Green-ILC AAA-2014 Report

Advanced Accelerator Association Promoting Science & Technology

2014 AAA Green-ILC Working Group

2015.05.27

English Version

Content

1 Introduction

The total electrical power consumption of the International Linear Collider (ILC) reaches 164MW at 500GeV center-of-mass energy. With 106MW the two main linacs are the most consuming components where 49% is used by the RF system, 30% by the helium refrigerator and 20% by the remaining equipment (air conditioning, water cooling, lighting, and control racks). The Green-ILC (G-ILC) project focuses mainly on new technologies and approaches to save, recover and recycle energy as well as on the use of renewable energy for particle colliders.

The main linac is simply the repetition of many merely identical cells (or cryomodules), then the optimization of the energy consumption and efficiency of this basic element directly improves the overall energy performance of the ILC. Increasing the efficiency reduces the power lost on heat waste which also, to be dissipated, consumes energy but it also reduces capital cost when fewer parts are needed to provide the same output power.

Large scale research infrastructures like the ILC have major impacts on the environment in terms of electrical power supply, heat waste recycling, water management, landscape integration and road traffic. G-ILC intends to make ILC a world-wide reference on handling these issues to the best benefit of the local people and of the society.

After colliding, both beams must be recycled or actually simply dump as in the current design. In total, 10MW released in 1ms short pulse at a 5 Hz rate must be absorbed. G-ILC will address conventional and advanced technologies to recover and recycle this energy keeping the produced radioactive elements at minimum.

ILC as a large energy consumer similar to big factories, data centers or medium cities must work towards sustainability to curb carbon emission and global heating. G-ILC will study the use of renewable energies in its energy mix focusing on production, storage and transport (smart grid).

Energy is one of the most prominent concerns of the 21st century and a global endeavor backed both by the private and public sectors. G-ILC addresses the same issues in a basic research framework which has proved to be innovative and able to manage large industrial programs. With a deep cooperation with the high-tech industry and energy experts, solutions will be found and tested and then transferred to the society.

The Technical Group of the Advanced Accelerator Association Promoting Science and Technology formed the Green ILC working group with the fact-finding mission to bring energy-saving technology to the ILC accelerator. Getting together the technical capabilities of cutting-edge companies, accelerator and experimental researchers, we propose to incorporate energy-saving technology to an advanced accelerator such as ILC.

This report is a collection of presentations given during meetings held in 2014/15. It is a first step towards greening the ILC.

Green-ILC WG Chair: Takayuki Saeki
AAA Technology Study Group Chair: Hitoshi Hayano

2 AAA Technology Study Group

Green-ILC Working Group

Green-ILC Working Group

To reduce the environment and social impacts as well as the operating cost of a large scale advanced accelerator, energy saving and high efficiency component are required from the design stage to the operation. In addition, the integration of renewable energy in the ILC mix is a necessary step to reach sustainability. The "Green ILC Working Group" set as part of the technical group has been created to cover these issues.

The suggestions from AAA technology studies in the 2014 fiscal year have also been included. The activities are summarized in the following table.

Green ILC・WG	Date	Green technology proposer and Technology presenter (affiliation, w/o title)
1-st	2014-2-25	Denis Perret-Gallix(LAPP/IN2P3/CNRS), Junpei Fujimoto(KEK), Atsuto Suzuki(KEK)
2-nd	2014-5-8	Yoshio Kawakami(Toshiba electron tube), Masato Noguchi(Maekawa), Tadashi Fujinawa(Riken), Junichi Honda(Solar power association), Mitsuo Takeda(Kabuki)
3-rd	2014-7-1	Junpei Fujimoto(KEK), Ken Watanabe(KEK), Hiroyuki Nishi(Shinnihon-Kucho), Tadashi Fujinawa(Riken), Denis Perret-Gallix(LAPP)

4-th	2014-9-24	Tadashi Fujinawa(Riken), Osamu Takehisa(NTT facilities), Takafumi Shimokouchi(Takenaka), Takayuki Saeki(KEK)
5-th	2014-12-10	Toru Shibagaki(Toshiba), Hajime Sakuma(NEC), Kentaro Otsuki(Tohoku Electric), Denis Perret-Gallix(LAPP), Takayuki Saeki(KEK)
6-th	2015-2-18	Kunihito Kikuchi(Fujikura), Naoko Nakamura(Maekawa), Manabu Miyamoto(MHI), Mitsuhiro Yoshida(KEK), Takayuki Saeki(KEK)

The presentations can be broadly organized in 4 sections: energy saving technology (10), energy recovery technology (2), storage technology of recovering energy (4), implementation of renewable energy (8). They are summarized in details in the following table. It should be noted, the energy-saving technologies presented during the 34th Technology Study meeting are also included.

Technology	**Sub-system**	**Report Title (concise)**	**Presenter (w/o title)**	**Affiliation (concise)**	**Meeting**
Power saving	RF System	CPD Klystron	Kawakami	Toshiba	G-ILC
		CPD Klystron Test	Watanabe	KEK	G-ILC
		Power Electronics	Yamada	Mitsubishi Electric	Technology Study
	Cryogenics	Helium compressor power saving	Noguchi	Maekawa	G-ILC
		HTS cryogenics	Nakamura	Maekawa	G-ILC
	Infra-structure	Friction reduction chemicals	Nishi	Shin-Nihon Kucho	G-ILC
		High-voltage Substation power saving	Fujinawa	Riken	G-ILC
		Data center power saving	Takehisa	NTT Facilities	G-ILC
		YBCO HTS cable	Kikuchi	Fujikura	G-ILC
		Smart Community	Shimokouchi	Takenaka	G-ILC
Energy recovery	Beam Dump	Energy recovery from beam dump	Fujimoto	KEK	G-ILC
		Related Beam experiments	Yoshida	KEK	G-ILC
Energy storage	Energy management	Co-generation	Osaki	MHI	Technology Study

		Iron energy storage	Hosoyama	KEK	Technology Study
		Power storage for power line	Sakuma	NEC	G-ILC
		Energy management	Miyamoto	MHI	G-ILC
Renewable Energy		Accelerator power saving	Suzuki	KEK	Technology Study
		New Energy Power Plants	Fujinawa	Riken	G-ILC
		LN2 Economy	Perret-Gallix	LAPP/IN2P3	G-ILC
		Green-ILC	Perret-Gallix	LAPP/IN2P3	G-ILC
		Renewable Energies and Environment	Perret-Gallix	LAPP/IN2p3	G-ILC
	Solar Power	Solar power generation	Honda	Solar Power Association	G-ILC
	Biomass Energy	Biomass power generation	Takeda	Kabuki	G-ILC
	Geo-thermal power	Geothermal power generation	Shibagaki	Toshiba	G-ILC
		Geothermal Power Station	Otuki	Tohoku Electric	G-ILC
	Wind Power	—			
	Marine power	—			

As a reference, find here the power consumptions computed for the ILC Technical Design Report (Vol 3.II, sec 11.4.4)*

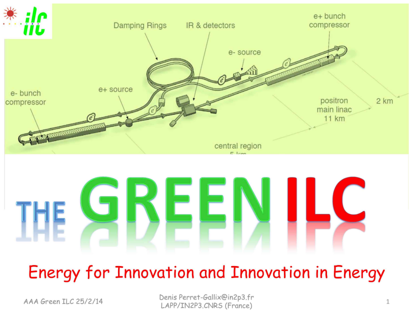
Table 11.6
Estimated DKS power loads (MW) at 500 GeV centre-of-mass operation. 'Conventional' refers to power used for the utilities themselves. This includes water pumps and heating, ventilation and air conditioning, (HVAC). 'Emergency' power feeds utilities that must remain operational when main power is lost.

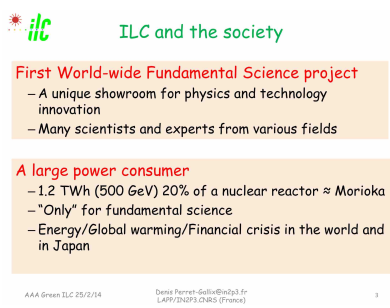
Accelerator section	RF Power	Racks	NC magnets	Cryo	Conventional Normal	Conventional Emergency	Total
e^- sources	1.28	0.09	0.73	0.80	1.47	0.50	4.87
e^+ sources	1.39	0.09	4.94	0.59	1.83	0.48	9.32
DR	8.67		2.97	1.45	1.93	0.70	15.72
RTML	4.76	0.32	1.26		1.19	0.87	8.40
Main Linac	52.13	4.66	0.91	32.00	12.10	4.30	106.10
BDS			10.43	0.41	1.34	0.20	12.38
Dumps					0.00	1.21	1.21
IR			1.16	2.65	0.90	0.96	5.67
TOTALS	68.2	5.2	22.4	37.9	20.8	9.2	164 MW
Rank:	1	6	3	2	4	5	
% :	42	3	15	23	13	5	

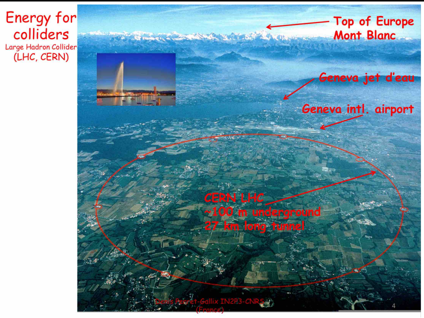
* http://edmsdirect.desy.de/edmsdirect/file.jsp?edmsid=D00000001021265&fileClass=native

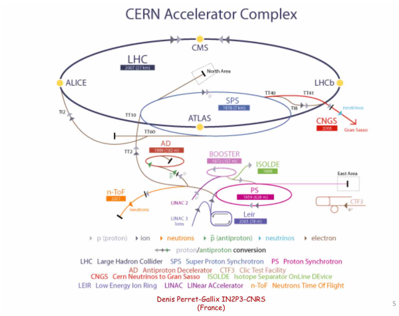
3 Green Technology Trends and Application to Accelerator in the World

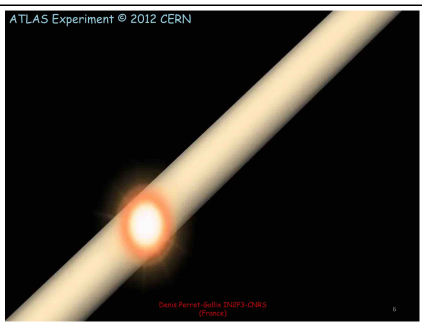
The Green-ILC
(Denis Perret-Gallix, LAPP/IN2P3/CNRS)

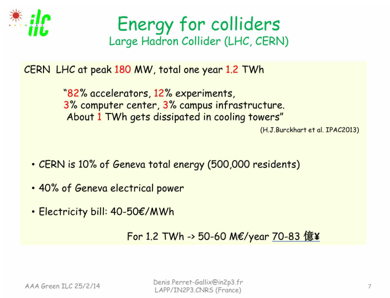


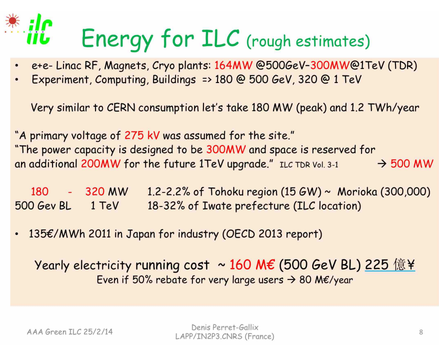


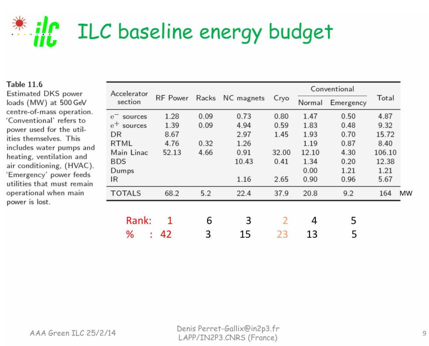












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					Normal	Emergency	
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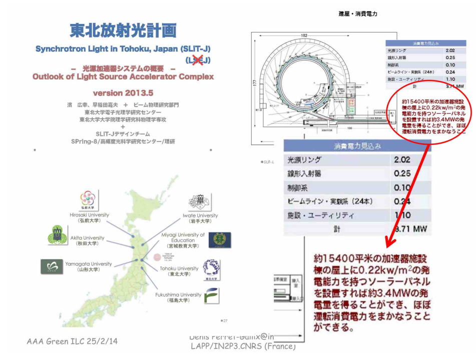
Some other Green Projects

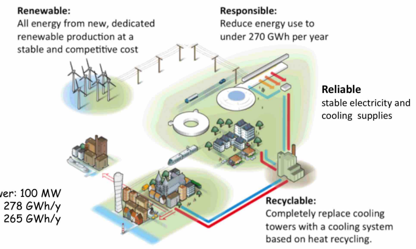
- Synchrotron light (Tohoku) 3.7 MW
- European Spallation Source (ESS) 100 MW
- Studies of the Future Circular Colliders 500 MW
- Hyperloop high speed train 21 MW
- Car factories and Mori Tower 38 MW
- Workshop " Energy for sustainable science"
- ……



The Green ESS

European Spallation Source -- 4R

neutron source



Wind Power: 100 MW
Machine: 278 GWh/y
Cooling: 265 GWh/y

Future Circular Collider Study - SCOPE

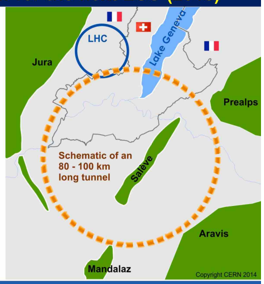
CDR and cost review for the next ESU (2018)

Forming an international collaboration to study:

- *pp*-collider (*FCC-hh*)
  → defining infrastructure requirements

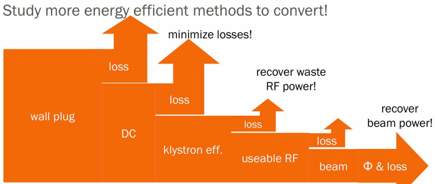
~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

- e^+e^- collider (*FCC-ee*) as potential intermediate step
- *p-e* (*FCC-he*) option
- 80-100 km infrastructure in Geneva area



Energy Efficiency

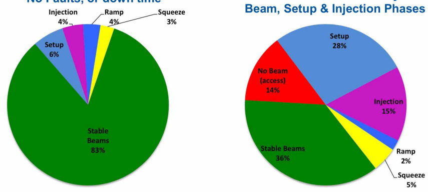
- For FCC-ee of major importance – 100 MW CW RF requires at least 200 MW from the grid to produce (in addition to cryogenic power mentioned above)
- Study more energy efficient methods to convert!



LHC Operational Efficiency

LHC Design
Minimum Time for each operation
10 hour Physics Coasts
No Faults, or down time

LHC 2012
Average Time in each phase
6 hour Average Physics Coasts
Faults and down time mainly in No Beam, Setup & Injection Phases



In spite of how it looks LHC operation in 2012 was very good !!

FCC-ee Power Consumption Estimates

Based on the 80km Machine Study – Should not be too different to a 100km version. Pre-injectors not included.

It includes the infrastructure scaled to the need for TLEP and not that which would be installed to allow a future installation of a pp machine.

TLEP (175)	MW
RF System	218
Cryogenics	24
Cooling & Ventilation	60
Magnet Systems	6
General Services	15
Experiments	25
Total	353

The Key Driver here is the RF system: Cavity characteristics and efficiency of the RF power sources (assumed 55%)

FCC-hh Power Consumption

System	LHC	FCC-hh
Power Converters	20	80
Machine Cryogenics	35	140
Cooling	20	80
Ventilation	14	56
RF	18	72
Other Machine	2.5	10
Experiments	22	30?
Total / MW	131.5	468

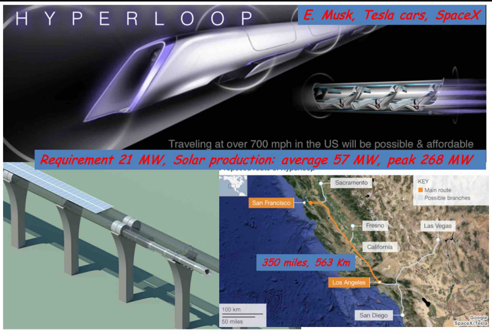
To first approximation:

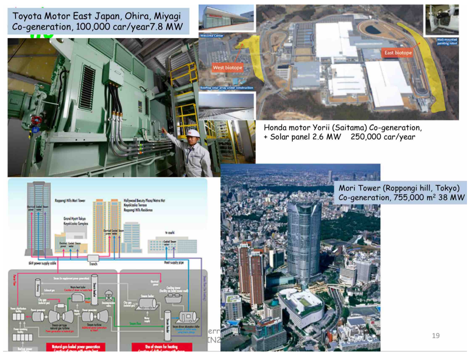
Most will scale to FCC-hh very approximately according to length (ie x4)

The Experiments are likely to be more than LHC but not by a large factor

Beware: This is a ball-park figure to set a rough scale!!

Clearly the Cryogenics is a key driver
But the infrastructure itself (cooling/ventilation) will also be a large consumer
The RF system itself (if >60MV is needed) is significant
➢ same R&D for ee and hh machines !!





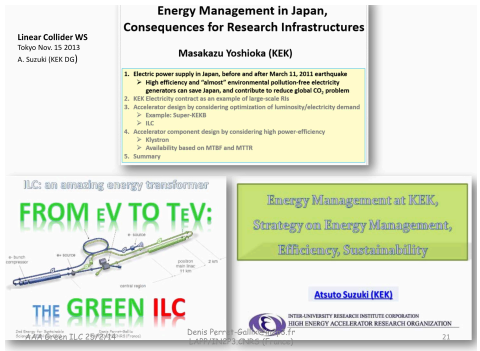
Energy for Sustainable Science

23-25 October 2013
CERN

2nd Workshop Energy for Sustainable Science at Research Infrastructures

- Campus and building management
- Co-generation
- Computing energy management
- Energy efficiency of the facilities
- Energy management, quality, storage
- Energy management technologies developed in Research Facilities
- Waste heat recovery

CERN — EUROPEAN SPALLATION SOURCE — ERF European Association of National Research Facilities



Green ILC strategy

1. Energy Saving: improving efficiency
2. Energy Recovery: recycling energy
3. Energy Production: Renewable energies
4. Energy Storage
5. Distribution and Management: Smart Grid

➡ DESIGN

Green ILC
Energy Saving

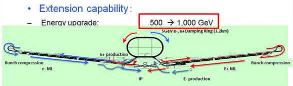
On components:
- klystrons R&D for higher efficiency
- cryocooler and cryogenic system optimization
  - New ideas: Thermoacoustic Stirling Heat Engine Pulse Tube
- ILC Lattice optimization

On operation
- Power reduction during idle periods:
  - system on standby and energy saving mode
  - More effective if made on design
  - Long running period (fewer, but longer shutdown due to cryo)
- Increase reliability (to avoid down time)

Power Balance of Consumption and Loss in ILC

Linear Collider WS
Tokyo Nov. 15 2013
A. Suzuki (KEK DG)

Requirements from Physics Exp.
- Basic requirements:
  - Luminosity : $\int Ldt$ = 500 fb⁻¹ in 4 years
  - E_{cm} : 200 – 500 GeV and the ability to scan
  - E stability and precision: < 0.1%
  - Electron polarization: > 80%
- Extension capability:
  - Energy upgrade: 500 → 1,000 GeV



ILC 500 GeV Total Power : ~200 MW

Improve efficiency

		loss rate
Infrastructure : 50 MW		50 % : 25 MW
RF System : 70 MW		50 % : 35 MW
Cryogenics : 70 MW		90 % : 60 MW
Beam Dump : 10 MW		100 % : 10 MW
200 MW		~ 130 MW

Obligation to Us

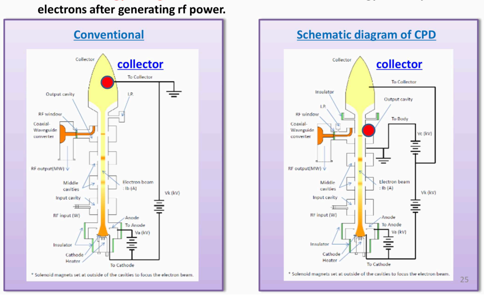
Increase recovery

How to Improve RF Efficiency

Linear Collider WS
Tokyo Nov. 15 2013
A. Suzuki (KEK DG)

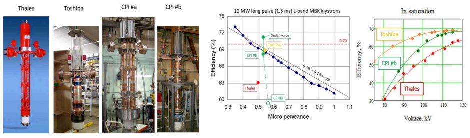
R&D of CPD (Collector Potential Depression) Klystron

CPD is an energy-saving scheme that recovers the kinetic energy of the spent electrons after generating rf power.



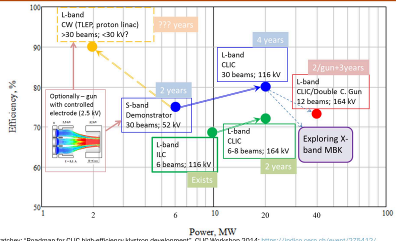
Multi-beam klystrons: State of the art

- Space charge is limiting efficiency → many small beams to reduce space charge effects.
- State of the art: Developed for ILC/X-FEL, 1.3 GHz, 10 MW peak (1.5 ms · 10 Hz), $\eta = 65\%$.



Igor Syratchev, CLIC Workshop 2014

90% efficiency on the horizon?



I. Syratchev: "Roadmap for CLIC high-efficiency klystron development", CLIC Workshop 2014: https://indico.cern.ch/event/275412/

IOTs

Inductive Output Tube: density modulation with a grid (like a tetrode) output to a cavity (like in a klystron). IOT shorter, less gain than klystron. IOT in 70 kW class used for DVB transmitters.

- Klystrons reach maximum efficiency only in saturation.
  - Is it necessary to back-off in operation? (we did during LEP2!)
- IOTs (Inductive Output Tubes) may be better in this respect:

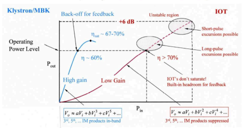
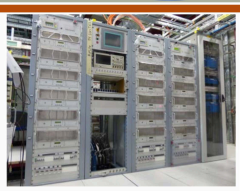


Illustration from CPI

Solid state?

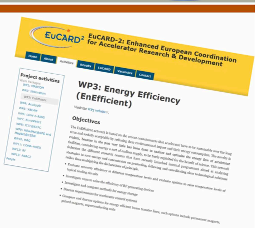
- Picture shows a 100 kW installation for Linac4 (352 MHz)
- 100 MW may not be possible today (or at least much more expensive), but investment into R&D may pay off!
- Interesting feature (concerning availability, to be studied) – one may consider a module replacement while the systems continues to run at nominal performance with small built-in fault tolerance margin…



The goal of the Linac4 project is to build a 160 MeV H− linear accelerator replacing Linac2 as injector to the PS Booster (PSB). The new linac is expected to increase the beam brightness out of the PSB by a factor of 2, making possible an upgrade of the LHC injectors for higher intensity and eventually an increase of the LHC luminosity

Energy Efficiency

- High efficiency, high power RF generation is needed for many future accelerator projects (proton drivers for several applications, linear colliders, material test facilities) and certainly has impact beyond the accelerator community.
- A network called "**Energy Efficiency**" has started to pick up momentum inside the European Project EuCARD2, see http://eucard2.web.cern.ch/activities/wp3-energy-efficiency-enefficient
- You are invited to become part of this network!



Green ILC
Energy Recovery

– Heat recovery from cooling systems:
  - More than 80% of the consumed electrical power is lost as heat: highest temperature preferable
  - Sterling engines and heat pumps, thermoelectricity, heat recovery steam generators, …
  - Heat/cool close by cities, green houses, fish farms, …
  - Recycling efficiency ? Cooling efficiency ? Saving/investment ratio ?
  - Many Industrial applications

– Beam energy and beam dump energy recovery
  - Linear collider (single pass) vs circular collider (recycling beam), but
  - 10-25 MW/beam … a lot of heat and high-radiation
  - Energy Storage
  - New idea … Plasma deceleration dumping

Plasma Deceleration Dumping

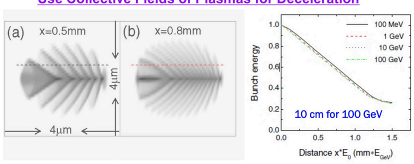
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 13, 101303 (2010)

Linear Collider WS
Tokyo Nov. 15 2013
A. Suzuki (KEK DG)

Collective deceleration: Toward a compact beam dump

H.-C. Wu,[1] T. Tajima,[1,2] D. Habs,[1,2] A. W. Chao,[3] and J. Meyer-ter-Vehn[1]
[1]Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany
[2]Fakultät für Physik, Ludwig-Maximilians-Universität München, D-85748 Garching, Germany
[3]SLAC National Accelerator Center, Stanford University, Stanford, California 94309, USA
(Received 10 December 2009; published 5 October 2010)

Use Collective Fields of Plasmas for Deceleration



- The deceleration distance in the underdense plasma is 3 orders of magnitude smaller than the stopping in condensed matter.
- The muon fluence is highly peaked in the forward direction.

