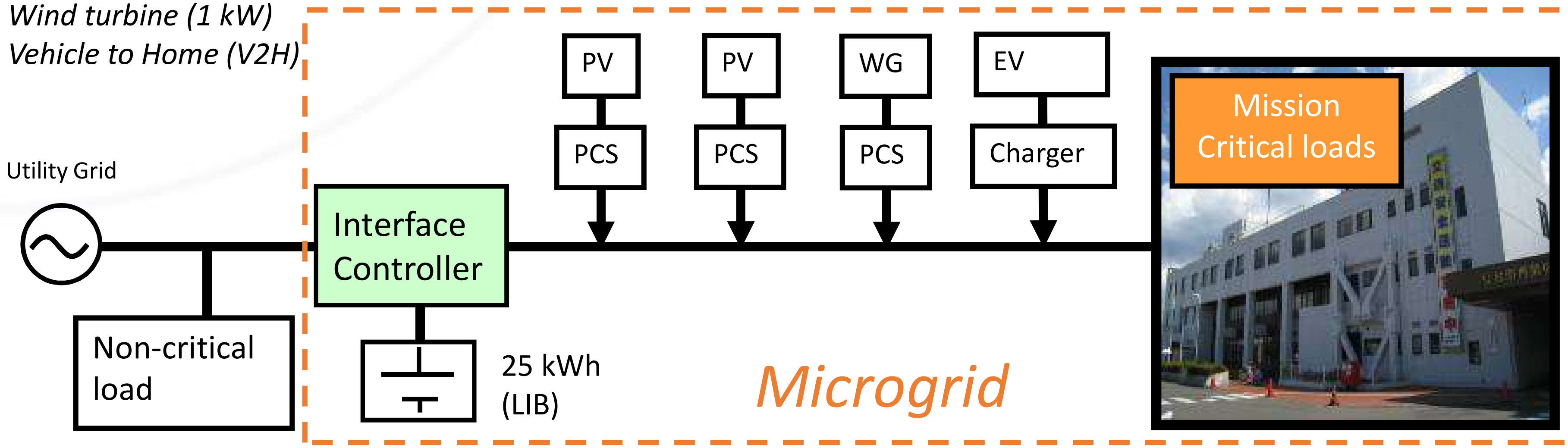
Outline

Sendai city officially decided to install disaster preventive power systems at up to 200 sites by FY2015.