Green ILC

- Energy Production: Sustainable energies for ILC
  – Study the (dis)-advantages of the various sources: solar, wind, geothermal, sea, …)
    - A case study: Availability, Price, Flexibility, Potential to improvement, Environmental impact
  – Find the best mix to cover ILC specific needs ? 24/7, long shutdowns
  – Accommodate the ILC component power requirements to the various energy sources distinctive features:
    - RF power converter: PhotoVoltaic (DC) , wind/sea (variable AC, DC), geothermal,
    - Cryocooler or asynchronous liquefactors, Solar (DC motors), wind/sea Variable AC, or mechanical compressor (no electricity)
    - New cooling technology (
- Energy Storage
  – liquid helium, SMES(Sc Magnetic Energy Storage), Flywheel energy storage, Hydrogen, Hydro (Dam), Compressed air, Batteries,
- Distribution: Smart (Local) GRID:
  Full scale multi-sourced, AC/DC, GRID management and control
  – Smooth and rapid switching between energy sources, including conventional supply
  – Energy Monitoring, Management and forecast: production, storage and backup

ILC site

The Japanese GRID

Jones, R. S. and M. Kim (2013), "Restructuring the Electricity Sector and Promoting Green Growth in Japan", *OECD Economics Department Working Papers*, No. 1069, OECD Publishing.
http://dx.doi.org/10.1787/5k43nxrhfjtd-en

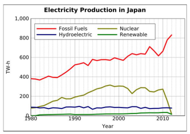
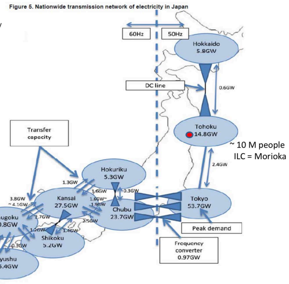
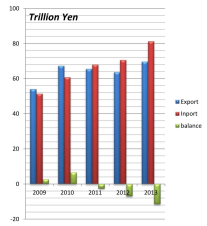


Figure 5. Nationwide transmission network of electricity in Japan

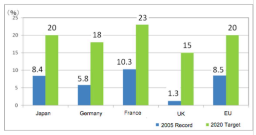


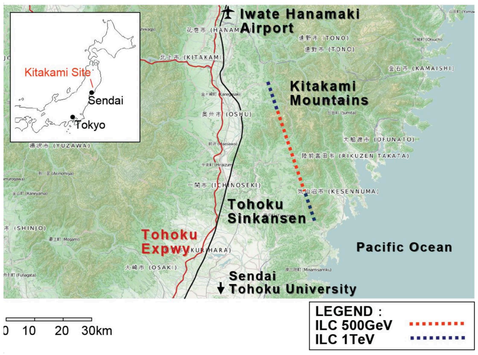


-12 TYens

Yen depreciation and energy

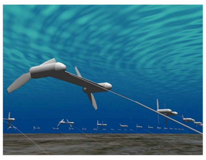
Renewable energy share 2005-2020





Wind/Marine Energy

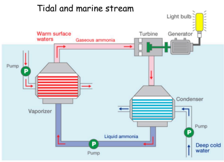
2 MW Goto island prototype



Tidal and marine stream

2.3 GW installed, none failed after 3/11

Wind Projects
6 floating 2MW wind turbines off Fukushima
up to 80 in 2020



Sea temperature gradient

Biomass/biofuels Energy

Idemitsu Kosan Co. 5 MW

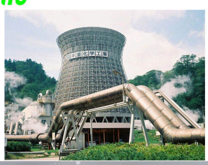
Miyasaki, Nishinippon Env. Energy co. 11.7 MW

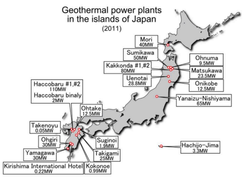
Installed 2.3 GW (2011)
very little progress since 2011

Many sources including:
Rice, fishery and agricultural wastes
Algae
Other cattle and human wastes

Co-generations heat and electricity

Geothermal Energy





Installed 2011 : 0.5 GW.
Geothermal potential sources : ~ 20 GW

No substantial progress since 2011

But:

- Avoid National Parks
- Get agreement with the onsen industry
- No Fracking

Photovoltaic and Thermal Solar energy

10 MW Komekurayama 30 km Fuji-san (TEPCO)

70 MW in Kagoshima started Nov. 7 2013

Installed: 8.5 GW
Projects:
341 MW in Hokaido
100 MW Minami Soma

2009 Target Japanese gov.
28 GW of solar PV capacity by 2020
53 GW of solar PV capacity by 2030
10% of total domestic primary energy demand met with solar PV by 2050

Solar thermal Energy

C. Benvenuti
CERN Physicist

Funny note
ILC: an amazing energy transformer

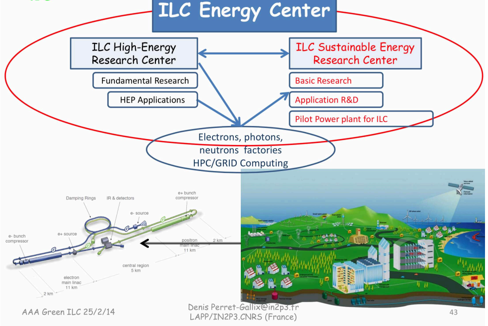
Assuming an ILC powered by photovoltaic energy:

Energy at the particle level:
from 1 eV to 1 TeV:
12 orders of magnitude, a Tera scaling, x 10^{12}

Energy concentration:
Ratio of the PV surface to collect 82 MW(one beam) to the beam size:
20 orders of magnitude, almost Zetta scaling, x 10^{20}

But energy transformation efficiency:
Beam power/AC power: 6-7%

Global organization for Green ILC



ILC Sustainable Energy Research Center

- Two main objectives:
  - R&D on Sustainable Energies, attracting the best experts.
  - Powering ILC
- Industry participation
  - Energy issues relate to most of the industry (much more than HEP)
  - Twofold interest: be part of a global research endeavor and reach ILC market
  - ILC achievements: a showcase for the companies
- Institutes and organizations over the world can be involved:
  - In Japan: JCRE (Japan Council on Renewable Energies), JREF (Japan Renewable Energy Foundation), ..
  - In the world: IEA, NREL (US), CREST, Narec(UK), CENER(SP), ..

However:

- Must run parallel to ILC, minimum impact on ILC timeline
- Must have its own specific budget from:
  - public programs, governmental and regional (EU) plans (US-EU energy council, …)
  - Industry participation and contribution

Main missions

- Contribute to the most advanced and promising researches:
  - Basic research … is the most needed and less funded
    - Nanotech for energy production and storage, for lighting, …: graphene, nanotubes, quantum dots, …
    - Biomimetic research (artificial photosynthesis) and quantum effects in solid states
    - New materials for: catalysts, fuel cell membranes, high-Tc SC, solar cells high efficiency
    - Low energy harvesting devices, STEG (thermo-electricity), …
    - Characterization tools and computer modeling
  - Technology and engineering (devices and systems)
    - Hybrid systems, best mix, energy transformation, matching energy source and accelerator components
    - Specific equipment like: Solar Powered Cryocooler (DC compressor, Thermoacoustic Stirling Heat Engine Pulse Tube), solar energy to RF, fuel cells for computing systems
    - R&D on biomass, geothermal, wind/stream turbines
    - Smart GRID
- Power the ILC:
  - Identify power plant locations with low environmental impacts.
  - Design and build pilot power plants (a few 10 MW each) from various complementary energy sources for real scale studies and substantial ILC power supply.
  - Build the ILC Smart Grid with connection to: conventional grid, pilot plans, storage

Can the ILC project reach energy self-sufficiency? How and when ?

Benefits for Energy Research

Research in a cross-disciplinary and global center.

"*Scientific work is still too fragmented and specialized, with a focus on incremental change rather than on transformation.*" OECD Sustainable Energy Forum 2013

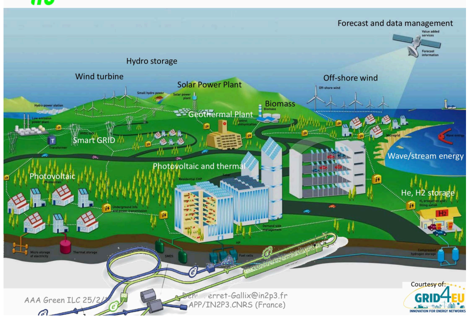
Focus on basic research, rarely done in other frameworks: Innovation and Industry target short term returns

"*Science can be perceived as working too much for vested corporate interests and not enough for the public interest*" OECD Sustainable Energy Forum 2013

Comprehensive framework: From basic research to pilot plants

Synergies with HEP/accelerator:
- Material analysis (photon factories (XFEL), neutron sources, …)
- Large computing centers (GRID), Geant4 simulations, turbulences,
- Expertise in advanced electronics, large electronics and computing system management,
- Expertise in very high vacuum, surface treatment and cleaning, …
- Expertise in large scale manufacturing industrialization (cavities and magnets): from design to commissioning (quality control, …)

ILC center futuristic view



Gradual Multi-Staged Implementation

1. As a backup of the conventional power supply (~ 7 MW current diesel engines)
2. To cover buildings energy (electricity and heating) (~ 10 MW) (zero energy)
3. To power some parts of the ILC components: some of the cryo plants, computers, …. (10-20 MW)
4. To power more of the previous components (30-40 MW)
5. To power some of the klystrons (100 MW)
6. All 500 GeV ILC electrical supply (170 MW)
   - Conventional power supply is now in backup mode
7. Get ready for the 1 TeV (additional 150 MW)

ILC Sustainable Energy Research Center Location

- Most genuinely close to ILC, in Kitakami vicinity
- But not necessarily, through special agreements between electrical power utility companies
  - could be anywhere in Japan or even with plants disseminated at the most favorable locations
  - Anywhere in the world, could be part of the country running costs contributions, but should be sustainable energy… reinventing the Data GRID model

Green ILC tasks (some)
Design and R&D

- Estimation of the energy saving and recovery potentials for all major ILC components
- Setup a baseline project and an advanced research line on more innovative technologies.
- Evaluate the impacts on the ILC project in term of:
  - ILC Design modification, implementation and timeline
  - Budget: additional spending and saving
- Design a global sustainable energy project for the ILC
  - Propose an "ILC Energy Center" global organization
  - Identify short term renewable energy pilot plants with build-in upgradability
  - Identify basic energy researches in line with the ILC project

Green ILC tasks

Governance and Communication

A global open-research framework between Research, Academy, Industry and (Local) Government (Citizens)

- First time in the world
- A pluri-disciplinary R&D dedicated to Energy
- Open to foreign research organizations and companies
- Intellectual Property issues, cross-funding, …

Green ILC Communication

- Towards the ILC community: LCWS workshops and other CERN LHC, CERN FFC, ESS, …..
- More general Conference on "Power Innovation" for large research/industrial infrastructures
- Within the industries involved
- Toward the public and the local citizens

  Prototype: http://tinyurl.com/mj8t3o3

Green ILC Feasibility report by 2014-2015

Conclusions

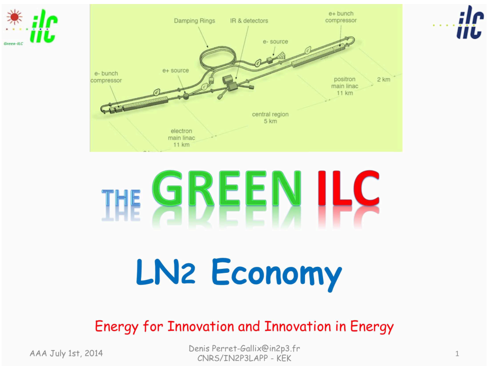
- ILC being the size of a city, is a real scale workbench to develop, maintain and manage a mix of sustainable energy sources.
- HEP: a driver for innovation: a unique opportunity to link HEP and Energy R&D in an ambitious but rewarding endeavor:
  - Societal impacts:
    - One of the most important issue: Energy, boost basic energy research which is most needed today
    - Raise ILC and fundamental research public visibility and appreciation
    - Better local appraisal: ILC provides rather than consumes energy resources
  - Great saving in running cost particularly if R&D/infrastructures are supported by a separate additional budget. ILC is a (very) long term effort, investing in green energies makes sense.
  - Better flexibility in ILC operations (less GRID dependence)
- Additional motivations for the decision makers: ILC goes beyond basic science
  - In Japan:
    - Revitalization of the economics (Abenomics), Re-industrialization after Tsunami in Tohoku, Global cities (Japan Policy Council), industry (AAA) and internationalization
  - Elsewhere: fewer incentives. But energy is a big and motivating issue for everyone

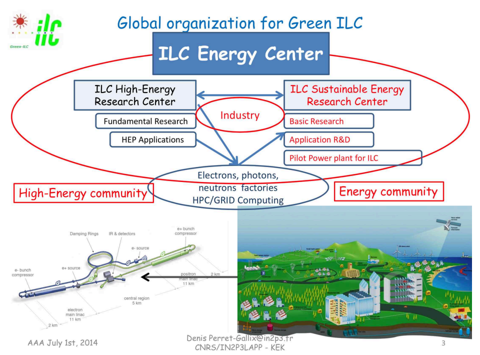
Additional slides

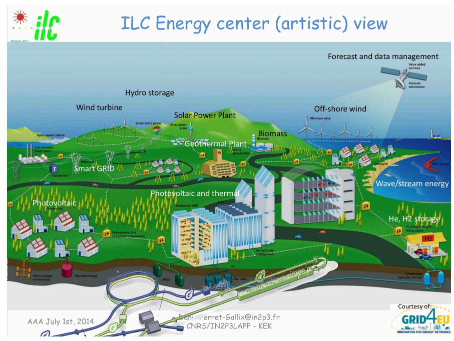
Renewable energy Japan (METI)

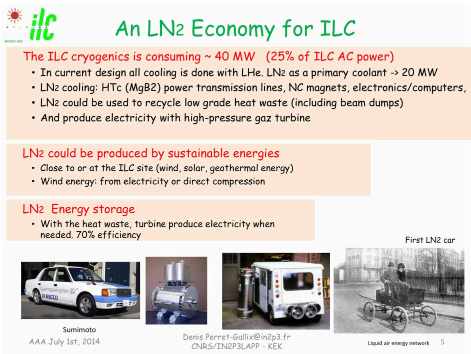
Energy Source	Total capacity before FY2011	Total capacity starting operation in FY2012	Total capacity starting operation in FY2013 (as of May 31, 2013)
Photovoltaic power (for households)	4.4 GW	1.269 GW	0.279 GW
Photovoltaic power (non-household)	0.9 GW	0.706 GW	0.961 GW
Wind power	2.6 GW	0.063 GW	0.002 GW
Small and medium hydropower (1,000 kW or more)	9.4 GW	0.001 GW	0 GW
Small and medium hydropower (less than 1,000 kW)	0.2 GW	0.003 GW	0 GW
Biomass power	2.3 GW	0.036 GW*	0.038 GW
Geothermal power	0.5 GW	0.001 GW	0 GW
Total	**20.3 GW**	**2.079 GW**	**1.280 GW**

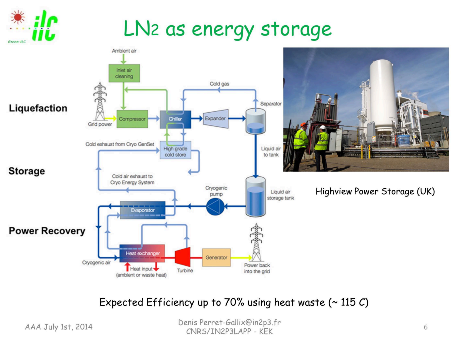
LN_2 Economy
(Denis Perret-Gallix, LAPP/IN2P3/CNRS)

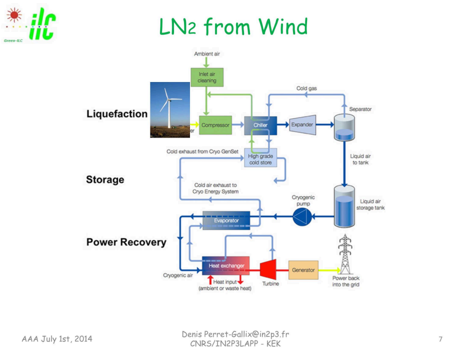


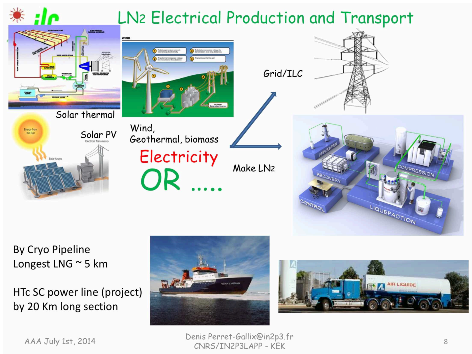




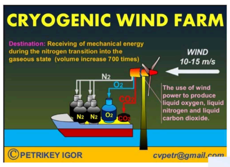






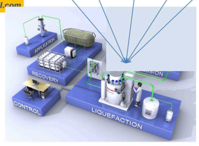


LN2 direct from wind, no electricity … ???



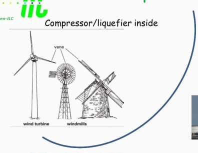
Only compressor in the nacelle

Or …



LN2 process cycle

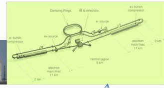
Compressor/liquefier inside



LN_2 →

- Cryocooler may save 50% electrical power
- Cooling NC magnets
- HTc power Transmission lines
- Cooling electronics and computers

Energy storage



LO_2, LAr, SCO_2 Dry ice

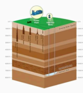
To Industry — For Cooling or Sequestration

LN2 — heat waste

Turbine → electrical generator

N2 gas applications — Electricity Back to ILC/GRID

i.e. Drying and preservation industry



Air cleaning !!!

LN2 for ILC, just as an example Needs R&D

Many positive aspects:
- Negative (less than zero) carbon emission technology, air cleaner
- Important cryogen for ILC:
  - Cooling: cryocooler, HTc transmission lines, ..
  - Heat waste recovery
  - Storage: 1 gazometer (like for NLG): ILC runs ~ 4 days
    - Fast startup (minutes)
    - Long life-time

Applications to industry
- Energy Storage
- Heat waste recovery
- Drying

Safety issues, specially in ILC tunnel:
- N2 gas suffocation
- Cryogenic fluid hazard
- LN2 may liquefy ambient oxygen

Other discussions …. Hydrogen economy

Soon at: Research-up.kek.jp/group/Green-ILC

Green ILC

Energy for Innovation, Innovation in Energy

Home | Blog | Archives | Energy Saving | Energy Recycling | Sustainable Energies | Contacts | Search

MAR 30TH, 2014

The Green ILC Project

ILC, the International Linear Collider, is the next fundamental science project in high energy physics and the first ever true global basic science center.

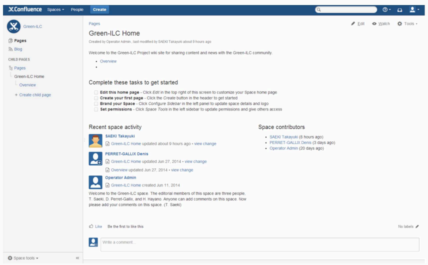
What CERN did for the European HEP community, ILC will do for the world. But the e+e- ILC project may go even beyond mere fundamental science and contribute to one of the world most pregnant issue: Energy, not merely high-energy but, more generally: energy for the society.

Artistic view of the ILC center in Kitakami (Japan)

The ILC scientific goal is simple: high precision study of the Higgs particle recently discovered at LHC (CERN) and other signals LHC could possibly single out. New effects will also be searched for, effects which could have been missed by the LHC due to the heavy background. Higher precision here concerns, more particularly, the various Higgs couplings, limited at LHC, in part, by the

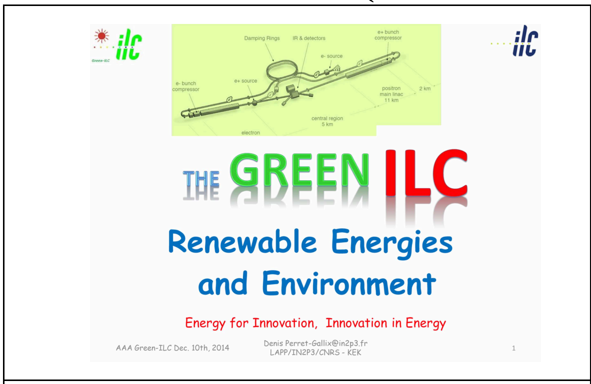
Recent Posts

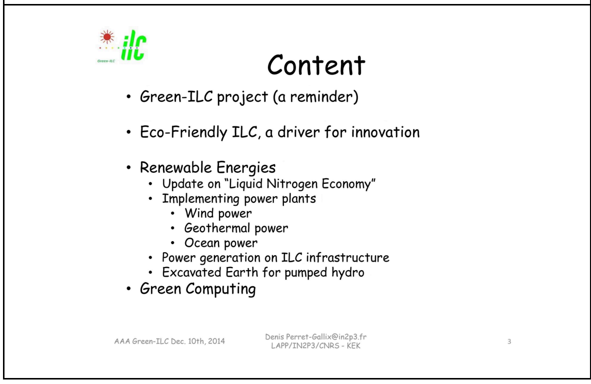
Wiki site for Green-ILC internal discussion:
http://wiki.kek.jp/ Space-> Green-ILC

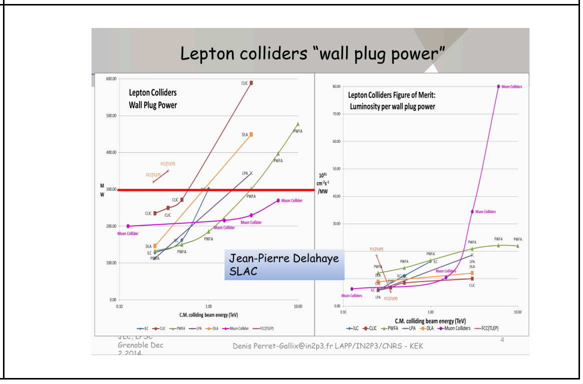


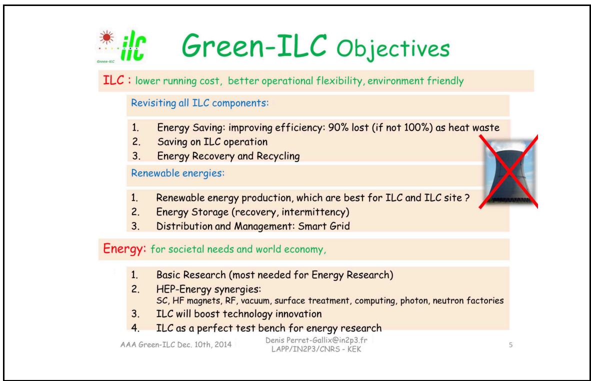
Thank you

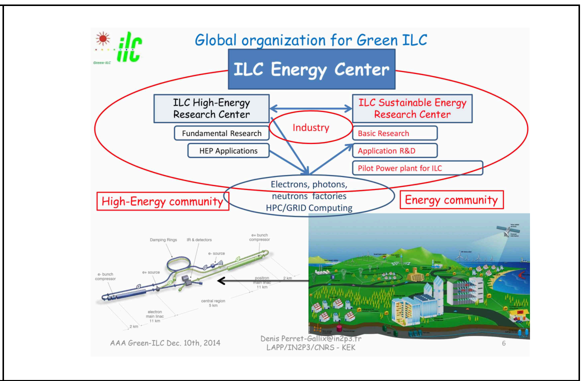
Renewable Energies and Environment
(Denis Perret-Gallix, LAPP/IN2P3/CNRS)

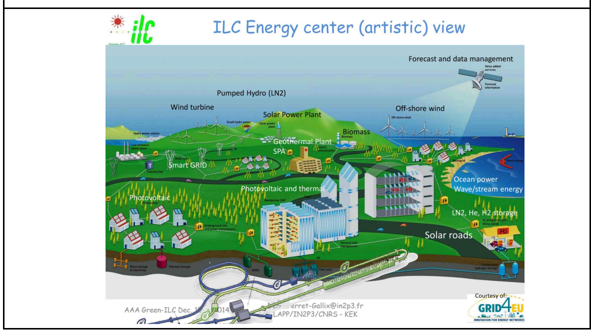


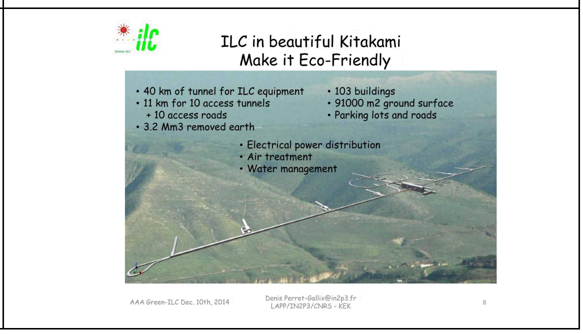












ILC: an Eco-Friendly Model

We know how to build ILC, let's make it beautiful.

- Conserve resources: land, water, air, energy
- Minimize pollution
- Keep it aesthetic

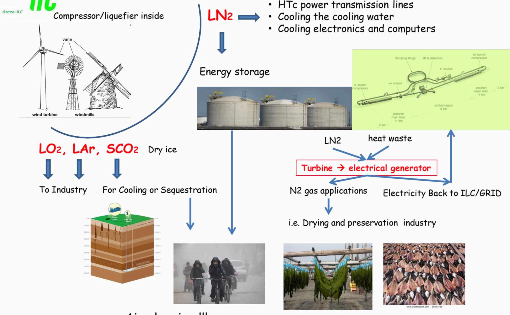
- For the quality of life at ILC site and for the local people
- For Japan and the world: ILC should be a model… should be inspiring
- A green field project: new concepts, new methods, new technologies: Rewarding to the society

- Be ready for environmental impact evaluation (by the local Gov. and people)
- Should be planned from the start, for quality and efficiency
- Driver for innovation: Business opportunities and growth potential
  - Mitigation of construction impact, landscape (re)design, energy plant integration, gardening,
  - Transportation and security: personnel and equipment over ~ 30-40 km long lab. Drones, balloon, …
  - Water and air management,

LN2 Economy Update

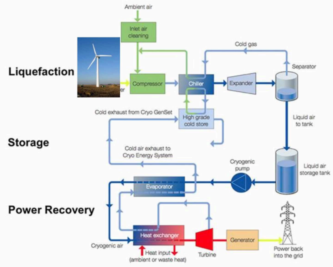
LN2 process cycle

- May save 30-50% on cryocooler consumption
- HTc power transmission lines
- Cooling the cooling water
- Cooling electronics and computers



Air cleaning !!!

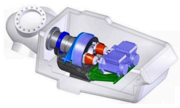
LN2 from Wind



Hydraulic Wind engine

"Liquid nitrogen economy" update:

- The Fukushima Offshore Wind Consortium project update:
- November 2014: 7MW first large scale hydraulic wind engine (MHI, Artemis)

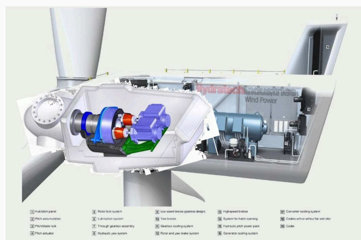


Many technical advantages:

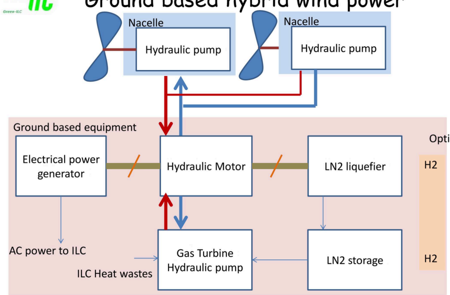
- Smaller, lighter nacelle
- Less mechanical parts and vibration
- Hydraulic accumulator
  - Larger wind speed range
  - No electrical frequency converter
- Easier maintenance at ground level

Good for the LN2

- "Base" based LN2 liquefier
- Many mills to one liquefier
- Hybrid: LN2 and electricity



Ground based hybrid wind power



Implementing Sustainable Power plants for ILC

Access tunnels: Power plants

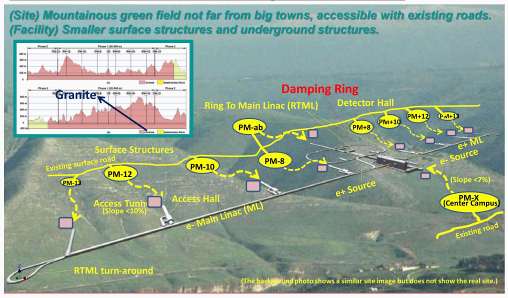
- 10 access points on ILC main Linac
- Proposal: Each house a renewable energy plant
- ~ 10-20 MW at each of the 10 tunnel/pit access
  - 3 - Geothermal/biomass: close to cities, ILC lab site
  - 3 - Wind power: electricity and LN2:ILC lab site, costal side
  - 3 - Solar (best orientation)
  - 3 - 1 - Ocean Power: ocean side

~ Total 100-200 MW

ILC Candidate site in Kitakami, Tohoku

Global Design Effort - CFS

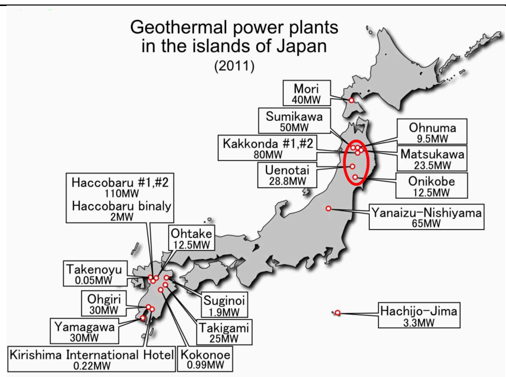
Asian Site Conventional Facility – Introduction



Geothermal power

- Japan has a huge potential
- No fracking, medium depth…
- Let's work with the onsen/spa industry for hybrid projects
- Output warm water: Many applications:
  - Onsen/spa for the local community
  - Heating close-by cities/villages
  - Greenhouses for vegetable and flowers growing
  - Fish farming needs to adjust water temperature

Similar for Biomass power



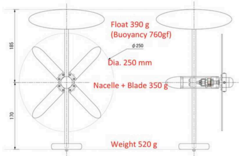
Geothermal Energy and SPA center

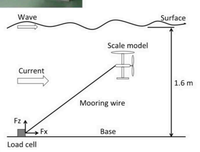
Iceland Svartsengi

- Geothermal plant: electricity 75 MW, thermal 150 MW
- 37 years of operation
- 600 m drill 240 C + 1000m and 2000m steam wells
- Hot drinking water to the city

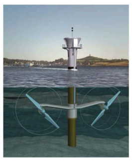
Swartsengi Power plant and Blue lagoon

Ocean Power (by Tsumoru Shintake, OIST)





- Many big projects:
  - Little impact on landscape
  - little intermittency, but variable power
  - Could be close to the shore
- Prof. T. Shintake future presentation



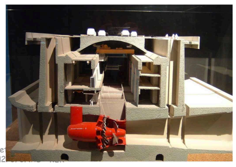
0.5 MW France

Tide power (Canada)

Tidal power

Rance Tidal Power station (1966), France

Type of dam	Barrage
Length	700 m (2,300 ft)
Reservoir	
Tidal range	8 m (26 ft)
Power station	
Type	Tidal barrage
Turbines	24
Power generation	
Nameplate capacity	240 MW
Capacity factor	40%
Annual generation	600 GWh



Solar power on Infrastructure

Infrastructures, not very eco-friendly, but necessary,
Better to use them to produce energy ?

Assuming: solar panels (thermal or PV) ~200 W/m2

- ILC Buildings: ~ 103 buildings ~ 91,000 m2 (80%) -> ~15 MW
- Roads: 10 tunnel access → 10 semi-private roads (1-2 Km each)
  - ~ 10-20 km
    - Side road: * 3m = 30-60.000 m2
    - Top road: * 10 m = 100-200,000 m2
- Parking lots: covered by solar panels

- PB.: cleaning, snow, support structures, storage, … price …

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"Renault" car company to install 450,000m2 of solar panels: 60 MW
140W/m2

Shandong Huayi Sunlight Solar Energy
115W/m2

SRB and CERN: Thermal panels, Geneva airport roof

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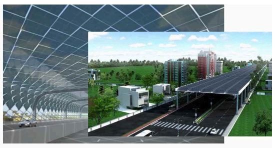
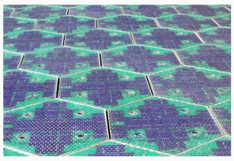


http://www.greenpepperenergy.com/index.php/roof-over-roads-to-tap-solar-power/



Solar roadways

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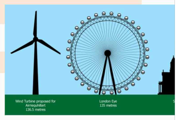
Visually disruptive equipements

Industrial complex, reuse of polluted zone,

Fos sur mer (France)

Off-shore

Amusement parks (Ferris Wheel ~165 m high)



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Excavated earth for pumped hydro dam

~ 3.2 Mm^3 will be removed from tunnels digging
Can be used to build earth dams see for comparison:

Kutataragi Pumped Storage Power Station (奥多々良木発電所) 1.9 GW
Kansai Electric Power Company (Hyōgo Prefecture

Kurokawa Reservoir (3.6 Mm^3 earth)
98 m tall, 325 m long

Tataragi Reservoir (1.4 Mm^3 earth)
64.5 m tall, 278 m long

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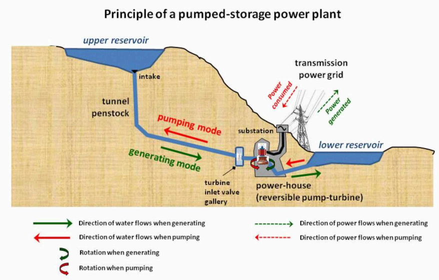

Energy Saving in Computing

Suiren, KEK computer ranking 2nd in the GREEN500 Nov. 2014 listing

- ~ 5 GFLOP/S/W for ~ 0.185 PFLOP/S submersion liquid coolant fluorinet
  http://www.kek.jp/ja/NewsRoom/Release/20141121140000/ Tadashi Ishikawa (KEK)

Green500 Rank	MFLOPS/W	Site*	Computer*	Total Power (kW)
1	5,271.81	GSI Helmholtz Center	L-CSC - ASUS ESC4000 FDR/G2S, Intel Xeon E5-2690v2 10C 3GHz, Infiniband FDR, AMD FirePro S9150 Level 1 measurement data available	57.15
2	4,945.63	High Energy Accelerator Research Organization /KEK	Suiren - ExaScaler 32U256SC Cluster, Intel Xeon E5-2660v2 10C 2.2GHz, Infiniband FDR, PEZY-SC	37.83
3	4,447.58	GSIC Center, Tokyo Institute of Technology	TSUBAME-KFC - LX 1U-4GPU/104Re-1G Cluster, Intel Xeon E5-2620v2 6C 2.100GHz, Infiniband FDR, NVIDIA K20x	35.39

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And more …

- Ground water power generation
- Natural Tunnel ventilation and heating/cooling
- SmartGRID

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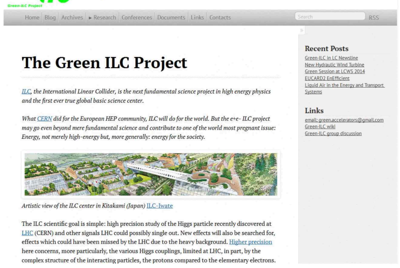
Needed: ILC site region data

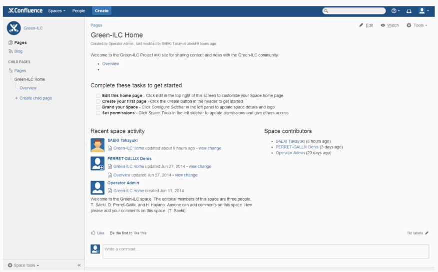
- Temperature
  - Daily Day-night T° for these last 20 years or more
  - Degree-days: nb of days above or below a given T° and |T- T°|
- Solar
  - Map of solar irradiance (max. 1 kW/m2) Morioka ~ 180 W/m2
  - Map of the average sunshine days or hours per week (Morioka 176D, 1684H)
- Wind
  - Map of wind conditions: costal, off-shore, in land. Weekly average
- Ocean
  - Map of the ocean streams and tides
- Geothermal and Biomass
  - Map of geothermal data (water T°, depth, water quality, …)
  - Map of biomass availability
- Geography
  - Possible locations for pumped-hydro storage
  - Underground water
  - Reusable lands

Green ILC
Energy for Innovation, Innovation in Energy

http://green-ILC.in2p3.fr
Now on http://interactions.org "blog watch"



Wiki site for Green-ILC internal discussion:
http://wiki.kek.jp/ Space-> Green-ILC



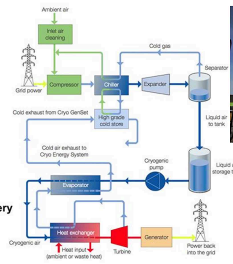
Thank you

LN_2 as energy storage

Liquefaction

Storage

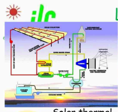
Power Recovery



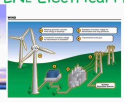
Highview Power Storage (UK)

Expected Efficiency up to 70% using heat waste (~ 115 C)

LN_2 Electrical Production and Transport



Solar thermal



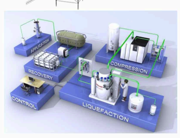
Solar PV

Wind,
Geothermal, biomass

Electricity
OR …..

Grid/ILC

Make LN_2



By Cryo Pipeline
Longest LNG ~ 5 km

HTc SC power line (project)
by 20 Km long section

LN2 for ILC, just as an example
Needs R&D

Many positive aspects:
- Negative (less than zero) carbon emission technology, air cleaner
- Important cryogen for ILC:
  - Cooling: cryocooler, HTc transmission lines, ..
  - Heat waste recovery
  - Storage: 1 gazometer (like for NLG): ILC runs ~ 4 days
    - Fast startup (minutes)
    - Long life-time

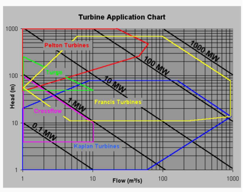
Applications to industry
- Energy Storage
- Heat waste recovery
- Drying

Safety issues, specially in ILC tunnel:
- N2 gas suffocation
- Cryogenic fluid hazard
- LN2 may liquefy ambient oxygen

Other discussions …. Hydrogen economy

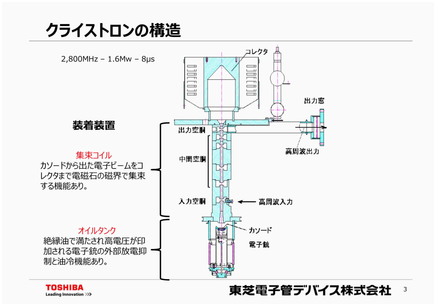
Underground water power ?

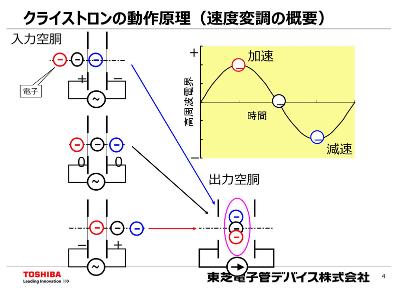
- Currently expect: 1m3/km/minute ~0.5 m3/s
- High pressure underground water experienced at LEP/LHC at one point 100m deep: 0.6m3/s pressure 20 atm ~ 200 m of water ~ 1MW
- 1 MW enough to tunnel light and ventilation

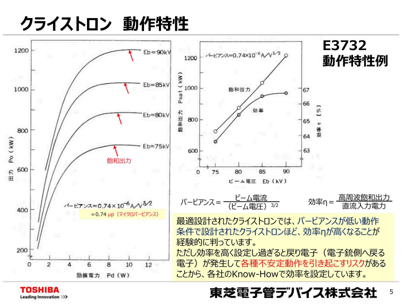


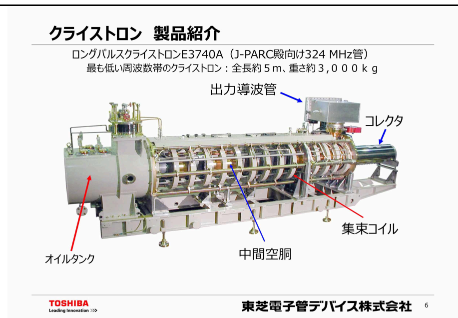
4 Energy Saving Technology of Accelerator Device

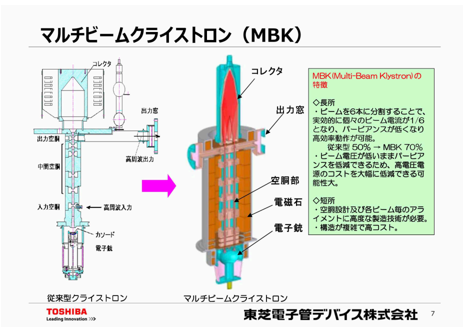
Collector Power Depression (CPD) Klystron (Yoshio Kawakami, Toshiba-Electrontube)

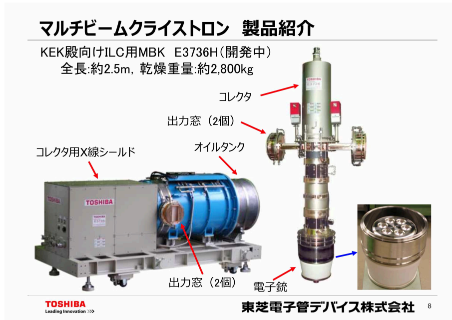


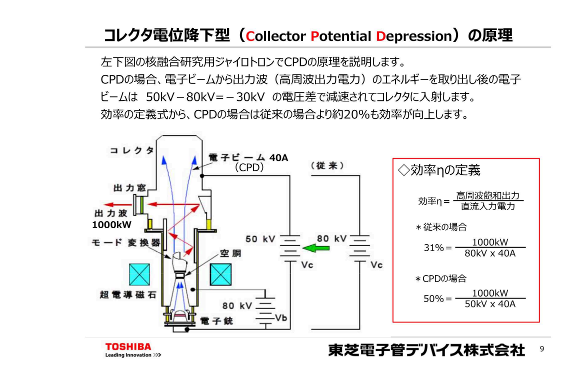


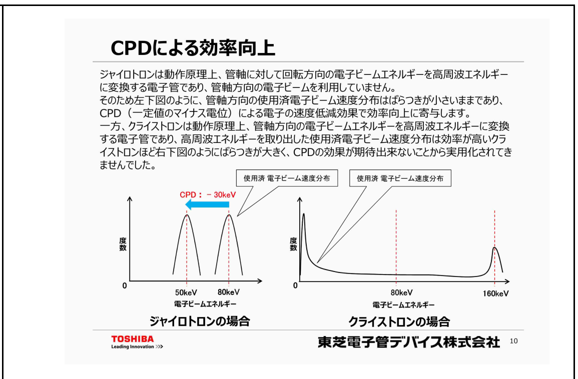


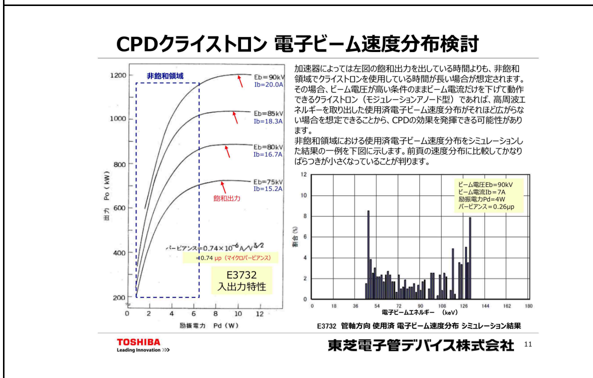


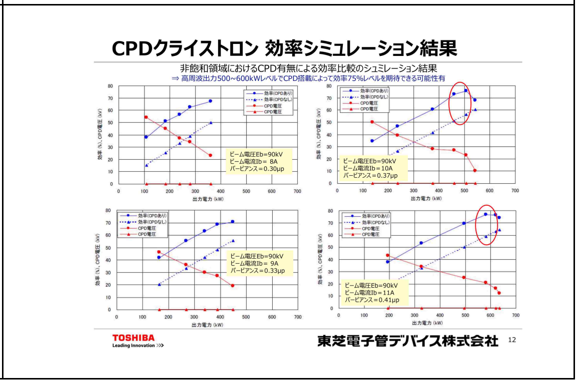


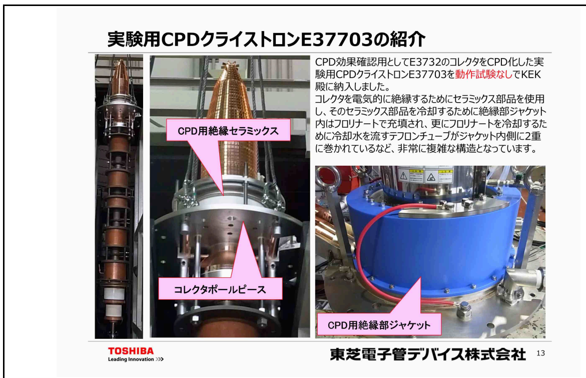


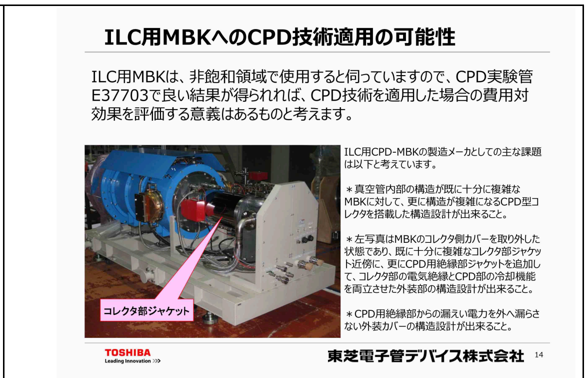












TOSHIBA
Leading Innovation

Operation test of CPD klystron
(Ken Watanabe, KEK)

CPD（コレクタ電位降下型）クライストロンの動作試験について

高エネルギー加速器研究機構　加速器研究施設
第三研究系　渡邉　謙

先端加速器科学技術推進協議会(AAA)
第3回グリーンILC WG
2014年7月1日(火)　 20min+10min　=30min

1

はじめに

・本報告は、先日行われた第2回グリーンILC WGで発表された

「コレクタ電位降下型(CPD)クライストロン」 :　東芝電子管デバイス　川上氏

の続きとなり、製作した本クライストロンのKEKにおける動作試験の準備状況および試験プランについて報告するものである。

・クライストロンの動作原理などついては、先の報告を参照のこと。

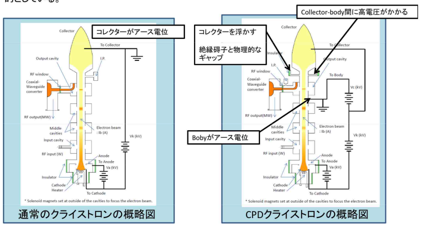
・本試験はクライストロンへのCPD方式の適用、これの原理実証を目的としている。
コレクターへ入射された電子ビームから電力回収できるという原理実証までが試験の範疇である。取り出された電力は、ダミー抵抗器などで吸収する。
なお、本クライストロンはCWで運転するものである。パルス動作のものとは異なる点が多い。

最終的には回収電力をクライストロン電源へ戻し、再利用することを行う必要があるが、それは本報告の範疇では無い。今後の課題である。

2

クライストロンへのCPD方式の適用(1)

・CPD (Collector Potential Depression) クライストロンでは、コレクターへ入射され、熱に変換される電子ビームの運動エネルギーを電力として回収、再利用することで動作効率を向上させることを目的としている。

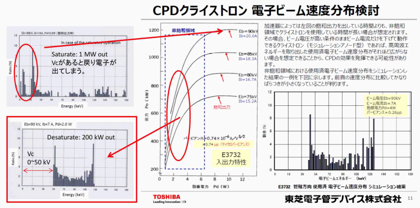


通常のクライストロンの概略図　　CPDクライストロンの概略図

3

クライストロンへのCPD方式の適用(2)

CW(連続波)運転のクライストロンの稼働に際しては、リニア領域(ドライブで出力を制限)での稼働となる事が多い(逆に飽和領域での稼働はしない/出来ない)。このことがCPD方式の検討を開始した要因の一つである。
飽和で効率70%の球があっても、リニア領域では効率が下がり、実際には55-60%程度での稼働になる。(パルスクライストロンとは状況が異なることを理解)



先日の東芝電子管デバイス　川上氏の報告より。

クライストロンへのCPD方式の適用(3)

クライストロン電源は既存の構成を出来るだけ保持する方式を考える。

以下、再利用する場合に考えられるセットアップ:

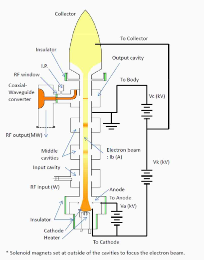
①VkとVcを直列にする「Power=(Vk+Vc)*Ib」

電源を直列に接続、回収した電力を用いてVcを発生させる。

②並列「Power=Vk*(Ik+Ic)」

マルクス回路等を用いてVkまで(DC 90kV?)昇圧、再利用する。
今回の原理実証試験ではこの方式を取る。出力は、隣にある別のクライストロンへ入力、ダミーロードとする。