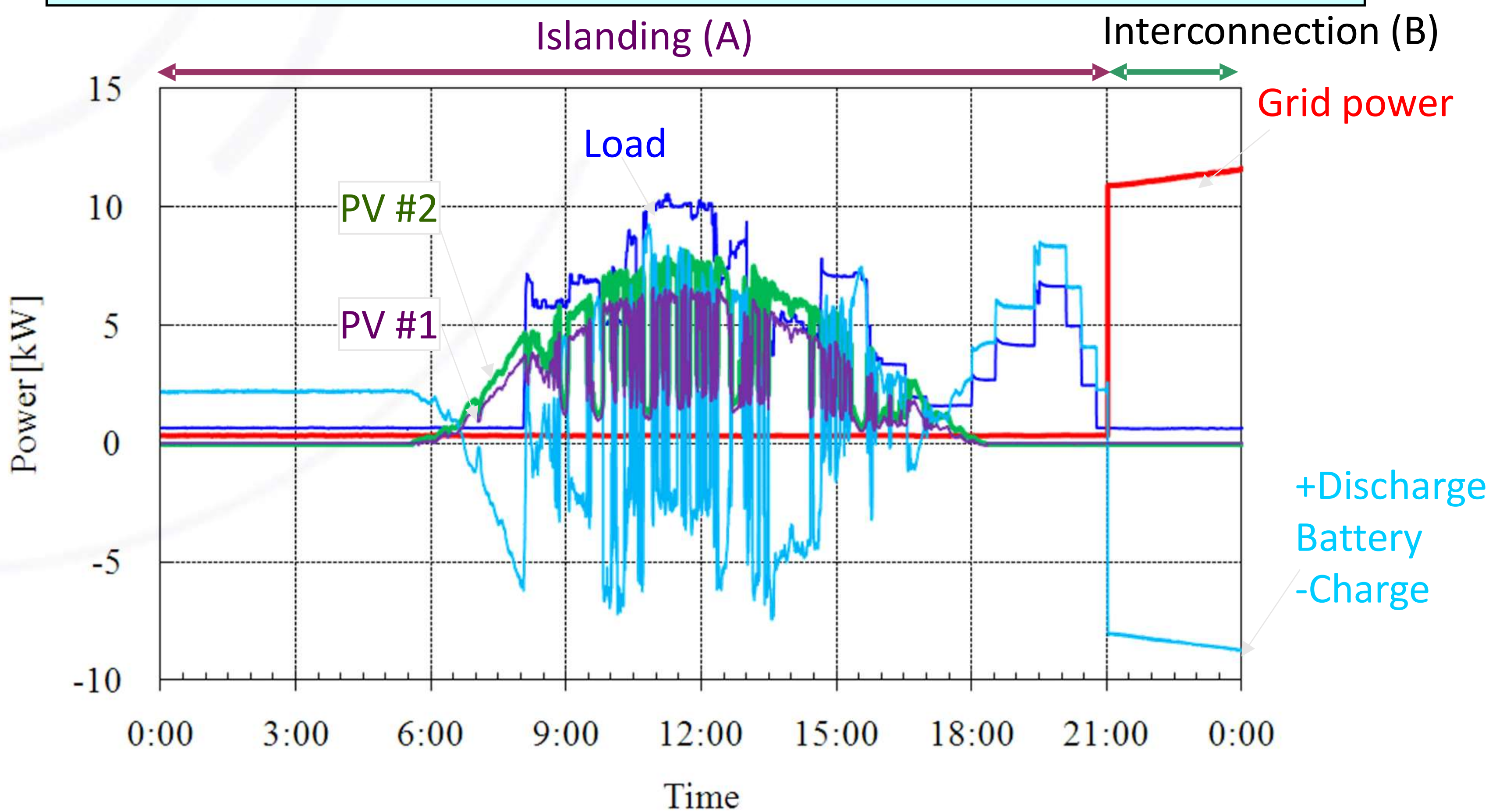
Main equipment/per site

- *Interface controller (ACSW + converter)*
- *PV panels (10 kW)*
- *Lithium-ion battery (25 kWh)*
- *Wind turbine (1 kW)*
- *Vehicle to Home (V2H)*


Opening ceremony, April 25, 2013



(A) Islanding operation with DES and battery
(B) Interconnection with battery charging
Seamless transfer between (A) and (B)

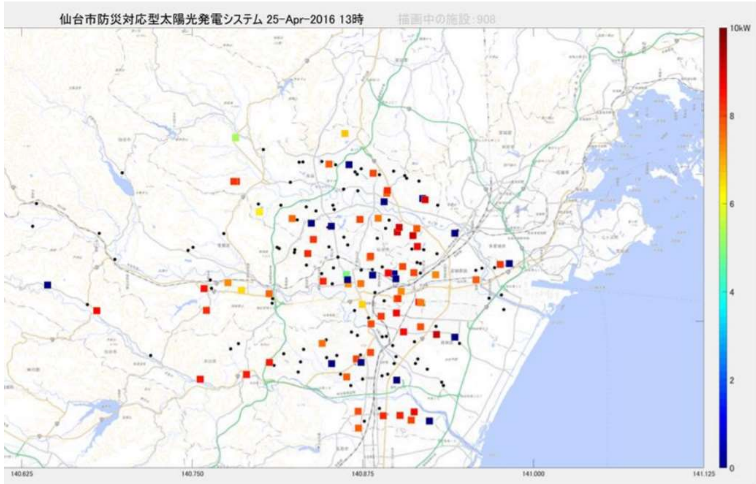


Introduction of disaster impact reducing solar power generation systems, to designated shelters in Sendai

In the Great East Japan Earthquake, supply of electricity, gas, gasoline, etc. was interrupted, causing various inconveniences in the initial response such as shelter management.

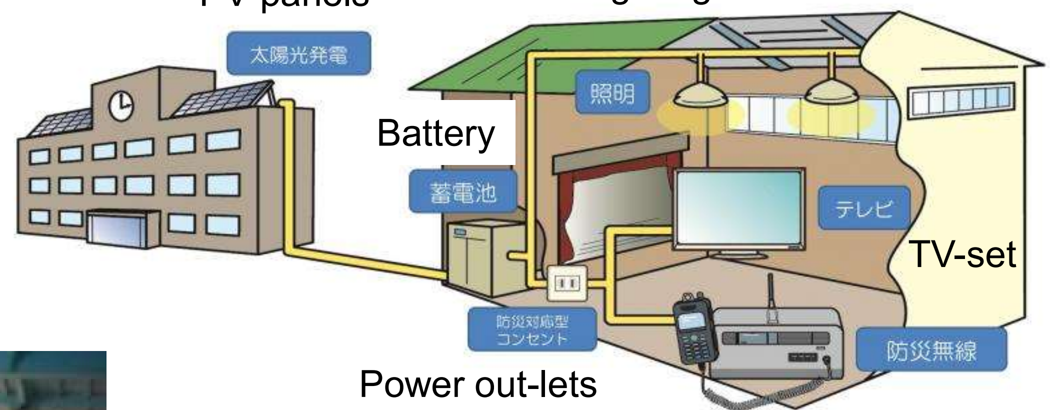
Based on this experience, in order to secure a self-sustainable power supply in the event of a disaster and reduce carbon dioxide emissions, 196 emergency shelters in the city, combined with photovoltaic power generation and storage batteries to respond to disasters.

Even if a long-term power outage occurs, by combining solar power generation and storage batteries, you can use information communication equipment such as disaster prevention radio and TV, lighting, outlets, etc. regardless of the weather.



Source: Sendai city web site

System utilization during disaster drills



During disaster drills, residents used LED lamps powered from disaster prevention outlets and disaster prevention altitude lighting. Even if a disaster occurs at night, necessary energy can be secured at the evacuation center, ensuring safety in emergency evacuation.

Source: Sendai city web site

Thank you for your attention

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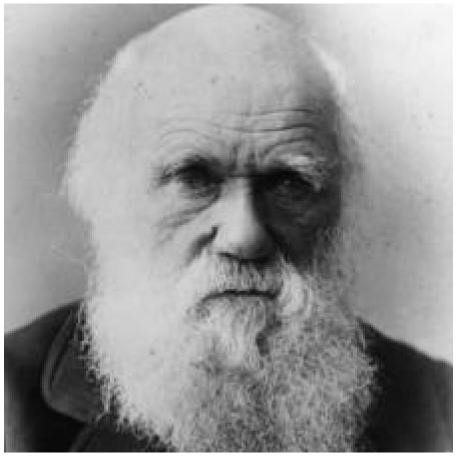
"It is not the strongest of the species that survives, nor the most intelligent, but the one most responsive to change."
Charles Darwin, British naturalist, geologist and biologist



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