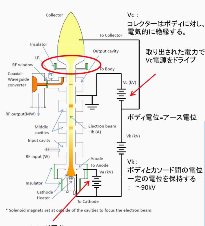
③6.6kV交流(50Hz)へ変換し既存電源の入力とする方式(詳細検討未だ)
複数のステーションから回収した電力を一か所にまとめて再利用することで、変動は減らせるか？



①VkとVcを直列にする「Power=(Vk+Vc)*Ib」の概念図

5

クライストロンへのCPD方式の適用(4):①の場合



Vc :
コレクターはボディに対し、電気的に絶縁する。

取り出された電力でVc電源をドライブ

ボディ電位=アース電位

Vk:
ボディとカソード間の電位
一定の電位を保持する
:　~-90kV

Va : アノード電位
ビーム電流を制御
25-60kV(カソードから正電位)
:エネルギー回収には直接寄与しない。

クライストロンへのCPD方式の適用
:ボディの電位をアース電位とし、コレクターは絶縁し、電位を発生させて電力回収する。
(CPD電位:両者間に電位を持たせる)

入力電力で作る電位 = カソード電位－CPD電位
稼働に必要な一定のカソード電位を作る為の入力電力はCPD電位分軽減される。
↑
Vk / Vc の割合で効率が改善する
90 kV / 50 kV = 1.8　 (元が30%程度の場合、54%まで改善する)

飽和運転では、電子のエネルギー分布（速度分布）の観点からVcを印加することができない。結果、非飽和の状態でしか適用できない。
CWのクライストロンの稼働に際しては、リニア領域(ドライブで出力を制限)での稼働となることが多い。このことがCPD方式の検討を開始した要因の一つである。

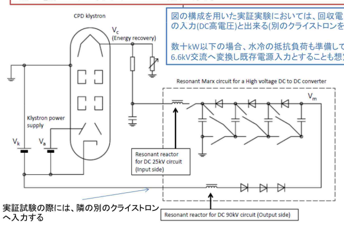
6

クライストロンへのCPD方式の適用(4):②の場合

実証試験では、できる限り既存システムと回収電力系を切り離すことを考える。
:電圧変動を経由してバンチングの恐れもあるか？
幸い、別の通常のクライストロンをダミーロードとして使用することが、比較的容易に設定できる状態である。
:別の電源システム、クライストロンが近くにある。

図の構成を用いた実証実験においては、回収電力を別のクライストロンの入力(DC高電圧)と出来る(別のクライストロンをダミーロードとする)。

数十kW以下の場合、水冷の抵抗負荷も準備している。実用の場合には、6.6kV交流へ変換し既存電源入力とすることも想定している（未検討）。

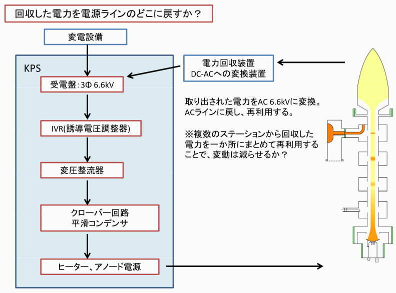


実証試験の際には、隣の別のクライストロンへ入力する

7

クライストロンへのCPD方式の適用(4):③の場合

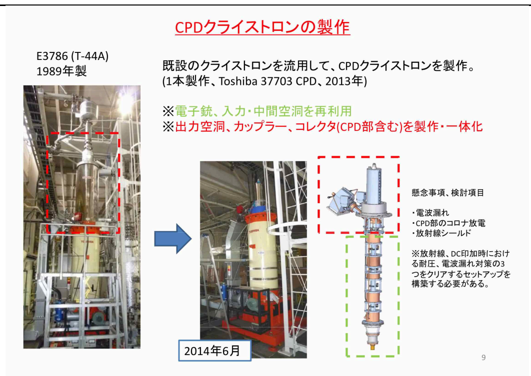
回収した電力を電源ラインのどこに戻すか？

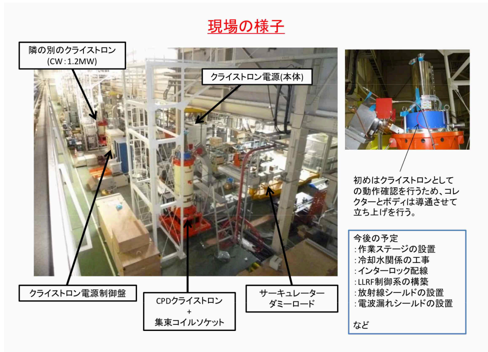


取り出された電力をAC 6.6kVに変換。
ACラインに戻し、再利用する。

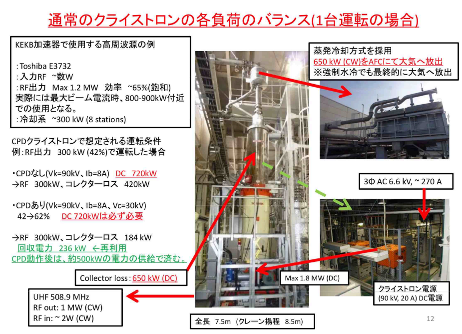
※複数のステーションから回収した電力を一か所にまとめて再利用することで、変動は減らせるか？

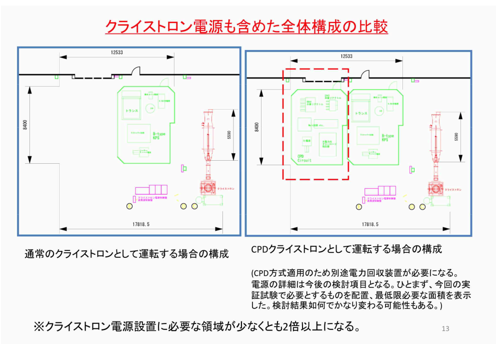
8

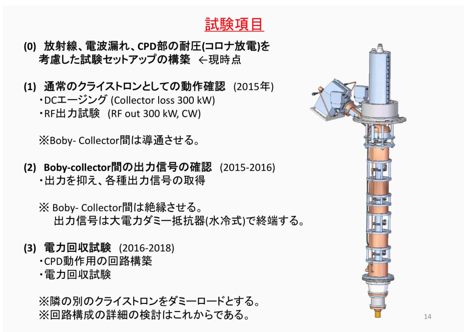


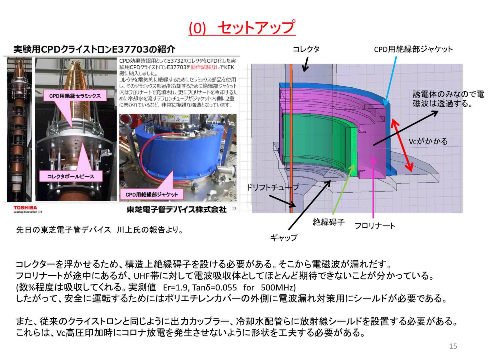


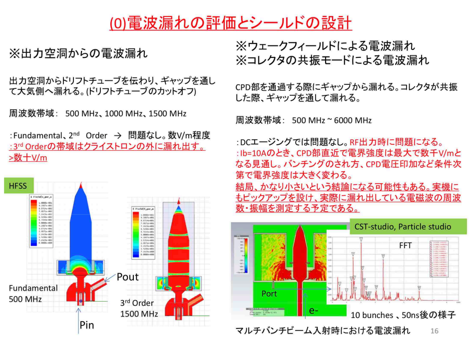
Item	E3732 (E3786)	E37703, CPD
運転周波数	508.9 MHz	508.9 MHz
最大出力	1.2 MW	500 kW
効率	20~65% (飽和運転時に最大効率)	CPDなし 20-60% (非飽和運転) CPDあり 40-80% (CPD動作により、最大20%程度向上)
コレクタ容量	1 MW	500 kW
コレクター冷却方式	蒸発冷却 (130 l/min + AFC)	強制水冷 (360 l/min)
冷却系	クライストロンBody 出力カップラー 集束コイル	クライストロンBody 出力カップラー 集束コイル CPD部絶縁碍子、電波吸収体
クライストロン電源	B-type 1台	B-type 1台 CPD用電源 1台
カソード電圧	47-90 kV	47-90 kV
アノード電圧	25-60 kV、 最大Ib 20Adc	25-65 kV、 最大Ib 20Adc
CPD電位	none	0 ~ -50 kV

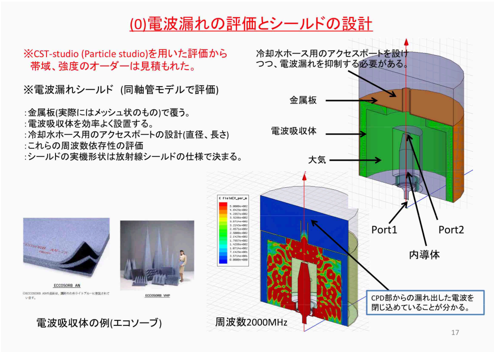


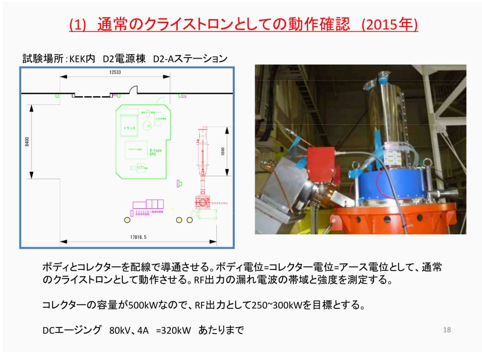


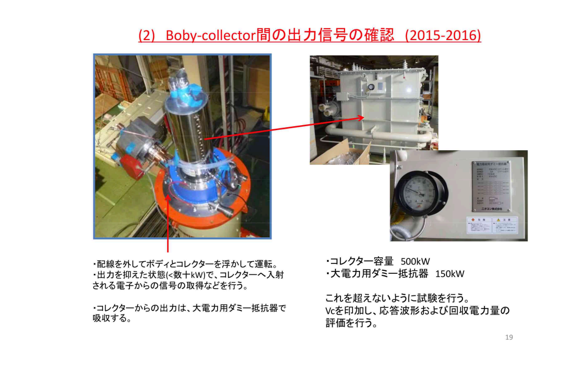


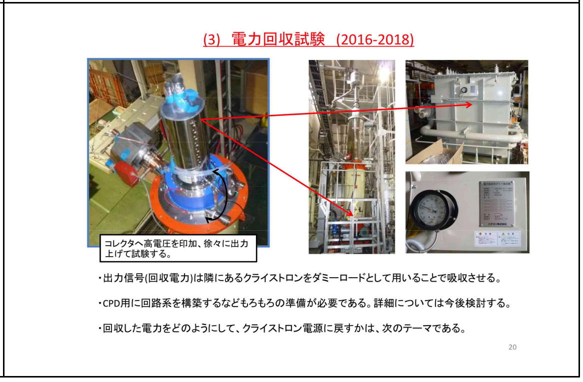


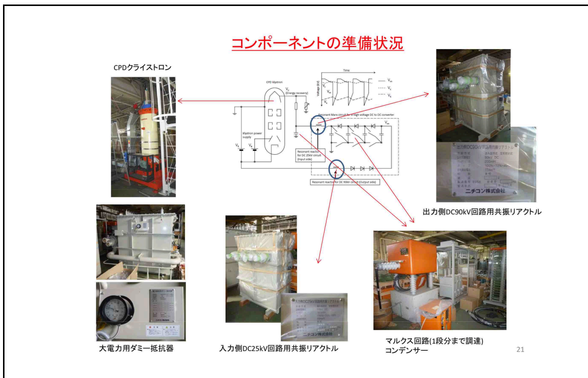


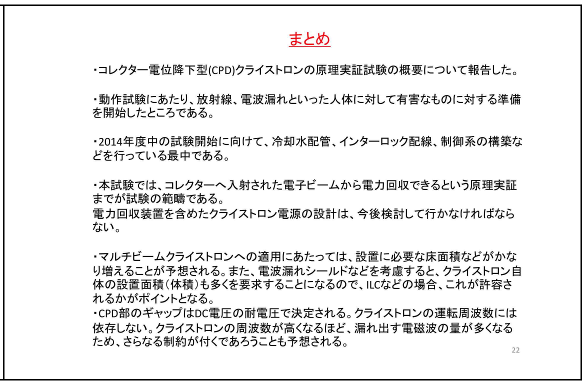

(0)電波漏れの評価とシールドの設計
※CST-studio (Particle studio)を用いた評価から帯域、強度のオーダーは見積もれた。
※電波漏れシールド (同軸管モデルで評価)
:金属板(実際にはメッシュ状のもの)で覆う。
:電波吸収体を効率よく設置する。
:冷却水ホース用のアクセスポートの設計(直径、長さ)
:これらの周波数依存性の評価
:シールドの実機形状は放射線シールドの仕様で決まる。
冷却水ホース用のアクセスポートを設けつつ、電波漏れを抑制する必要がある。
金属板
電波吸収体
大気
Port1
Port2
内導体
CPD部からの漏れ出した電波を閉じ込めていることが分かる。
電波吸収体の例(エコソーブ)
周波数2000MHz
17


(1) 通常のクライストロンとしての動作確認 (2015年)
試験場所:KEK内 D2電源棟 D2-Aステーション
ボディとコレクターを配線で導通させる。ボディ電位=コレクター電位=アース電位として、通常のクライストロンとして動作させる。RF出力の漏れ電波の帯域と強度を測定する。
コレクターの容量が500kWなので、RF出力として250~300kWを目標とする。
DCエージング 80kV、4A =320kW あたりまで
18


(2) Boby-collector間の出力信号の確認 (2015-2016)
・配線を外してボディとコレクターを浮かして運転。
・出力を抑えた状態(<数十kW)で、コレクターへ入射される電子からの信号の取得などを行う。
・コレクターからの出力は、大電力用ダミー抵抗器で吸収する。
・コレクター容量 500kW
・大電力用ダミー抵抗器 150kW
これを超えないように試験を行う。
Vcを印加し、応答波形および回収電力量の評価を行う。
19


(3) 電力回収試験 (2016-2018)
コレクタへ高電圧を印加、徐々に出力上げて試験する。
・出力信号(回収電力)は隣にあるクライストロンをダミーロードとして用いることで吸収させる。
・CPD用に回路系を構築するなどもろもろの準備が必要である。詳細については今後検討する。
・回収した電力をどのようにして、クライストロン電源に戻すかは、次のテーマである。
20


コンポーネントの準備状況
CPDクライストロン
出力側DC90kV回路用共振リアクトル
大電力用ダミー抵抗器
入力側DC25kV回路用共振リアクトル
マルクス回路(1段分まで調達)
コンデンサー
21

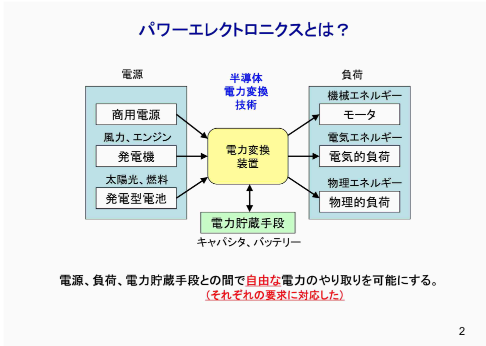

まとめ
・コレクター電位降下型(CPD)クライストロンの原理実証試験の概要について報告した。
・動作試験にあたり、放射線、電波漏れといった人体に対して有害なものに対する準備を開始したところである。
・2014年度中の試験開始に向けて、冷却水配管、インターロック配線、制御系の構築などを行っている最中である。
・本試験では、コレクターへ入射された電子ビームから電力回収できるという原理実証までが試験の範疇である。
電力回収装置を含めたクライストロン電源の設計は、今後検討して行かなければならない。
・マルチビームクライストロンへの適用にあたっては、設置に必要な床面積などがかなり増えることが予想される。また、電波漏れシールドなどを考慮すると、クライストロン自体の設置面積(体積)も多くを要求することになるので、ILCなどの場合、これが許容されるかがポイントとなる。
・CPD部のギャップはDC電圧の耐電圧で決定される。クライストロンの運転周波数には依存しない。クライストロンの周波数が高くなるほど、漏れ出す電磁波の量が多くなるため、さらなる制約が付くであろうことも予想される。
22

Power electronics technology for power saving power-supplies (Masaki Yamada, Mitsubishi Electric)

電源系の省エネに貢献する
パワーエレクトロニクス技術

2013年 12月 16日
三菱電機株式会社　 山田 正樹

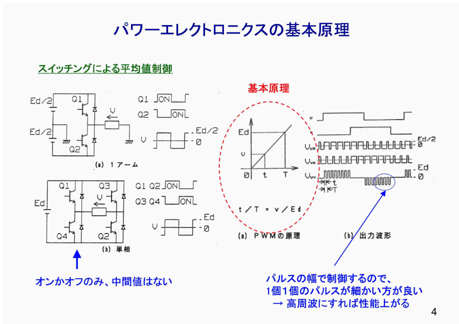
1

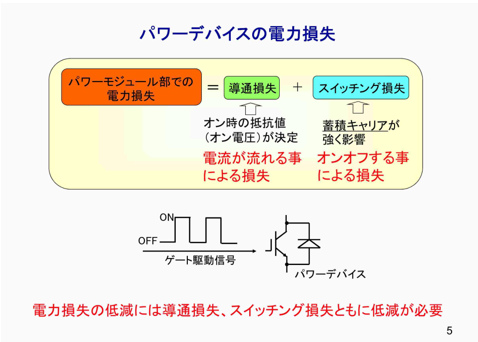


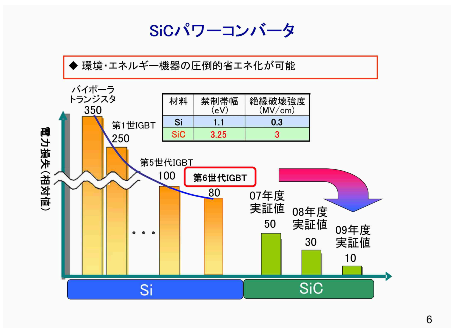
電力変換装置

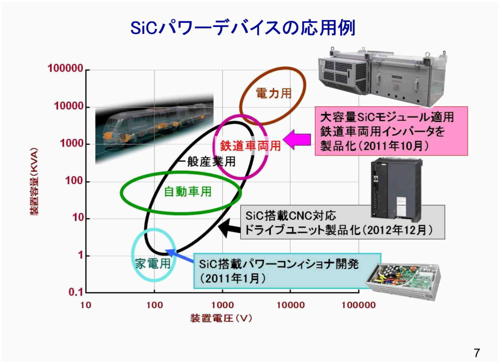
		入力	
		AC	DC
出力	AC	AC−AC	DC−AC インバータ・逆変換
	DC	AC−DC 順変換	DC−DC

3







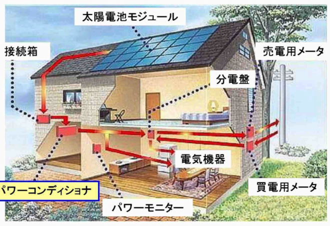


PV用インバータの例

8

PV用パワーコンディショナとは

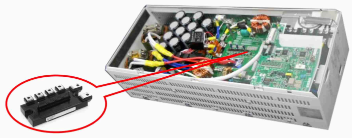
•発電した直流電力を、パワーコンディショナで交流に変換、電力メータを介して電力系統に接続する



9

SiCモジュール搭載パワーコンディショナ

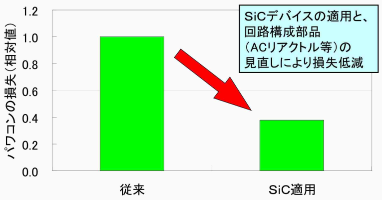
単相200V 5kW機種の太陽光パワーコンディショナに
SiC-MOSFET、SiCダイオードを適用したパワーモジュールを搭載し、
変換効率(98%)を達成



SiCパワーモジュールを
パワーコンディショナに搭載

10

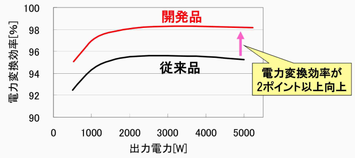
損失低減効果



5kW定格出力時のパワーコンディショナの損失比較

11

電力変換効率



開発品と従来品※との電力変換効率比較

※当社製パワーコンディショナ(PV-PN50G1)

12

DC/DCコンバータの例

13

DC/DCコンバータ動向

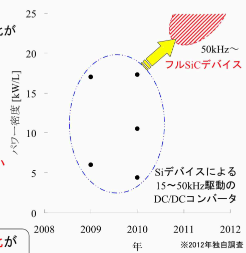
HEVをはじめとして車両の電動化が拡大しつつある

車載向け電力変換器では設置スペースの制約がある

HEV・PHEVでEV走行が求められることも…

→ エンジンとの併設でスペース小
→ 変換器の高出力化

電力変換器の高パワー密度化が求められる



DC/DCコンバータのパワー密度トレンド

14

高パワー密度化への方策

①小型化

DC/DCコンバータで大きな体積を占めるコンデンサとリアクトルの小型化
●スイッチング素子の高周波駆動

冷却器の小型化
●デバイスの高温動作

②低損失化

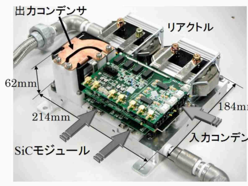
半導体素子における損失低減
●低抵抗なスイッチング素子
●テール電流の解消
●リカバリ電流の解消

Si-MOSFETが扱えない高圧・大電力のアプリケーションにおいて一般的に用いられるIGBT+FWDによる構成では改善が困難

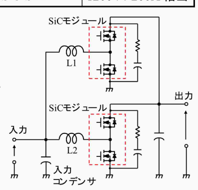
SiCデバイスの適用

15

試作機概要



SiC-MOSFET	1200V / 200A 相当
SiC-SBD	1200V / 200A 相当



2相で構成された
マルチフェーズチョッパ回路

入力電圧	350V
出力電圧	600V
定格出力	65kW
駆動周波数	50kHz
冷却水温度	25℃

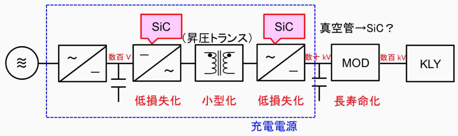
2.45L
(冷却器除く)

16

加速器用途への展開

17

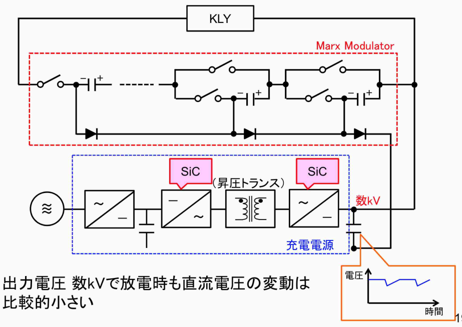
大型加速器システムへの適用時のメリット



特にモジュレータ入力部のコンデンサ充電電源にメリットが大きい
（1）SiC適用で低損失化
（2）高周波駆動し、昇圧トランスを小型化
（3）高周波駆動し、出力電圧を高精度化

18

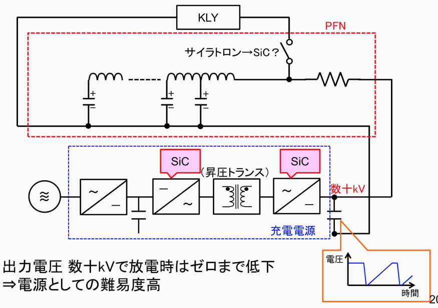
長パルスシステム



出力電圧 数kVで放電時も直流電圧の変動は比較的小さい

19

短パルスシステム



出力電圧 数十kVで放電時はゼロまで低下
⇒電源としての難易度高

20

むすび

- パワー素子の損失低減により、機器の性能向上を実現、特にSiCデバイスの適用により、パワーエレクトロニクス回路を構成するパワー素子の損失を低減
- パワー素子の損失低減効果と共に、機器全体を対象とする最適設計により、システム全体の効率改善を実現
- 加速器用途への展開においては、特に充電電源の低損失・小型化に有効であり、今後適用例が増加するものと考えられる

21

Power Saving of Large-scaled Helium compressor (Masato Noguchi, Maekawa)

Abstract

About one-third of the power consumed by the linear collider is consumed by helium refrigeration equipment. For the purpose of power consumption reduction of helium refrigeration unit, it was examined the combination and optimization of the helium compressor and chemical refrigerator. Cooling the compressor suction gas by an adsorbed refrigerator with a required non-large power consumption, it was confirmed to be effective in power reduction of the entire refrigeration system. It was confirmed that heat source required to drive an adsorption chiller is to be well managed by extracting from lubricating oil system of the high-pressure-stage helium compressor. The study that was modeled on the refrigeration system of the CERN / LHC as a representative of a large refrigeration system, it was confirmed to be about 7% of the power reduction in linear collider. (This document is a report of re-validation based on what was presented at the 24th SOFT: Symposium on Fusion Technology [1].)

1. Introduction

In the linear collider, cryomodules with built-in superconducting accelerating cavities are arranged in many areas to accelerate electrons and positrons. Helium refrigeration system for cooling the cavities in cryomodule will be arranged, as shown in Figure 1, ten large 2K refrigeration station, four small 2K / 4.5K refrigeration station, and seven large refrigeration station [2]. Among the power consumed by the ILC, the power consumed by a helium refrigeration equipment is large and it is 45.81MW. The most of power is consumed in the helium compressor [2]. For this reason, it is easily leading to think about a reduction in power consumption in helium compressor in ILC. However, it can not be expected now more efficiency improvement, since the efficiency improvement has been studied in the long history of the helium refrigeration system development and the helium compressor development.

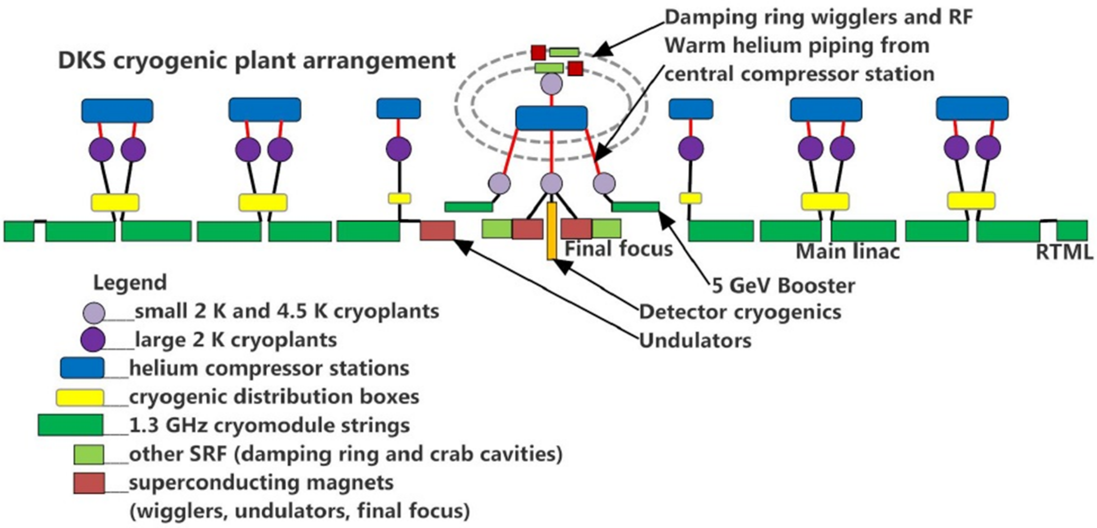


Figure 1 layout plan of ILC refrigeration unit

In an oil injection screw compressor used in the helium compressor, the suction volume capacity and the shaft power are not changed when the suction gas temperature is changed. As a result, it has been confirmed in a large helium compressor for NIFS / LHD [3,4] that the power consumption per unit weight flow rate will reduce, as the intake gas temperature become low.

On the other hand, when we install a refrigerator for the purpose of cooling the suction gas, the power consumption for the refrigerator is required, so that the benefits of power reduction of the compressor will be cancelled.

Assuming a large helium compressor be applied to the ILC, we investigated the relationship between the temperature and the heat capacity of the waste heat recovered from them. Also, we investigated what type of the chemical refrigerating system which can be driven by the waste heat, and to determine the relationship of the cooling performance and the driving waste heat.

Finally, we made to optimize the power consumption of the helium compressor and chemical refrigerator.

2. Heat balance of oil injection type screw compressor

In the development stage of helium liquefier, reciprocating helium compressor has been the standard. Later, after adopted the oil injection type screw compressor in satellite cooling system of TEVATRON at Fermilab in 1979, for large helium refrigerator system with long-term operation, oil injection type screw compressor has become a global standard.

Features of the oil injection type screw compressor is to inject a large amount of oil during the compression of the helium gas. The temperature of the lubricating oil supply is approximately 313-318K, the temperature of the discharge oil becomes comparatively low temperature (349-365K).

Considering the large helium refrigeration system, such as ILC, refrigeration systems of CERN / LHC is a good reference [5]. As a basis for comparison, we examined a similar model compressor as described above using a Japan-made compressor. The model compressor is shown in Figure 2.

The highest temperature is the discharge side of the high-pressure-stage compressor. The lubricating oil of that side has a lot of heat capacity. For heat recovery from the lubricating oil, a new heat exchanger is necessary. Recovering heat quantity from the heat exchanger is decided from the circulation amount and temperature of the lubricating oil, as shown in Figure 3.

On the other hand, the amount of heat required to add cooling of the helium gas is decided from the amount of circulation and the temperature difference between the gas. The cooling heat from the 310K is shown in Figure 4.

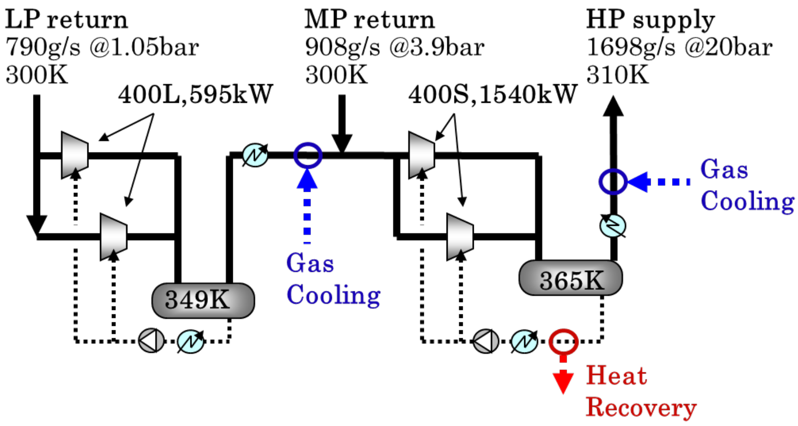
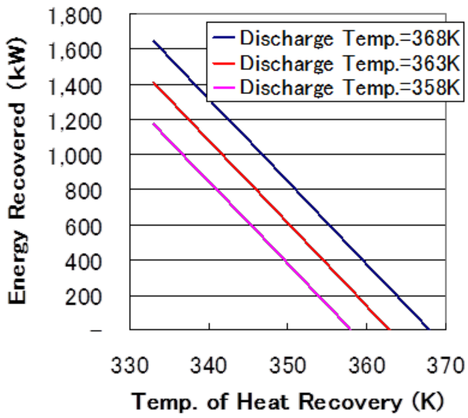


Figure 2 model compressor based on the CERN / LHC specifications.



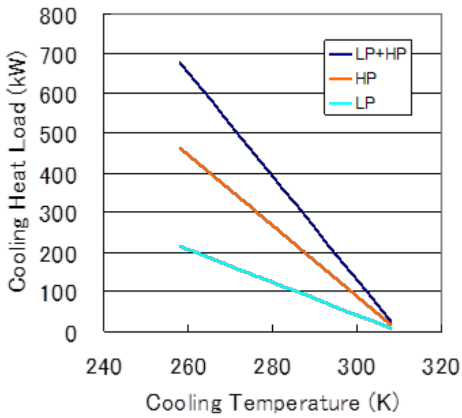


Figure 3 heat recovery temperature and the amount of recovered heat
Figure 4 required heat to add cooling of gas

With reference to Figures 3 and 4, the ratio of the cooling heat amount and the recovery amount of heat required for each heat recovery temperature, COP, can be obtained. When the discharge temperature of the high-pressure-stage compressor is set to 363K, the COP curve are shown in Figure 5. It is good if there is a chemical refrigerating machine which has a higher COP than shown in the curve.

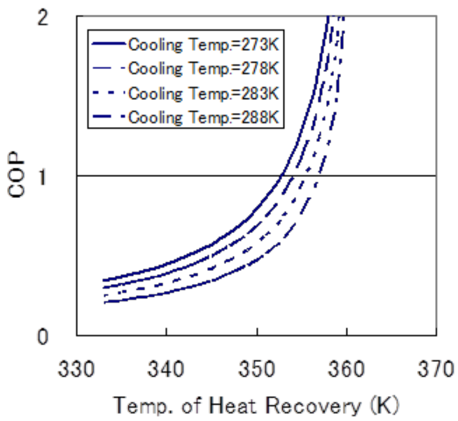


Figure 5 COP which is required in the chemical refrigerating machine

3. Chemical refrigerator characteristics

For the chemical refrigerator not consuming a lot of power to drive, there are absorption chiller and the adsorption chiller. Each of the representative structure are shown in Figure 6 and Figure 7. Also, each of the COP characteristics are shown in Figure 8.

Absorption refrigerating machine with lithium bromide solution as a refrigerant is the most common in the chemical refrigerating machine, and the COP in the drive temperature range is high. To separate the water from the dilute solution, it requires the waste heat of a relatively high temperature (≧ 360K), and seem not suitable for heat recovery applications from the helium compressor.

On the other hand, application of the adsorption chiller that can make the cold water from the lower temperature of the waste heat in recent years has been increasing. Adsorption refrigerating machine consist of two adsorbent layers, a water condenser with a built-in silica gel, and an evaporator, is operated by periodically switching the adsorption layer A / B. In the state in Figure 7, moisture adsorbing layer B is desorbed by the waste heat, and liquefied by the cooling water in the condenser. The condensed water is fed to the evaporator and evaporated in the adsorption effect of the adsorbent layer A, then it becomes low temperature.

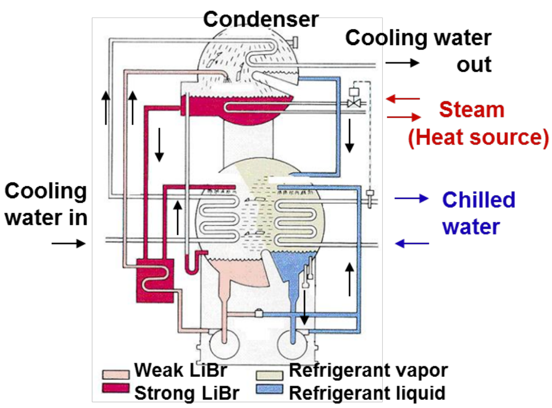


Figure 6 Absorption chiller

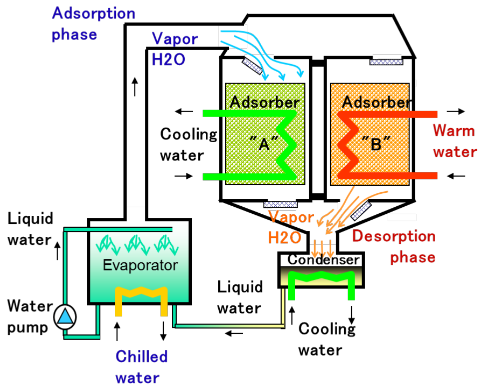
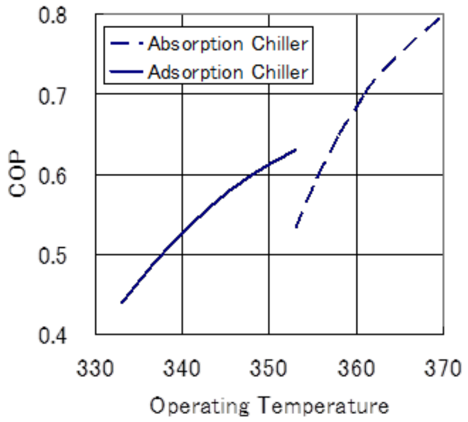


Figure 7 Adsorption chiller

An overlay to the requirements of Figure 5 with the refrigerator COP in Figure 8 is shown in Figure 9. Absorption refrigerating machine itself has high COP, however, it is not possible to exert the COP required by the system, so it is not suitable. Although the COP of the adsorption chiller is low, operating temperature is low and it has the COP required in this system.



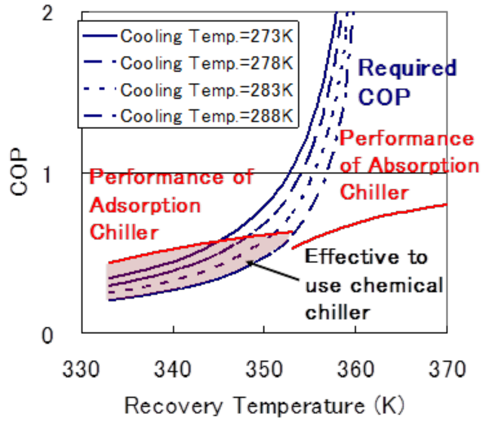


Figure 8 Chemical refrigerator refrigeration efficiency (COP)
Figure 9 Comparison of the request COP and the actual performance of the refrigerator

4. study of low temperature cycle of incorporating the adsorption refrigerator compressor suction gas

The compressor system incorporating the adsorption chiller is shown in Figure 10. By installing additional heat exchanger in the lubricating oil system of the high pressure-stage, the recovered heat is sent into the adsorption refrigerator by circulating hot water made in the heat exchanger to the adsorption refrigerator. By sending the cold water produced by the adsorption refrigerator to the newly installed heat exchanger to the gas system, the discharged gas of the low-ptessure-stage compressor and high-pressure-stage compressor is cooled.

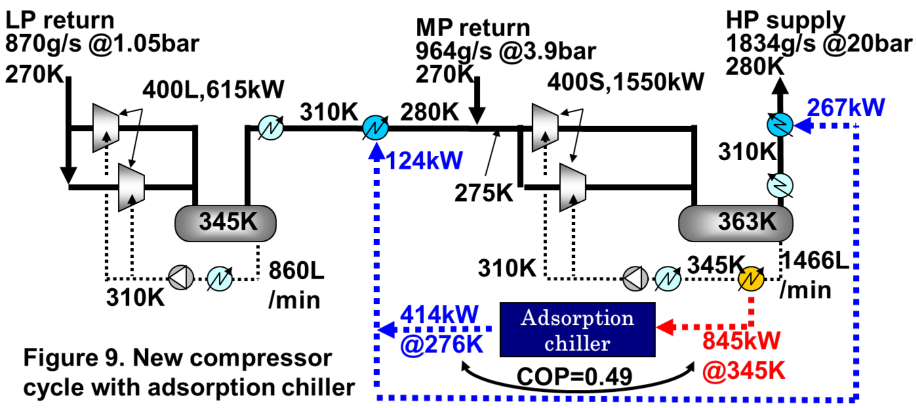


Figure 10 new compressor system incorporating the adsorption refrigerator

When the discharge temperature of the high-pressure-stage compressor is set to 363K, as shown in Figure 10, it is possible to obtain the recovered heat of 845kW with given cooling down to 345K. On the other hand, in order to cooled the helium gas of 310K to 280K by water cooling, 124kW at a low-pressure-stage, 267kW at a high-pressure-stage, total of 391kW refrigeration capacity is required. When the hot water temperature is set to 345K, and the cold water temperature is set to 276K in a heat source water of the adsorption chiller, the COP of the adsorption-type refrigerator will be 0.49, cold water of 414kW is able to produce from the input of 845kW. Accordingly, refrigeration capacity of the adsorption refrigerator has exceeded the cooling heat amount necessary for cooling of the gas, it was confirmed to be established as a system.

Incidentally, considering the helium refrigerator side, the temperature of the helium gas fed to the cold box will be down to 280K from 310K. If the temperature of the cold end of the first heat exchanger inside the cold box (here 80K) is not changed before and after the system change, and temperature of the supplying gas is changed to 280K from 310K, the high temperature portion of the heat exchanger becomes unnecessary. As a result, the temperature of the gas returns to the compressor is even down to 270K from 300K. The density of the suction gas of the compressor is increased, it is possible to make more gas flow in the same compressor. Meanwhile, the discharge pressure of the compressor is increased by adding the heat exchanger to the discharge side of the compressor, the power consumption increases.

The compressor performance under these conditions is shown in Table 1. If we use the same compressor, by making inhalation gas temperature drop, the low-pressure-stage gas flow rate (LP) / intermediate gas flow rate (MP) / high-pressure-stage gas flow rate (HP), respectively 790/908/1698 g/s will increase to 870/964/1834 g/s. On the other hand, the power consumption of the low-pressure-stage / high-pressure-stage compressor will also increase from 1190/3080 kW to 1230/3100 kW. Assuming that one can arbitrarily increase or decrease the capacity of the compressor, as a result of translation of these performance criteria of the LP800/MP880 g/s, the total power consumption of the compressor and the adsorption chiller was confirmed to be reduced to 3965kW from 4252kW, that is 7 %.

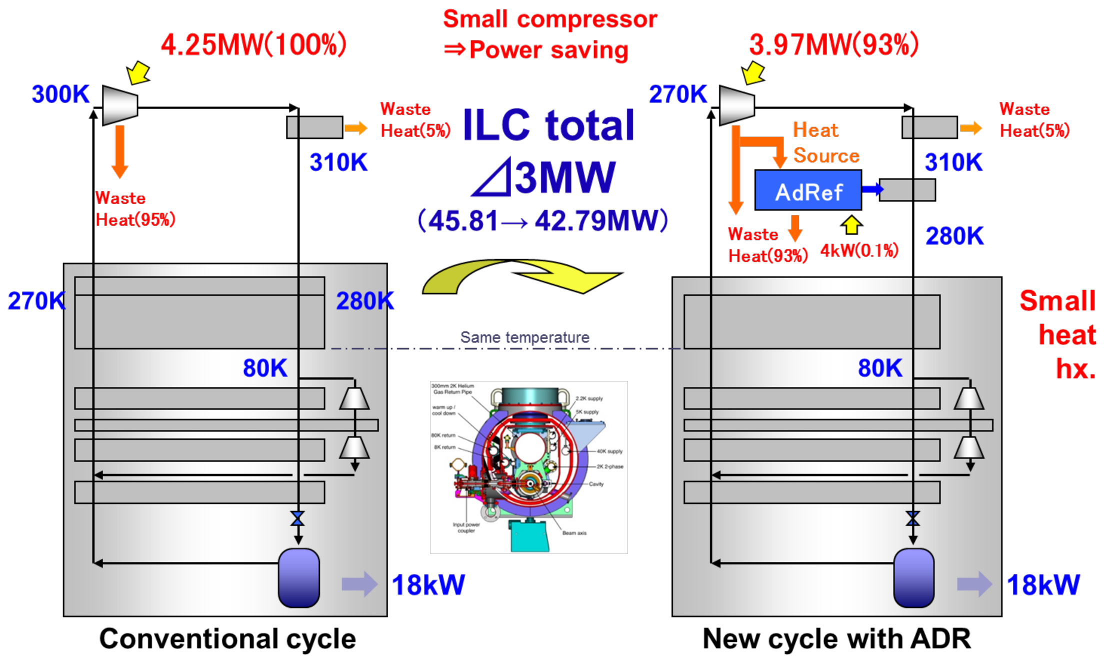


Figure 11 new helium refrigeration system incorporating the adsorption refrigerator

Table 1 power consumption comparison

			Normal Temp.	Cold Temp.
Mass Flow	LP	g/s	790	870
	MP	g/s	908	964
	HP	g/s	1,698	1,834
Shaft Power	LP-MP	kW	1,190	1,230
	MP-HP	kW	3,080	3,100
Shaft power converted to LP800/MP880 g/s condition				
	LP-MP	kW	1,205	1,131
	MP-HP	kW	3,047	2,830
	Total	kW	4,252	3,961
Power for Chiller		kW	0	4
Total Power		kW	4,252	3,965 (-7%)

5. Summary

For the purpose of power consumption reduction in large-scale helium refrigeration system in the ILC, the combination of adsorption chillers was examined.

By the study discussed above, the following results were obtained.

(1) It is possible to construct the heat cycle with the lubricating oil, as a heat source, of the compressor combined with the adsorption refrigerator.

(2) It is possible to reduce power consumption of about 7% by combining an adsorption type refrigerator.

(3) It is possible to reduce the size of the cold box, by lowering the gas temperature.

(4) The present system is self-contained, and can be operated without being affected by the load of the other lines.

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Development status of High-Tc YBCO superconducting wires (Kunihito Kikuchi, Fujikura)

1. Introduction

Superconductivity is a phenomenon in which the electrical resistance of the material is reduced to zero in the lower side of a certain temperature. Although the electrical resistance of the normal metal drops along with the temperature going down, in the superconducting material, the property of the electric resistance becomes zero below a certain temperature (the critical temperature) (Figure 1). It is not necessarily restricted only the temperature in the superconducting state, in practice, under the three critical points of the current (critical current), the temperature (critical temperature), and the magnetic field (critical magnetic field), superconducting state is emerged (Figure 2). Since superconductivity is zero electrical resistance, it is very fascinating material. From the fact that a practical application of high critical temperature superconducting material is expected in recent years, not only to the conventional superconducting equipment, but more wide range of applications are expected.

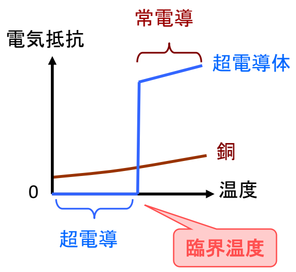

Figure 1 temperature and electrical resistance

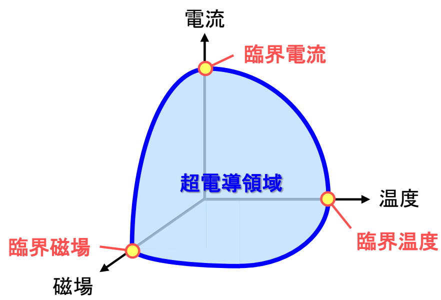

Figure 2 Three critical points of superconducting material

Superconducting was first discovered in Hg in 1911, it has been found in a variety of metal material (Figure 3). In the 1970s superconducting applications advances in particle science, metal-based superconducting material such as NbTi, Nb_3Sn, are applied to realize the wire mass production technology at an early stage. And it was established to put a practical use in superconducting applications equipment such as current MRI and NMR. These metal-based superconducting material are necessary to be cooled to cryogenic temperatures of liquid helium temperature (4.2K / -269℃). In the second half of the 1980s, the high temperature superconducting materials that exhibit superconducting state at the liquid nitrogen temperature (77.3K / -196℃) or even higher were discovered. In addition to attract much attention as the next generation of the superconducting material, many studies have been made. Unlike conventional metal-based superconducting material, the high-temperature superconducting materials are intended to be a copper oxide-based. From the commitment to the wire of the past, practical use of Bi (bismuth) system and Y (yttrium) system of high-temperature superconducting material is expected. Bi-based high-temperature superconducting wire is the first generation because it is mass-produced initially, Y-based high-temperature superconducting wire is referred to as the second-generation high-temperature superconducting wire because it is expected to mass production following the Bi-based. As described below, Fujikura has been conducting research and development of Y-based superconducting wire as a high-temperature superconductor of the second generation for practical use, and it has started the wire supply.

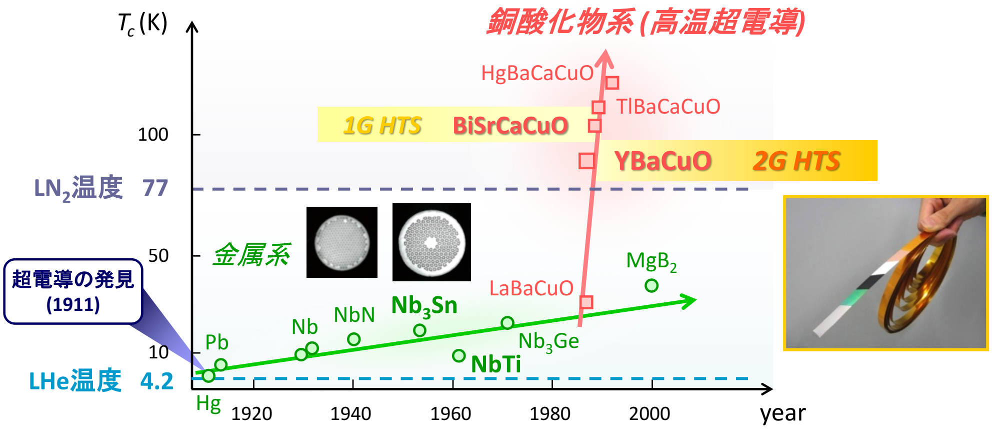

Figure 3 transition history of superconducting material

2. Superconductivity research and development of in Fujikura

Starting from the 1970s, with long history of superconductivity research and development in Fujikura, it has been done research and development of metal-based superconducting material wire and magnet, such as NbTi and Nb_3Sn. Since the discovery of high temperature superconductivity, it is quickly focus on the Y-based high-temperature superconductor, over more than 20 years since the early 1990s, it has been done research and development aimed at the wire of the Y-based high-temperature superconductor. At initial stage of development, making a short wire was the best. Since there was a boost in the wire development and application equipment development by the national project of the Ministry of Economy, Trade and Industry through the New Energy and Industrial Technology Development Organization (NEDO), wire performance increased yearly, and in 2004 Fujikura succeeded in making the world's first 100m grade wire (Figure 4) [1]. In recent years, it is reached by the level that can be supplied in the production stably of several 100m grade long wire. In 2010, Fujikura starts to supply commercial Y-based electric conductor material manufactured in-house and the wire feed for the various projects to date.

Y-based high-temperature superconducting wire has a structure obtained by laminating a thin film multi-layer (Figure 5), meanwhile, there is a technical problem that superconducting properties can not be obtained when no specific crystal orientation of the superconductive layer is aligned on a metal substrate. Fujikura solved these problems by the fundamental substrate technology that was originally developed, and has been realized the wire performance of world-class [2]. There are two of these fundamental technologies, and one is the IBAD method and the other is PLD method. First, IBAD method stands for Ion Beam Assisted Deposition, a method of forming the intermediate layer. For forming the superconducting layer having uniform crystal orientation, crystal orientation rising required to be aligned at the stage of the intermediate layer. In the IBAD method, a film-forming particles as a raw material of the intermediate layer is fed onto a metal substrate. By irradiating the assist ion beam from a particular angle at the same time, has enabled formation of a uniform intermediate layer of crystal orientation (Figure 6). Next, PLD method stands for Pulsed Laser Deposition, is a method of forming a superconducting layer. Although the PLD method itself is a general technique as a method for forming the thin film, and Fujikura employs a hot-wall type PLD method to elaborate their own ideas in. In the deposition of the superconducting layer, a deposition temperature is very important parameter. In the hot wall type PLD method, by adopting a method of enclosing the film formation area in a hot wall, the film-forming particles are succeeded in stabilizing the deposition on a substrate, and to achieve high crystallinity superconducting layer (Figure 7).

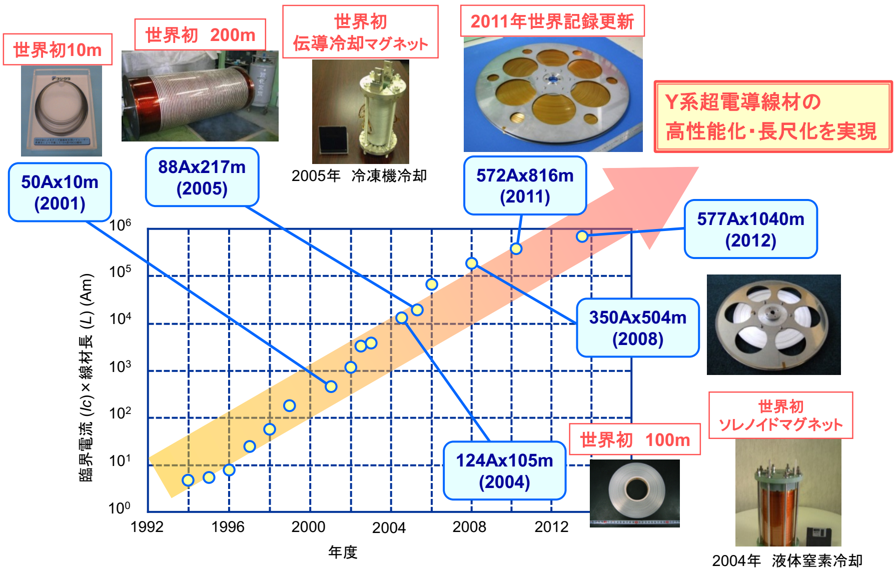

Figure 4 development of Y-based high-temperature superconducting wire in Fujikura

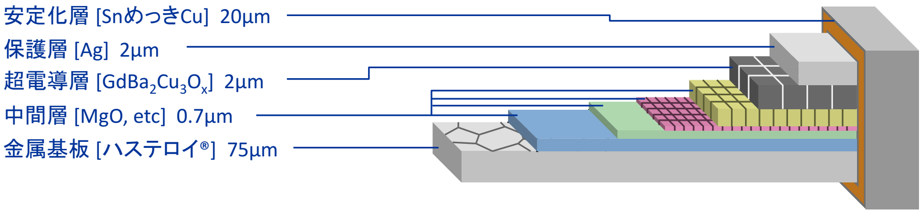

Figure 5 Fujikura Ltd. Y-based structure of the high-temperature superconducting wire (schematic diagram)

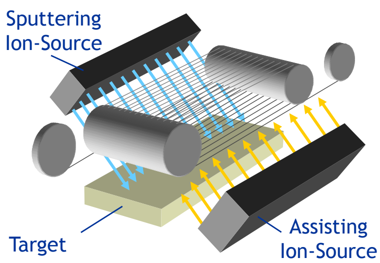

Figure 6.1 IBAD apparatus schematic

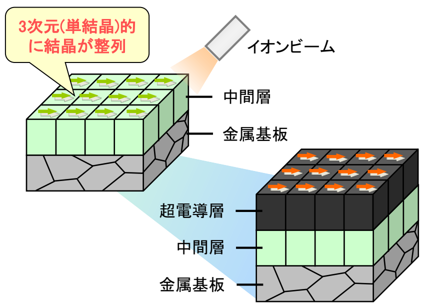

Figure 6.2 IBAD method schematic

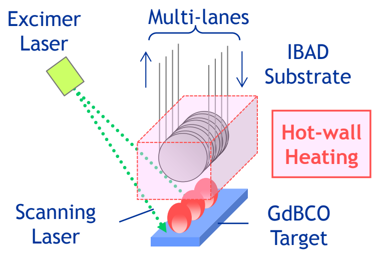

Figure 7.1 PLD device schematic

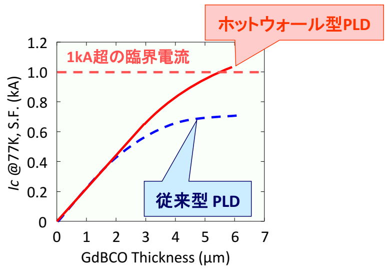

Figure 7.2 superconducting layer film thickness and the critical current in the PLD method

3. High-performance Y-based high-temperature superconducting wire

Y-based superconducting wire of Fujikura has a high critical current and a high critical current uniformity, by using a manufacturing method that was originally developed with the aforementioned feature. Critical current, in 77K, and in the self-magnetic field, is proud of the 500A / cm-wide and the world's top level of performance, has achieved a very uniform critical current distribution also in the longitudinal direction in the several 100m class of long wire (Figure 8). Although longitudinal current flow in conventional copper wire is uniform, it is difficult to get uniform current flow in the Y-based superconducting wire, because of a process of laminating a thin film, it is not easy to obtain a uniform superconducting characteristics in the longitudinal direction. From efforts for wire production over the years, Fujikura has been to improve the critical current and the longitudinal direction of uniformity, at present is being reached to a level that can be supplied to practical use [3].

When a magnetic field is applied to the superconducting material, there is a property that the critical current is reduced. Fujikura have done the evaluation of medium-critical current characteristics for the Y-based superconducting wire, including the area of up to a strong magnetic field and at low temperature, in cooperation with universities and research institutions (Figure 9) [4]. The application equipment to be used in a magnetic field as a superconducting magnet require a high critical current density in a magnetic field, it has started to consider an improvement of the critical current in a magnetic field as a future technological challenges.

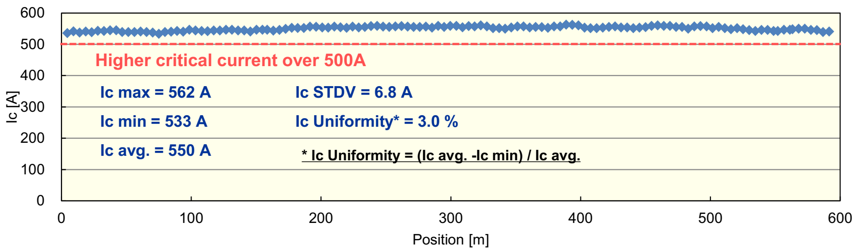

Figure 8 critical current distribution of Fujikura Ltd. Y-based high-temperature superconducting wire (reference data)

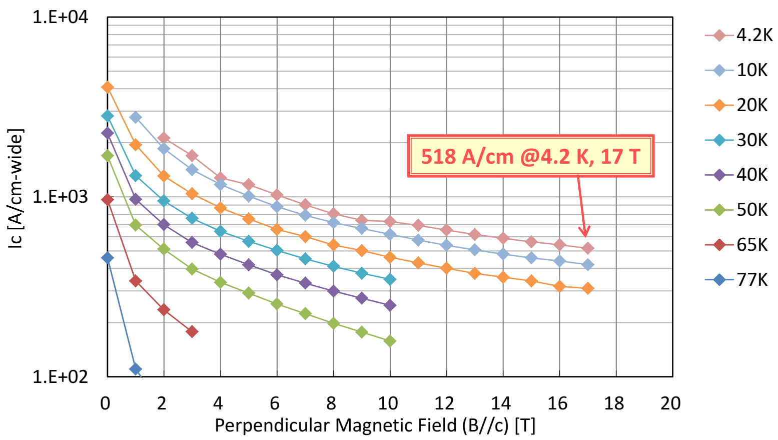

Figure 9 Fujikura Ltd. Y system in a magnetic field critical current characteristics of high-temperature superconducting wire (reference data)

※ Some of the measured data (3T ~) include the data measured by the Institute for Materials Research, Tohoku University High Field Superconducting Materials Research Center.

4. Application of Y-based high-temperature superconducting

The Y-based superconducting wire is not put to practical use yet, in recent years, long wire is able to produce stably, verification demonstration in various projects have been started. The conventional metal-based superconductor had been limited to use in a range of liquid helium temperature, the high temperature superconductor is to exhibit a critical temperature higher than the liquid nitrogen temperature, and further subject to the influence of the magnetic field for the Y-based high-temperature superconductor, it is expected commercialization in both wide area of operating temperature and magnetic field (Figure 10). Strong magnetic field magnet or the like, some of the superconducting equipment, in the future, are expected to further strong magnetic field, especially the Y-based high-temperature superconductor with less susceptible to the influence of the magnetic field, the application is expected in the strong magnetic field superconducting equipment there.

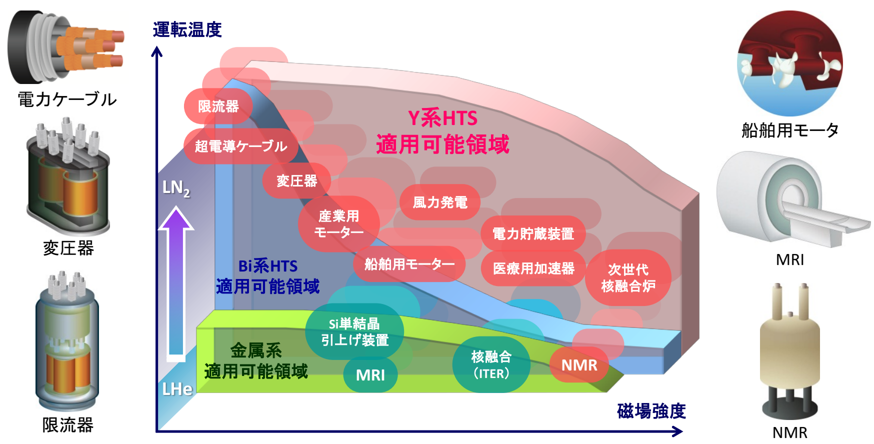

Figure 10 superconducting applications equipment

In addition to research and development of superconducting wire, Fujikura has been done a basic study of the application to the superconducting magnet and power cable. In the evaluation of the small coil is advanced for the superconducting coil, for the first time in the world, we have successfully developed a 5 T large-diameter high-temperature superconducting magnet of the room temperature bore diameter of 20cm in 2012 (Figure 11). This superconducting magnet uses a Y-based superconducting wire 7.2km manufactured in-house (the coil configuration: 300m × 24 layers), and the center magnetic field strength 5T at operating temperatures 24K, a stored energy 426kJ were achieved [5]. For superconducting power cable, by participating in the yttrium-based superconducting power equipment technology development project of the New Energy and Industrial Technology Development Organization (NEDO), we developed a 66kV / 5kA class superconducting power cable in 2013, to verify the AC loss reduction successful (Figure 12). In this project, we constructed the test line by 66kV class superconducting power cable prepared using the Y-based superconducting wire, performs 5kA energized which is largest as a power cable, and to be less 1W/m per one phase was verified. AC loss of less than 1W/m per phase at the 5kA energized, as compared with the working of the power cable (typically 154kV/600MVA class), the transmission loss of less than 1/4 in consideration of the cooling efficiency is estimated [6].

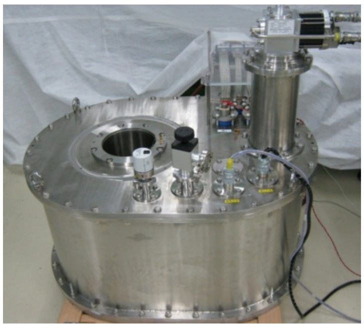

Figure 11 Y system 5 T high-temperature superconducting magnet

Figure 12 66kV/5kA class superconducting power cable

5. Summary

Fujikura have continued to research and development aimed at further improving the performance of Y-based superconducting wire. Among the project with aiming the practical use of Y-based high-temperature superconductor rises variety, Fujikura put the emphasis on the reliability of the wire itself, in addition to the performance improvement, also in wire-making that can withstand practical use, in recent years. In addition, to meet the future demand, it has also started consideration of mass production technology, there is not only in the area of traditional research and development, is also ready to enhance the production capacity as a supplier of Y-based superconducting wire. It is passed through a demonstration verification in various applications, to provide a high-performance Y-based superconducting wire which is excellent in reliability, we want to expect to be able to contribute to the realization of a low-carbon and high-efficiency energy society.

As a part of this report, "superconductivity application infrastructure technology research and development (II)," the Ministry of Economy, Trade and Industry and "yttrium-based superconducting power equipment technology development", National Institute of New Energy and Industrial Technology Development Organization (NEDO) are included for their outcome that was carried out by trustees.

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Status of High-Tc superconductor cryogenics for large volume, high efficiency and high reliability

(Naoko Nakamura, Maekawa)

1. Introduction

Adaptation of high-temperature superconducting cable to the ILC, we think useful as energy-saving technology to reduce the loss of ILC power supply. In order to introduce the current situation of high temperature superconducting cable, we report on the NEDO "high-temperature superconducting cable demonstration project", which was operated by connecting high-temperature superconducting cable to the ordinal power system, for the first time in Japan. In particular, the cooling system of high-temperature superconducting cable is an important key-technology, not only for the keeping of the superconducting state, but for the overall system efficiency and reliability improvement. In this paper, we will introduce the state of the art technology, such as developed refrigeration and cooling system in this project.

2. Outline of the NEDO "high-temperature superconducting cable demonstration project." [1], [2]

In NEDO project "high-temperature superconducting cable demonstration project", the system and the performance, operation, reliability, and maintainability of the system components were investigated, a high-temperature superconducting cable system to withstand the continuous automatic operation in the power system was build, and it was carried out to demonstrate an operation in the power system of more than one year. In parallel with the above demonstration, a large-capacity, high efficiency and reliability of high-performance refrigerator has been developed with considering the practical use of future high temperature superconducting cables. It should be noted that this project is the first project in Japan, which was operated a high-temperature superconducting cable by connecting to the power system.

Study of the impact of high temperature superconducting cable in the power system has been done by TEPCO. Study of the design, production and installation of the high-temperature superconducting cable have been done by Sumitomo Electric. Study of the design, production, and installation of the cooling system as well as development of high-performance refrigerator have been done by Maekawa Seisakusho. They were carried out respectively. The project was started from fiscal 2007. The design, manufacture, and a single verification test were done for the high-temperature superconducting cable and the cooling system. The power system interconnection test in October 2012 was carried out for continuous operation for more than one year, and in December 2013, the study was completed.

High-temperature superconducting cable that was used in this project was a three-core batch type cable with a rated 66kV, DI-BCCO of 200MVA, the length was about 240m. Considering the adaptation to the future of urban power cable laying situation in urban areas, the use of the joint, the cable bends and underground part were provided. In the Asahi substation, where the line is to step down the voltage from 154kV to 66kV, the part of the 66kV bus line was replaced to the high-temperature superconducting cable. Photos of the high-temperature superconducting cable used in this project is shown in Figure 1.

Figure 1 photo of high-temperature superconducting cable

3. cooling system used in the demonstration and its challenges [3]

The cooling system used in this project is the close circulation device. It is composed of refrigerators, circulation pump, and a reservoir tank. The sub cooled liquid nitrogen refrigerant (hereinafter, LN2) were used. LN2 that are sent by the circulation pump performs circulation cooling of the high temperature superconducting cable after cooled in the refrigerator. Flow of the cooling system and the installation situation are shown in Figure 2 and Figure 3.

Selection was made for a refrigerator type by the results to date, and it was also decided the number of refrigerator by the heat loss of the high-temperature superconducting cable system. In the cooling system, six of 1kW@77K Stirling refrigerator were used, and made them in three parallel × 2 units, considering pressure loss in the heat exchanger, the temperature controllability, and backup during the fault. Two centrifugal circulation pump were placed in parallel. In addition, one refrigerator one and one circulation pump is in the spare, they were automatically activating in the event of a fault. The volume of the reservoir tank was 1000L, considering of the volume change due to temperature change of LN2 in the high-temperature superconducting cable. Furthermore, it is necessary to maintain the pressure more than 0.2 MPaG in LN2 system for keeping electrical insulation of high-temperature superconducting cable, it was installed 3 types of pressure control device including the spare unit into the reservoir tank.

As described above, a circulation cooling of high-temperature superconducting cable using LN2 of sub-cooled state was performed in this project, but the operating temperature of LN2 was controlled to 69±1K (standard value) at the inlet temperature of the high temperature superconducting cable, considering the critical temperature of the superconducting material, LN2 temperature rise at the time of trouble such as a short circuit, and temperature margin. Specifically, the operation number control was performed in order to control the temperature by matching the variation in heat loss of the high-temperature superconducting cable between seasons and in a day. Control of operation number of the refrigerator is a commonly used method, even with cold water chiller refrigerator for pipe-tunnel cooling of underground cables, maintenance concept on the power plants are considered.

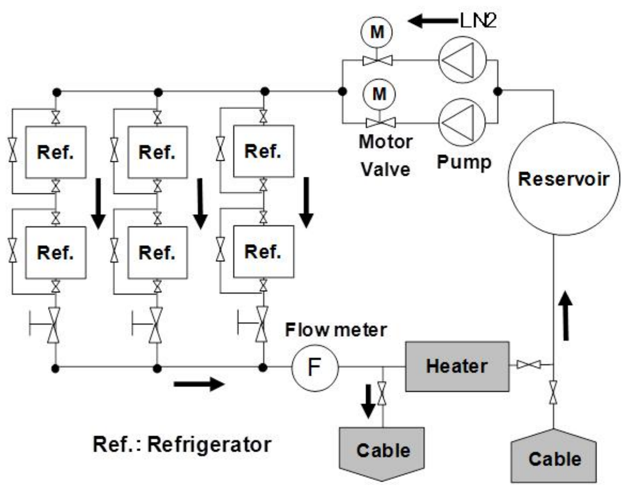

Figure 2 flow of high-temperature superconducting cable cooling system

Figure 3 photos of the high-temperature superconducting cable cooling system

Current through the high-temperature superconducting cable in the demonstration, temperature of LN2, pressure, and flow rate are shown in Figure 4. The demonstration test, which was lasted 1 year or more, was completed successfully without any big trouble. During this time, not stopping the circulation cooling may be considered as a major achievement. In addition, by the temperature control of the refrigerator, by the pressure control in the reservoir tank, sub cooled state of LN2 was kept, and even possible to achieve a stable long-term circulation cooling. Furthermore, even it was performed several times of the refrigerator replacement work during demonstration, LN2 circulation state was stable, no obstruction of LN2 circulation by ice or so, maintaining the LN2 circulation operation, so, it was able to establish a working techniques to replace disconnected the equipment only individually.

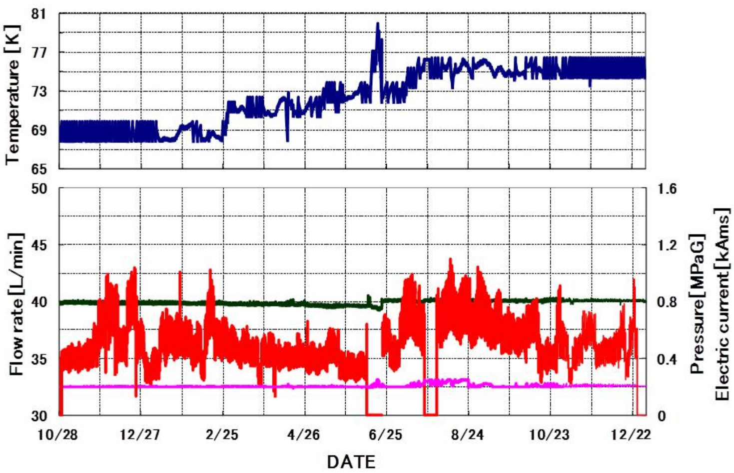

Figure 4 test results of the demonstration

While operation of high-temperature superconducting cable has verified without problems in the power system, however, for practical use, it has become clear that there are a number of challenges. Examples of the resulting problems are described below.

In this cooling system, the six refrigerator were connected with vacuum insulation piping, and further, the bypass line for the refrigerators for maintenance were installed. Therefore, increasing the number of valves of vacuum insulation pipes and bypass, their loss became comparable to the refrigerating capacity of one refrigerator in the cooling system. In order to increase the overall efficiency of the high-temperature superconducting cable system, improvement of the refrigerator efficiency, reducing the loss of the high-temperature superconducting cable, and reducing heat losses in the cooling system, are required. large capacity of the refrigerator which has reducing the effect of heat loss of the cooling system, is thought to contribute to the high efficiency of the entire superconducting cable system.

In this project, the power consumption of the cooling system required to cool the high-temperature superconducting cable is defined as the cooling system COP. In the cooling system used for the verification test, the efficiency has been unquestioned, however, in order to give the operational benefits of future high-temperature superconducting cable, it has to be a COP of 0.1. However, as the results of this verification test, the cooling system COP was approximately 0.04.

Lowering of the refrigerating capacity of the refrigerator started after the start of three months during verification test, sequential performance degradation was seen in the six refrigerator. In order to maintain the refrigerating capacity, 1-2 times of evacuation and the overhaul of the refrigerator by manufacturers were performed monthly. When we use it in a power system, the reliability of the cooling system and longer maintenance intervals of the device are also important. Therefore, it is necessary to develop a refrigerator of long maintenance intervals.

Considering above results, a large capacity, high efficiency, high reliability of the Brayton refrigerator has been developed and introduced in the next section.

4. Development of high-performance refrigerator [4]

In terms of the aim of practical application of high-temperature superconducting cable, since a large-capacity, high efficiency and high reliability refrigerator was essential, from February 2011, in parallel with the demonstration test at Asahi substation, development of a high performance refrigerator was performed in this project. Considering the loss of high-temperature superconducting cable during practical application, required single refrigerator capacity was assumed as 5 ~ 20kW, this time target refrigerator capacity was set to 5kW which was 5-6 times the capacity of the current Stirling refrigerator. Furthermore, the loss of the cable system is required to be reduced by 50% over than ordinal cables, in order to achieve this, the goal COP of the cooling system was 0.1. Also, considering the practical use, maintenance intervals of the refrigerator is also an important evaluation items, and 30,000 hours, which were general industrial refrigerator equivalent, were targeted in this project.

To achieve the development goals above, reversed Brayton cycle was adopted in the refrigerating cycle. Reverse Brayton cycle is a refrigeration cycle consisting of insulating process and isobaric process, it is a gas cycle, but, it is the heat pump radiating heat out of the system. The basic system flow and photographs of Brayton refrigerator that was developed in this project are shown in Figure 5 and Figure 6. In adiabatic compression process, considering the refrigerator efficiently become better for plus work from the outside isothermally, and considering the proper pressure ratio of the compressor, the refrigerator employs the three-stage compression. In addition, the turbo type compressor and expander were adopted in order to maximize the characteristics of the reverse Brayton cycle. In addition, in order to be the cooling system COP to 0.1, the design value of the adiabatic efficiency of the turbo compressor-expander was set to 0.8.

Considering refrigerator efficiency, the shape of the rotor blades, a motor specification, and the economical efficiency, first-stage and second-stage turbo compressor, and, the third-stage turbo compressor and turbo expander, are integrated. By integration of the turbo compressor and turbo expander of the third stage, power generated by the expander is consumed for a part of the power for driving the third-stage compressor, which contributes to the efficiency improvement of the refrigerator. The refrigerant of the refrigerator, the helium gas and neon gas has a potential, since it is required to be a low boiling point. In turbo machine, as the molecular weight of the working fluid is small, it become high rotation and tend to be compact, because much high difficulty of the manufacturing as to be compact as described above, we adopt the neon gas refrigerant in this development. Since the rotational speed of the rotary machine in the case of using the neon gas refrigerant becomes 40,000 ~ 70,000rpm high speed rotation, the bearings were used non-contact oil-free bearings. It realizes the increase of maintenance intervals by using non-contact oil-free bearings, and increased the reliability of the refrigerator. This horizontal type compressor with the pressure sealed structure placed the rotor blades in both ends around a built-in motor. Structure of three-stage compressor and the expander were also similar, but it had the vertical structure for disposing the expander side in the cold box.

This refrigerator consists of, a turbo compressor and an expander, first-stage and second-stage integrated turbo compressor, expander-integrated third-stage turbo compressor, cold recuperator heat exchanger for utilizing the cold heat generated in the expander, LN2 heat exchanger that performs heat exchange between LN2 and neon, and the water heat exchanger for dissipating the heat of compression to the outside air in the cooling water. The cold recuperator heat exchanger and LN2 heat exchanger were adopted aluminum plate-fin proven helium liquefaction refrigerator. Turbo expander, cold recuperator and LN2 heat exchanger were installed in the cold box, other devices were installed as a compressor unit on a single frame. Considering the ceiling height of the cooling system building of Asahi substation, it was making a structure for drawing the body of the vacuum chamber while leaving the top plate of the cold box down, and making easy maintenance of the equipment installed in the cold box in the cooling system building.

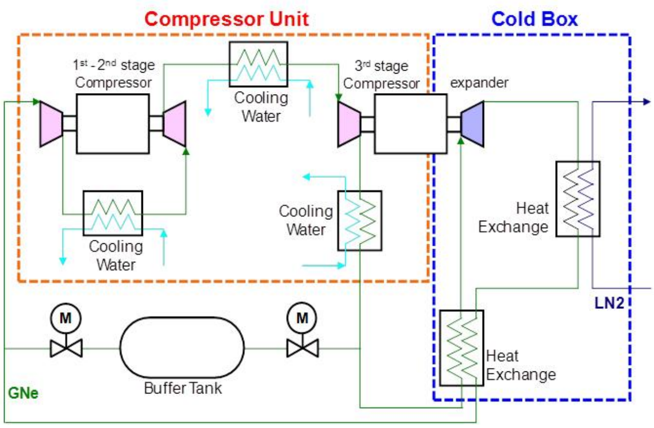

Figure 5 Brayton refrigerator flow

Figure 6 Brayton refrigerator photo

The results of performance test, the refrigerating capacity of the refrigerator was 5.8kW@77K, and COP was 0.1@77 K, then it was a certain degree of success. Therefore, as a basement of the structure of the circulation system, which was introduced in Chapter 3, we have developed a cooling system equipped with this refrigerator. At the factory testing, the performance of the cooling system, the controllability, and the operability and so on, have been transferred to the Asahi substation after confirming that there is no problem. Currently, in preparation for the long-term continuous operation in a power system on which we plan to start from summer 2015, the final confirmation of the cooling system has been performing.

5. Summary

Adaptation of high-temperature superconducting cable to the ILC, we think useful as energy-saving technology to reduce the loss at the time of ILC power supply. In this paper, we introduce the state of the art of refrigeration and cooling systems that have been developed by NEDO "high-temperature superconducting cable demonstration project" of high-temperature superconducting cable that is attracting attention as the future of energy-saving technology.

Demonstration that lasted more than one year, was successfully ended without any big trouble, and it made a big success. However, assuming a future superconducting cable commercialization, it also became clear that there are problems in the capacity of the refrigerator, the efficiency, and the reliability. Therefore, development of large capacity, high efficiency, high reliability of the refrigerator was carried out.

The refrigerator using turbo compressor and the expander, aimed large capacity, high efficiency, and high reliability, by reverse Brayton cycle, multi-stage of the compressor, and the adoption of magnetic bearings. The results of performance test, refrigeration capacity and COP were both able to accommodate certain results. We performed relocation to the Asahi substation. We are currently preparing for the demonstration test connected to the power system in summer 2015.

Reference

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Energy saving and Cost Reduction in High-Voltage Substation and Distribution System for Green-ILC

(Tadashi Fujinawa, Riken)

1. Introduction

Accelerators are mainly operated nonstop for a long time and require a large amount of electricity. From this point of view, an AC power supply system must be highly reliable, economical, and efficient.

The author proposes a new high-voltage (HV) substation and distribution system using Green ILC, which can achieve energy savings and cost reduction based on the RI beam factory (RIBF) experience of the RIKEN Nishina Center. Using this proposed substation and distribution system, the construction cost will be less than half of that of the technical design review (TDR), and the amount of energy savings will be 9,218MWh per year.

2. HV substation and distribution system of TDR

The plan for the transmission and distribution of ILC using TDR was accepted by both Kyusyu Electric Power Corporation and Tohoku Electric Power Corporation and is excepted to supply 275kV, according to the report of the Large-Project Division of AAA two years ago (2013).

Fig. 1 shows the general plan. Fig. 2 shows the main substation single-line diagram (SLD). Fig. 3 shows the SLD of a 66kV/6.6kV [HV/medium voltage: (HV/MV)] substation.

This plan was designed by an engineering consultant company requested by the High Energy Accelerator Research Organization (KEK), which is simply an expansion of KEK and the J-Pack facility.

Fig. 4 shows a photograph of the RIKEN Nishina Center HV/MV substation for reference.

The author expresses some doubts on the plan and will present my comments and explanation of each item.

1) Receiving voltage

TDR plans 275kV as the receiving voltage, but Kyusyu Electric Power

Corporation does not have a 275-kV system. It uses 220kV instead of 275kV. The power receiving voltage in the Kyusyu area is 220kV, and no other voltage option is available.

In the Tohoku area, the supply voltage is 154kV for a 200-MW load. In addition, the JFE Steel Corporation Chiba Works and Nippon Steel & Sumitomo Metal, both in Chiba Prefecture, and the Kashima Kita (north) Industrial area where Mitsubishi Chemical Corporation has its flagship

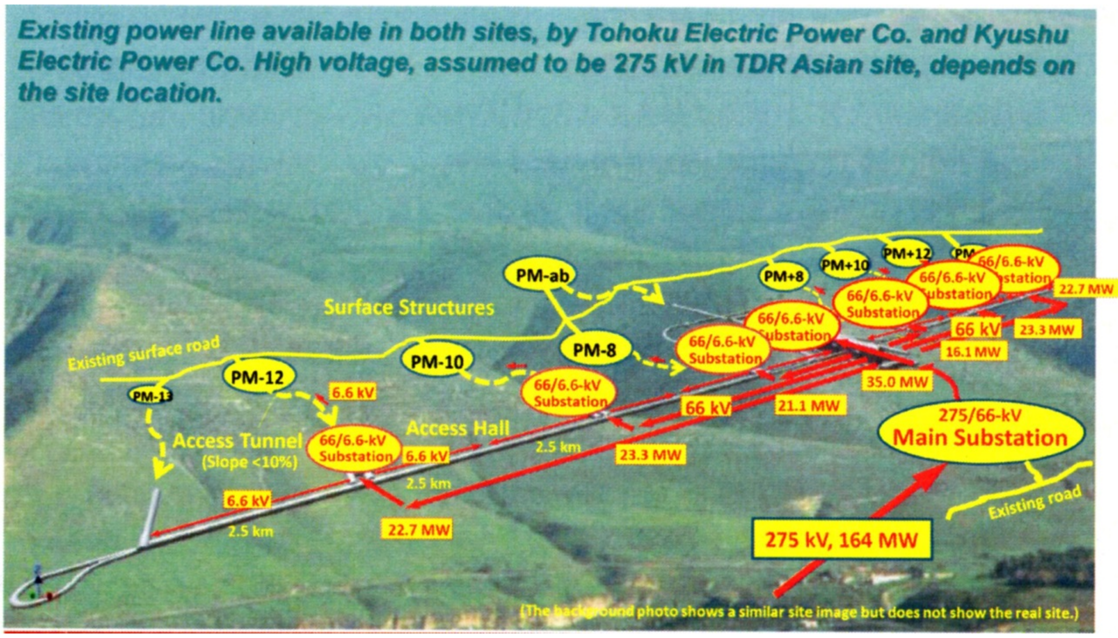


Fig.1 This drawing shows that the 164-MW power will be received at 275kV/66kV main substation from the utility company, and power is distributed to the seven 66kV/6.6kV HV/MV substations using 66kV underground cables. The received power at each HV/MV substation is less than 30MVA.

project receives 154kV from Tokyo Electric Power Corporation. The Kashima Minami (south) industrial area uses 66-kV distribution systems. Kashima area is in the Ibaraki Prefecture. The only example where a 275-kV supply exists is in Tohoku-epco for the East Japan Railway.

2) Economic performance

The 275 kV-transmission lines are directly connected to large power stations and create a basic power grid. However, in Japan, the manufacturers of 275-kV equipment are only Hitachi, Toshiba, and Mitsubishi Electric, and the equipment is very expensive compared with that in the 154-kV system. In addition, an expensive microwave tower and its communication systems are required in the 275-kV substation in the Tohoku-epco area. We have to note that a 275-kV substation requires a first-class licensed engineer (which is currently rare after the Fukushima Daiichi Nuclear Power Station disaster), whereas a second-class engineer is required for a 154-kV substation.

The Large-Project Division of AAA has estimated an HV substation system. Under the same voltage, a 60-Hz transformer will cost lesser than a 50-Hz transformer because the 60-Hz transformer is smaller than a 50-Hz one. However, in a 220-kV versus 154-kV system, the 50-Hz transformer has an advantage in terms of cost.

The TDR plan has twice the capacity and spare power; thus, we must consider the economic aspect. With this design, not only the construction costs but also the operation costs increase. The large number of transformers causes more iron loss (no-load loss), and the series connection of the 275-kV (154kV/66kV and 66kV/6.6kV) system creates large losses from both hysteresis and Joule heating losses.

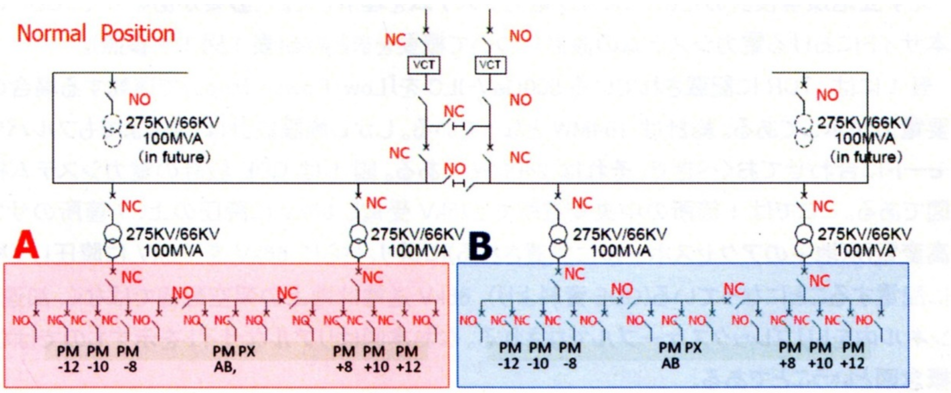


Fig. 2 The 275-kV/66-kV main substation is heavily-protected. NC means normal close (ON), NO is normally open (OFF). This SLD shows four times the number of 100-MVA transformers compared with a load of 164 MW as shown in Fig. 1. This plan also shows two extra gas circuit breakers (GCB). The areas colored pink and blue are layout of the 66-kV vacuum circuit breakers (VCBs). The feeders from A and B are connected to the 66-kV/6.6-kV HV/MV substations with the 66-kV underground XLPE/PVC cables.

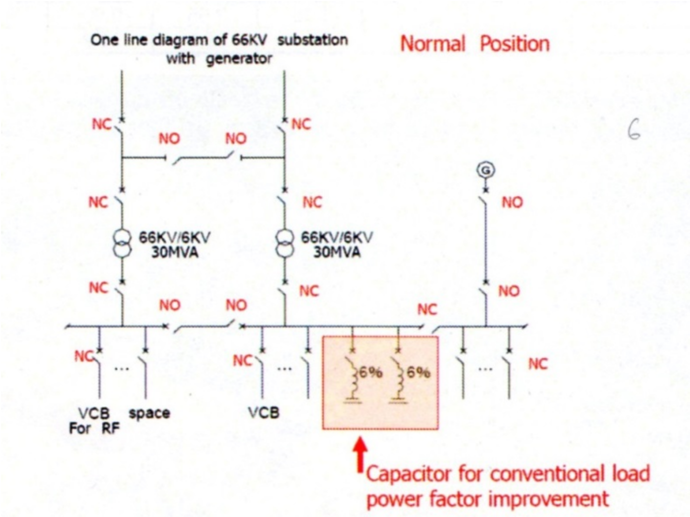


Fig. 3 SLD of the 66-kV/6.6-kV substation. The seven HV/MV substations are arranged. Each substation has loads from 10 to 15 MW, but the transformer capacity is 60 MVA. This drawing shows an emergency 6.6-kV generator and capacitors for conventional power factor improvement, but the capacities are unknown.

3) Reliability

The TDR has two lines for power reception: one is for normal use, and the one is for spare. However, the two lines are installed in one tower. From our experience, a jet plane simultaneously severed two lines due to engine trouble, and a crane ship severed two lines above a river. Both created long-time power outages. The two lines are connected to the same power source (substation). Thus, in the event of substation trouble, both lines will be de-energized.

A two- line power receiving system can be considered useful only for scheduled power outages, although it is costly. The RIKEN Wako campus employs the same system yet still experiences sudden power outages.

The most serious concern is the series connection of the HV/HV and HV/MV transformers. If one of them is damaged, the system will not work. Therefore, the two sets of equipment have a two times probability of failure compared with one set.

Fig. 4 RIBF substation. The front is a 66-kV gas-insulated substation with a VCB. The back row shows a transformer with a capacity of 25/30 MVA and the 6.6-kV metal-clad switch gears behind.

3. Proposed plan for Green ILC

Fig. 5 shows the proposed plan of the HV substation and distribution system made by the author.

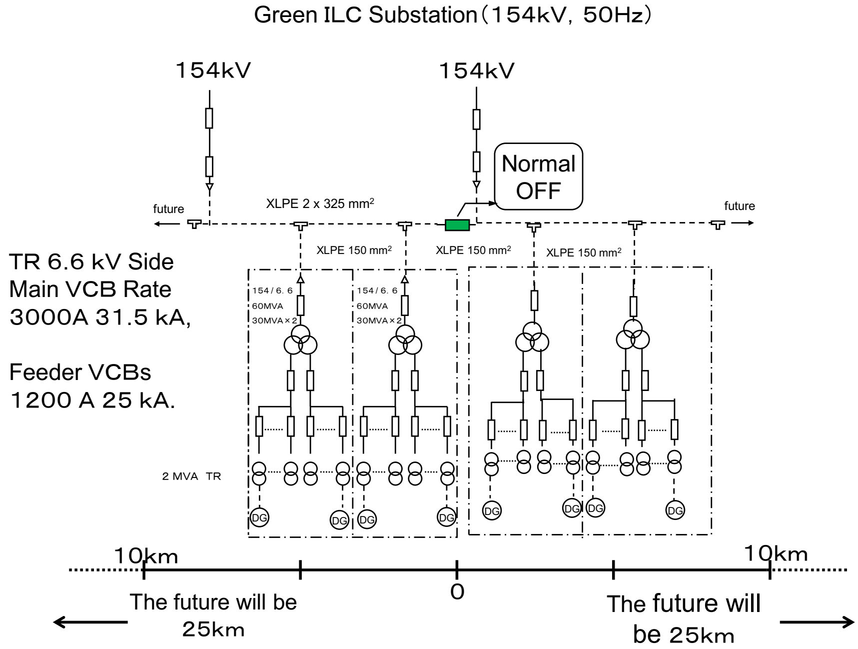


Fig. 5 SLD of the energy-saving system. The drawing corresponds to those shown in Figs. 3 and 4. Green ILC will arrange two switchyards and receive power from different power utility sources such as the A and B substations. The two lines are energized at all times and supply power via four 60-MVA HV/MV transformers. In case one line is de-energized, the green normally off GCB will switch on immediately and supply power within 6 Hz (12 ms). With this almost uninterruptible power supply system, we can operate cryogenic refrigerators, vacuum systems, and other important loads without interruption.

First, the voltage should be 154kV from the Tohoku-epco area, which was recommended by the Large-Project Division of AAA. The 275-kV system cost is very high compared with the 154-kV. In addition, the Tohoku-epco has no plan of supplying 275kV at all.

Green ILC has two switchyards and receives power from different power sources of Tohoku-epco. In case the total required power is 200MW, both substations will supply 100MW each. One normally off GCB is installed in between. If one side experiences a sudden power failure, the high-speed under-voltage relay automatically orders the GCB to “switch on,” as indicated by the green color. From this action, we can operate cryogenic and other systems without interruption. The main distribution cable size is two 325mm^2, and the feeder cables are 150mm^2. The main cable capacity is 240MVA, and the allowable power in each feeder is more than 60MVA. This type of different power supply system can be used in government prefecture and other essential loads.

The required transformer sets will only be four 154kV/6.6kV (HV/MV) 60MVA, and they will be distributed at the same interval. From this setup, this system does not require 154-kV/66-kV HV/HV transformers, and savings in terms of losses from the said HV/HV transformers can be realized. The 14 transformers in the TDR will be converted to only four transformers, thus a significant savings in terms of lesser number of circuit breakers, disconnect switches, bus bars, and other equipment will be realized. In addition, fewer parts mean fewer troubles, which increase reliability.

The reason for the HV/MV is that it has two windings of 6.6kV 30MVA for the MV circuit breaker maximum capacity of 3,000A, which makes the MV side achieve a maximum capacity of 30 MVA. I believe that TDR chooses 66kV/6.6kV for the 30MVA transformers.

The construction cost of the proposed system is approximately half that of the TDR system owing to its fewer equipment and simple structure.

The performance of both systems can be quantitatively calculated. The conditions are as follows:

The power requirement of Green ILC is 200MW. The amount of CO_2 emission from Tohoku-epco is 0.591kg/kWh in 2014. The electrical cost is ¥12/kWh. The operation time of Green ILC will be 7,000h/year. Fig. 6 shows the transformer efficiency: one 100 MVA, seven 30MVA, and eight 60MVA.

TDR system: (4 × 100MVA + 14 × 30MVA)

1) 100MVA at 50% load, η= 99.49 at 50MW: 1 - 0.9949 = 0.0051; 50MW × 0.0051 = 255kW. 4 × 255 = 1.02MW (total). The iron loss is 125kW for a total of 4 × 125kW = 500kW.
2) 30MVA at 47.6% load, η= 99.545% at 14.3MW: 1 - 0.9945 = 0.0055; 14.3 MW × 0.0055 = 79kW. 14 × 79 = 1.1 1MW. The iron loss is 22kW for a total of 14 × 22kW = 308kW.
3) Total loss

   During operation: 1.02MW + 1.11MW = 2.23MW

   During maintenance: 500kW + 308kW = 808kW (1,760h/ year)

Green ILC system: (154kV/6.6kV, 60MVA × 4)

Load factor is 83% of the 60MVA, which is 50MW. η= 99.40%: 1 - 0.994 = 0.006;

4 × 0.006 × 50MW = 1.2MW (almost half). The total iron loss is 4 × 50kW = 200kW.

The comparison of both systems is presented as follows:

Energy loss during operation time: 2.23MW – 1.2MW = 1.03MW (7,210MW/year)

During maintenance: 808kW – 200kW = 608kW (1,070MWh/year at 1,760h/year)

Total: 7,210MWh/year + 1,070MWh/year = 8,280MWh/year

Electrical cost of transformer loss:

During operation: 1,030KW × 7,000h/year × ¥12/kW·h = ¥86,520,000.00/year

During maintenance: 608kW × (8,760 - 7,000) × ¥12/kW·h = ¥12,840,960.00/year

Total amount: ¥86,520,000.00/year + ¥12,840,960.00/year = ¥99,360,960.00/year

CO_2 emission

During operation: 1,030kW × 7,000h/year × 0.591kg/kW·h = 4,261,110kg/year

During maintenance: 608kW × (8,760 - 7,000)h/year × 0.591kg/kW·h = 632,417 kg/year

Total: 4,261,110kg/year + 632,417kg/year = 4,893,527kg/year = 4,894ton/year.

Cable loss

The cable size capacity is same as the capacity of the transformers. The calculations were made by PAT No. 263544. The other conditions are same as those in the transformer loss calculations.

TDR system

1. 66kV XLPE/PVC Cable 150mm^2 for 14 feeders

2. Each cable length is as follows : 4 × 11.65km, 4 × 7.7km, 4 × 4.1km, and 2 × 0.4km
3. The current is 125A (14.3-MW base); the conductor temperature is 49.1°C.
4. The cable losses are 25.2kW for 11.65km, 16.6kW for 7.7km, 9.0kW for 4.1km, and 0.9kW for 0.4km.
5. The total loss is 205kW or 1,435,000kW·h/year; the CO_2 emission is 848tons per year.

Green ILC system

1. Main cable: 154kV XLPE/PVC 2 × 325mm^2 (51.4°C at normal current of 450A and maximum current of 900A)
2. Transformer feeder cable : 154kV XLPE/PVC 150mm^2, 225A at 60MVA and 200A at 50MVA at 69.5°C.
3. Each cable length is as follows: for the main cable—2 × 6.2km and 2 × 3.1km; for the feeder cable—0.4km.
4. Cable losses: main cable —for 2 × 6.2km, 375A at 100MW is 56kW and for 2 × 3.1km, 188A at 50MW is 6.9kW. The total loss for the four cables in the feeder is 8.1kW.
5. The total cable loss is 71kW. The electrical loss is 497,000kW/year. The CO_2 emission is 294tons.

Difference between the TDR and Green ILC:

1. Cable portion: 1,435,000kW·h/year - 497,000kW/year = 938,000kW/year. (¥11,256,000.00)
2. Grand total: 9,218MWh/year, ¥110,616,960.00/year, and 5,448tons of CO_2 per year. We can consider this as monergy.

2015年2月5日
三菱電機株式会社
系統変電システム製作所

100MVA油入変圧器の効率曲線

Efficiency Curve

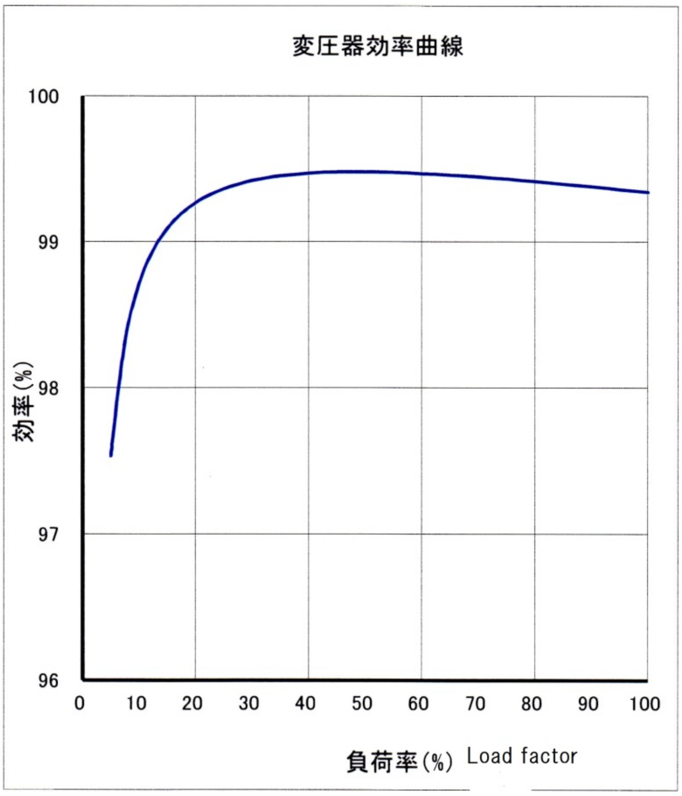
1. 変圧器仕様

特別三相，50Hz，導油自冷式，負荷時タップ切換器付，%Z＝11%，内鉄形，騒音値65dB（防音壁付）
一次側：F168～R154～F140kV，星形
二次側：66kV，星形
安定巻線（三角形）付

2. 損失

無負荷損失（鉄損）　125 kW　Iron Loss
負荷損失（銅損）　530 kW　Copper Loss
補機損失は含みません。
※損失は参考値であり，変圧器の仕様変更，詳細設計により変わる可能性があります。

3. 変圧器の効率曲線



変圧器効率	
Load （%）	効率（%）
5	97.54
10	98.71
15	99.10
20	99.27
25	99.37
30	99.43
35	99.46
40	99.48
45	99.49
50	99.49
55	99.48
60	99.48
65	99.47
70	99.45
75	99.44
80	99.42
85	99.41
90	99.39
95	99.37
100	99.35

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Fig. 6 TDR main transformer efficiency curve. 154kV/66kV, 100MVA, 99.35% at rated capacity.

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Efficiency Curve

30MVA油入変圧器の効率曲線

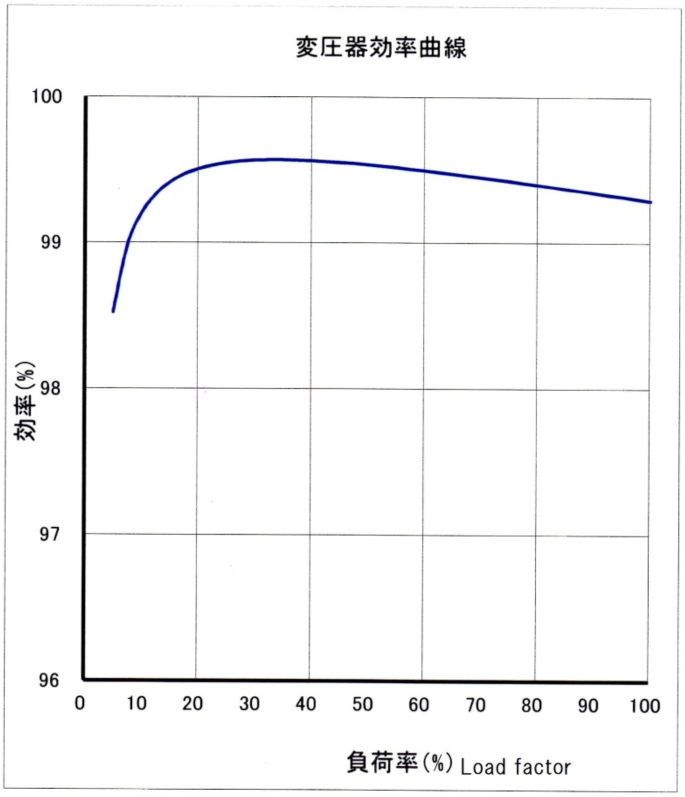
1. 変圧器仕様

三相, 50Hz, 油入自冷式, 負荷時タップ切換器付, %Z＝15%, 内鉄形, 騒音値65dB
一次側: F72～R64.5～F57kV, 星形
二次側: 6.9kV, 星形
安定巻線(三角形)付

2. 損失

無負荷損失(鉄損) 22 kW Iron loss
負荷損失(銅損) 190 kW Copper loss
※損失は参考値であり, 変圧器の仕様変更, 詳細設計により変わる可能性があります。

3. 変圧器の効率曲線



変圧器効率	
Load (%)	効率(%)
5	98.52
10	99.21
15	99.42
20	99.51
25	99.55
30	99.57
35	99.57
40	99.57
45	99.55
50	99.54
55	99.52
60	99.50
65	99.48
70	99.45
75	99.43
80	99.41
85	99.38
90	99.35
95	99.33
100	99.30

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Fig. 7 TDR HV/MV transformer efficiency curve. 66kV/6.6kV, 30MVA, 99.30% at rated capacity.

Efficency Curve
60MVA油入変圧器の効率曲線

2015年2月5日
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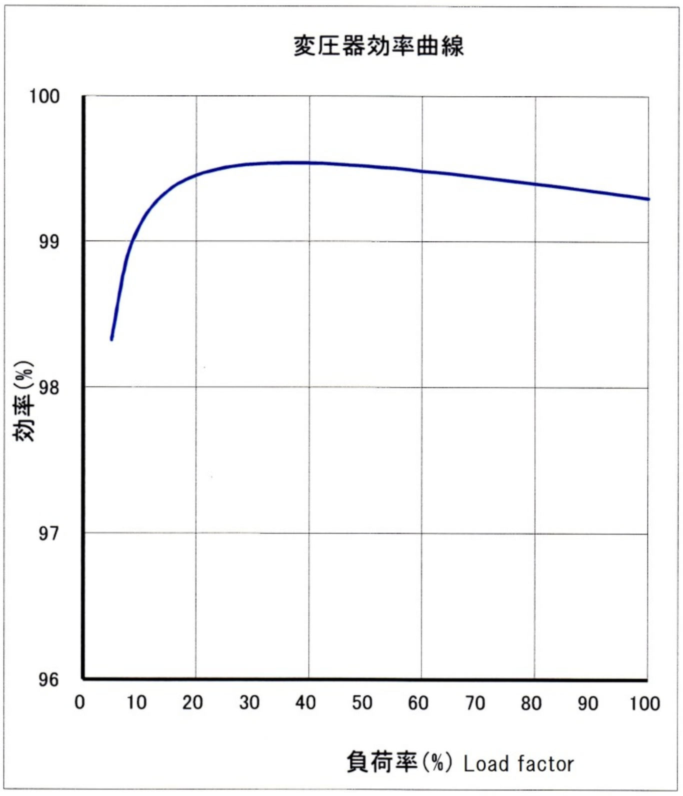
1. 変圧器仕様

三相, 50Hz, 導油自冷式, 負荷時タップ切換器付, %Z=15%, 騒音値65dB, 内鉄形
一次側: F168～R154～F140kV, 星形
二次側: 6.9kV, 星形
安定巻線(三角形)付

2. 損失

無負荷損失(鉄損)　50 kW Iron Loss
負荷損失(銅損)　370 kW Copper loss
補機損失は含みません。
※損失は参考値であり, 変圧器の仕様変更, 詳細設計により変わる可能性があります。

3. 変圧器の効率曲線



変圧器効率	
Load(%)	効率(%)
5	98.33
10	99.11
15	99.36
20	99.46
25	99.51
30	99.54
35	99.55
40	99.55
45	99.54
50	99.53
55	99.51
60	99.49
65	99.47
70	99.45
75	99.43
80	99.41
85	99.38
90	99.36
95	99.33
100	99.30

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Fig. 8 Green ILC transformer efficiency curve. 154kV/6.6kV, 60MVA, 99.30% at rated capacity.

4. Conclusions

The system that the author has proposed is the so-called “Green ILC system,” which offers a large reduction in the construction cost of more than twenty billion yen, and the operating cost will be more than one hundred million yen per year lower than the TDR system. In addition, the Green ILC system reduces the CO_2 emission by more than 5,000tons per year, a fact known by everyone.

We plan to use a superconducting cable for transmission and distribution. However, the cable loss in the Green ILC system is only 71kW. The author has some doubts whether a superconducting system, which requires cryogenic refrigerators can be sustained. This aspect must be very carefully studied.

Some people might worry about the direct transformation from 154 to 6.6kV. In fact, in Japan, many residential transformers from the nuclear power stations use 500kV/6.6kV. In addition, the Korea Proton Engineering Frontier Project has also a 154-kV/3.3-kV system.

The ILC system will provide large advantage derived from nuclear physics, but its need for huge consumption of electricity would be its weak point. Not only the construction cost but also the operation cost should be considered for the Green ILC, which the author has explained in details earlier.

Introduction of Friction Reduction Chemicals for water pipes

(Hiroyuki Nishi, Sin-Nihon Kucho)

1. Introduction

The method adding very small amount of pipe friction resistance reducing agent in the circulating water piping (Drag Reducing Additive: hereinafter referred to as DR agent), has been known technique to reduce the carrying power of the pump. This DR agent is used polymeric agent or a surfactant. Practical use of a surfactant has a long history, and has many examples, such as an increase in the navigation speed of the ship, improvement of the water discharge capacity for fire fighting, and oil pipeline transport capacity, they are examples of to transient flow field.

However, in the circulatory system DR agent will be destroyed its molecular structures by the mechanical shearing force such as a pump impeller, there is a problem of deterioration of the DR agent. Surfactant, on the other hand, because there is a regenerative capacity which will be mentioned later, become the mainstream in recent years of research carried out basic research and field tests in abroad. In the regions of the district heating pipes in Europe, it is used in practice. In Japan, it reached the stage of practical use from the basic research stage, the examples of the use have been increasing.

Shin-Nihon Kucho has about 15-year career and achievements with respect to DR agent introduction as energy-saving technology of air conditioning piping system. We introduce the basic characteristics of the DR agent description and example of application to the air-conditioning piping to the existing commercial building in this paper. It is our hope to help deep understanding DR agent for Green ILC WG participants, in turn, project promotion.

2. Mechanism of DR effect

When water is flowing in the pipe at a certain speed, water molecules at the pipe inner wall and the central portion disarray intensely in the flow, that is, the "turbulent flow" state. Most of the piping friction resistance rises due to the turbulent motion. Thus, by suppression of turbulence (laminating of the stream), the pipe frictional resistance can be reduced significantly. In Moody diagram showing the relation between the Reynolds number and the pipe friction coefficient in Figure 1, the friction coefficient of the turbulent flow is to close an extension of the diagram of the laminar flow zone shown by a broken line. This is a DR material has been developed for the purpose (the effect is called DR effect).

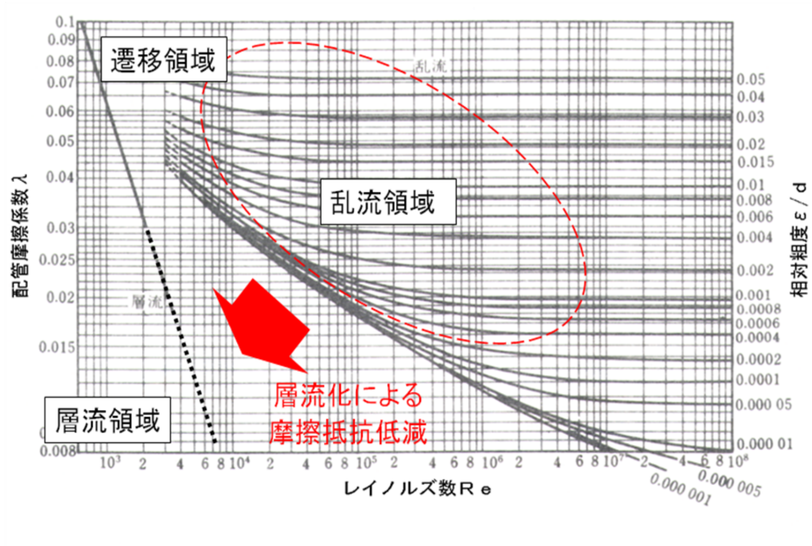


Figure 1 Moody chart

DR effect which was discovered by B.A. Toms in 1948 is a phenomenon which is also referred to as Toms effect. As the material of the DR agents, surfactants and polymeric agent is used. For example, by adding small amount surfactant to flowing water, collection of the surfactant molecules that form as if long chains as shown in Figure 2 (rod-like micelles) can modify the water flow to the non-Newtonian fluid, even rod-like micelles can be destroyed by mechanical external force, it will recover. While fresh water is Newtonian fluid is the constant viscosity regardless of the shear rate, the non-Newtonian fluid viscosity varies with shear rate. As shown in Figure 3, pipe flow state is almost the same as a fresh water at near-wall where is a large shear rate with small viscosity, at the center, since the place is in a large viscosity with small shear speed, the flow become small disturbance massive flow, then, turbulence is suppressed and the pipe frictional resistance is reduced.

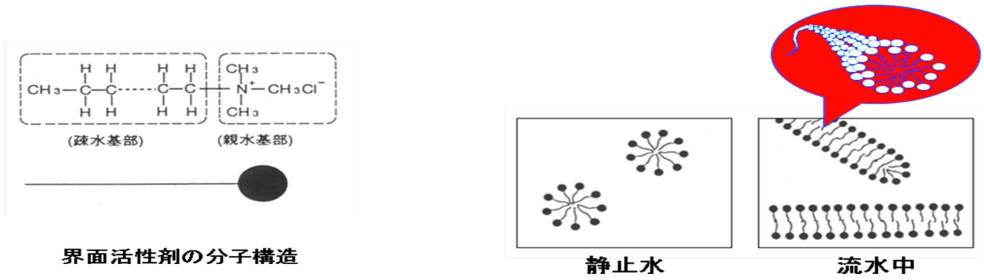


Figure 2 the molecular structure of the surfactant, and rod-like micelles in the flowing water

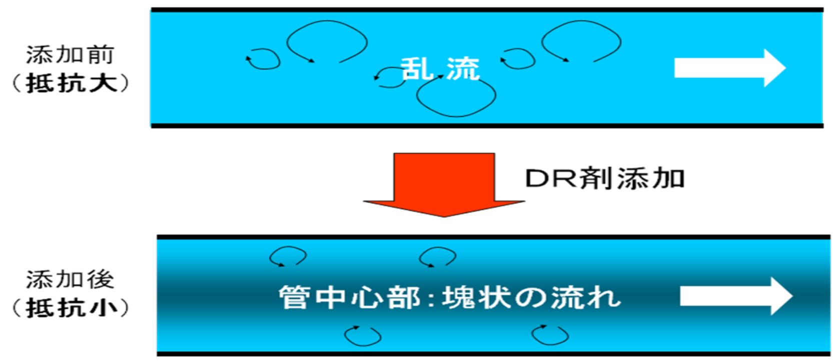


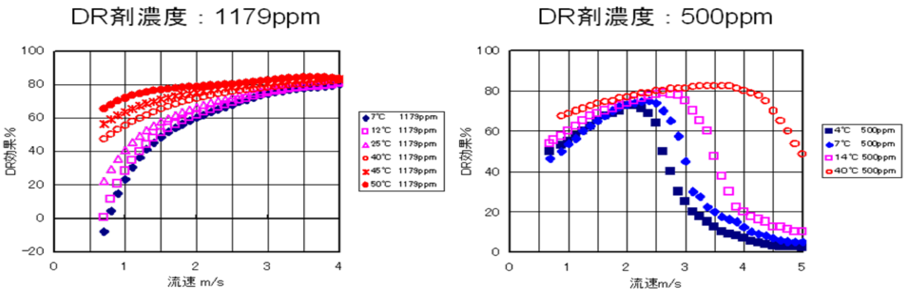
Figure 3 changes in the pipe flow state

3. Characteristics of DR effect

DR agent that we are using, is cationic surfactant of Ethoquad system, added counter ion conducive to form rod-like micelles, it is a product that also has anti-corrosion effect. DR effect determine mainly "flow velocity in the pipe", "the temperature of the circulating water", and "concentration of DR agent". As "flow velocity in the pipe (1m / sec ~ 4m/sec)" is faster, and as "the temperature of the circulating water (5℃ ~ 65℃)" is higher, and "concentration of DR agent (stock concentration 500ppm ~ 1,000ppm)" is higher, DR effect tends to increase.

Figure. 4 is a data of DR effect in the straight tube portion with stock concentration of DR agent 1,179ppm and 500ppm, has to organize the DR effect by the pipe flow velocity and temperature as a parameter. The DR effect is approximately up to 80% where DR effects increase by an increase in flow speed and temperature. Although, at the low concentration 500ppm, DR effect is greater at low flow rates range, if it exceeds a certain limit in the high flow rate region, the rod-like micelles is destroyed in a turbulence intensity and then DR effect is lost. Also in the joint portion of the curved portion, because of large turbulence intensity originally, DR effect can not be expected.

In addition, both of straight tube portion and the joint portion, for viscosity increase due to DR agent additive, sometimes DR effect is negative at below 1m/sec of the low flow rate region, where the viscous resistance becomes dominant.



$$DR\text{効果}(\%)=\left[1.0-\left(\frac{\text{ＤＲ溶液の配管摩擦抵抗}}{\text{清水の配管摩擦抵抗}}\right)\right]\times 100$$

Figure 4 DR effect of straight pipe section

The DR effect is up to 80% in the straight pipe section, on the other hand, for the effects of the resistance in the joint portion of and the resistance of the equipment inside are dominant in DR effect of the entire piping system, overall DR effect is shown in Figure 5. DR effect of the entire piping system will be determined by the ratio of the DR effect of the straight pipe portion resistance to total resistance (corresponds to a pump total lift).

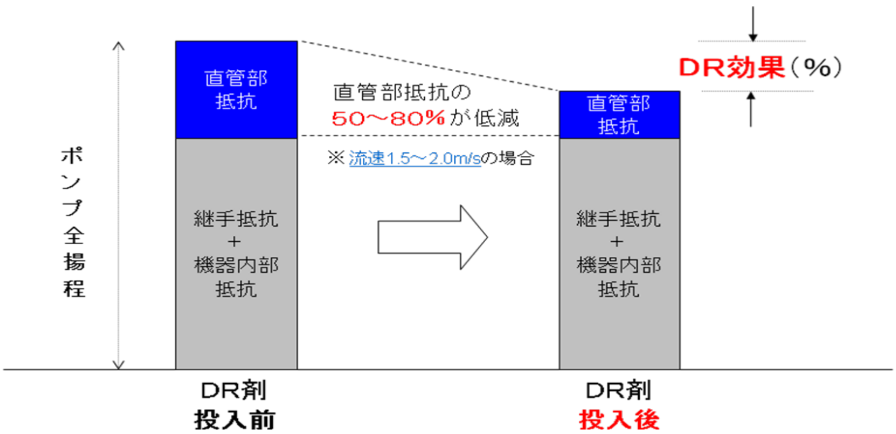


Figure 5 overall DR effect of piping system

Figure 6 shows the effect of DR additive to fin and tube type air/water heat exchangers which are used in air-conditioning fan coil unit. DR effect, because it is brought by the turbulence suppression, cause a reduction in heat exchange efficiency if generated in the heat exchanger tube. The heat exchange efficiency is hardly reduced because DR effect is relatively small in the case of cold water, reduction in heat exchange efficiency due to the relatively large DR effect is assumed to have occurred in the case of hot water. In DR agent case study on our company's existing commercial building, reduction of heat exchange efficiency is not observed for cold water heat exchanger.

However, decrease in heat exchange efficiency due to the DR effect in the internal heat exchanger can not be simply assessed, because of dependence on the diameter of the tube, the length of the straight pipe section, also the influence of the shape of the inner wall. For applying the DR agent to specialized equipment which is different from the commercial air-conditioning, it is expected to require more detailed examination and verification.

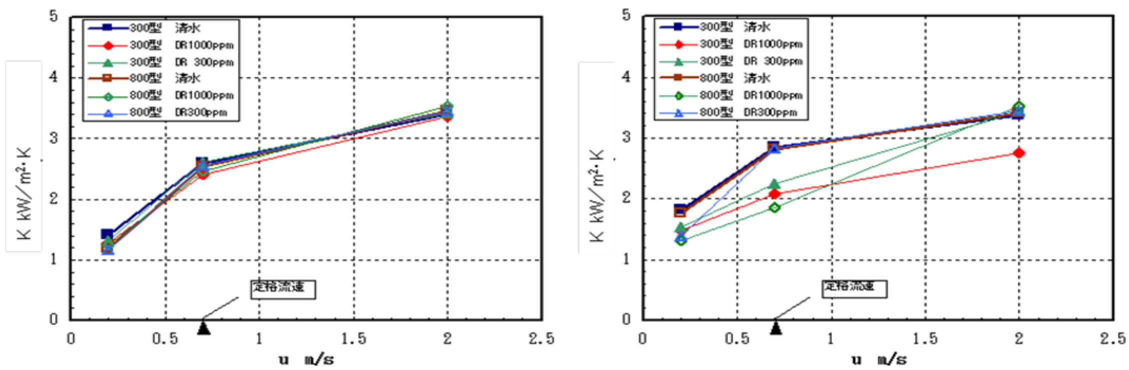


Figure 6 impact on the heat exchange efficiency of the fan coil unit

4. Input conditions of DR agent

Are shown below nine conditions (① ~ ⑨) is a study item at the time of the DR agent input for the existing business building. Since ① ~ ③ is a necessary condition, it can not be applied on as long as it does not meet this. ④ ~ ⑨ is not a necessary condition, since the higher the initial cost and running cost, since the cost-effective worse, the possibility that results as the input becomes unsuitable.

As for ①, the circulation of the water is significantly inhibited by capturing the gas bubbles into the circulation water, if it is an open circuit rather than a closed circuit. It should not be applied on because there are cases in which bubbles are blown out from the expansion tank. For ②, when components such as iron and zinc of the circulating water is at high concentrations, the expression of DR effect is interfered. In addition, since surfactant component is adsorbed on the rust that is generated inside the pipe, and is to peel off the rust which may inhibit the flow of the circulating water, DR agent can not be introduced into the system piping where internal corrosion has progressed. For ③, because the circulation amount of water due to the reduction of piping resistance increases only by applying DR agent, the carrying energy of the pump is increased. Therefore, it is essential to control or to adjust so as to be a proper flow rate by the inverter or something.

· DR agent conditions for input (for the existing business building)
① it is a closed circuit.
② water quality and piping internal corrosion is within the allowable range.
③ it is a inverter control pump (or manual inverter adjustment).
④ the flow rate is relatively fast in the system (more than 1.5m/sec).
⑤ resistance ratio at straight pipe section is a relatively large in the system.
⑥ chilled water system or similer piping system (hot water system is unsuitable).
⑦ no using rust inhibitor incompatible with the DR agent.
⑧ measurement environment (pressure, flow rate, the amount of power) are in place.
⑨ the pump has a mechanical seal.

5. Case example of DR agent introduction

We introduce the reality of DR effects and energy-saving effects based on the real case, although it is not possible to state the magnitude of DR effects unconditionally, where the air conditioning piping system has a variety of characteristics, such as the ratio of the resistance for straight pipe section and the rest (resistance of internal joints and equipment) depending on the design of the building equipment, difference of pipe flow velocity, flow rate change throughout the year, and properties such as temperature.

Building as a target of case studies, which is the 20th floor above ground, in the total floor area of about 50,000m^2 merchandise store building, is a DR agent application example to a heat source water piping system (for water heat source package air conditioning), where heat source water pump is a 15kW x 3units (parallel operation and constant control of discharge pressure).

In Figure 7, it is shown piping resistance curves, two of the upward curves showing the measured result of the circulation flow and the pipe pressure loss of the input before and after the DR agent of the building. At the rated flow rate at three pump operation (circulation flow rate 100%), the piping pressure loss after turning-on (DR solution) has been reduced by 13% compared to before (pure water). Reduction of the pipe pressure loss, that is, the DR effect.

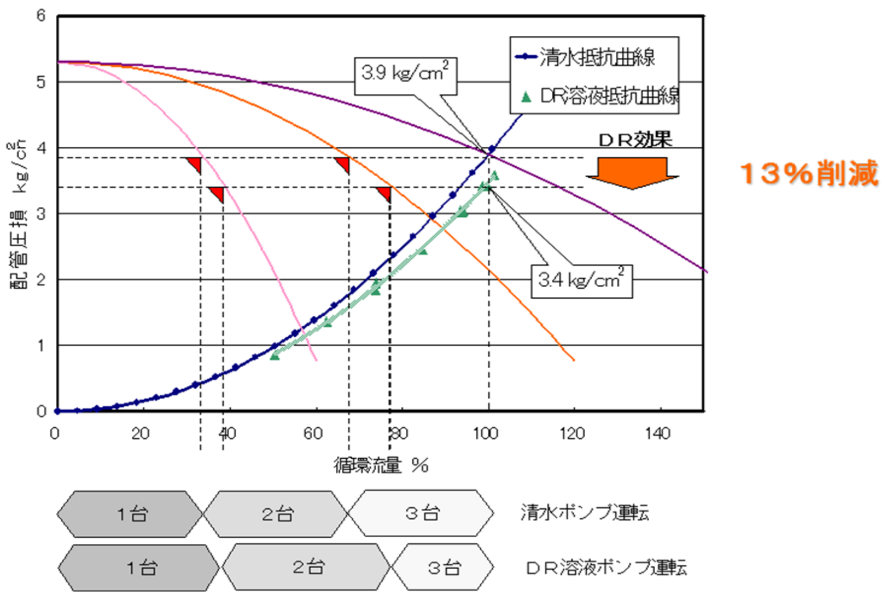


Figure 7 actual measurement result of the circulation water and the pipe pressure loss

Figure 8 is a plot obtained by actually measured the power consumption and the circulation flow rate, based on the measurement of the pressure and the flow rate of input before and after shown in Figure 7, in a state after the appropriate control settings change. Although, for the circulation flow rate less than $80m^3/h$, it was about 13% of the energy-saving effect with one pump operation before and after, it was about 37% of the energy saving effect together with operating unit reduction effect, for the circulation flow rate around $100m^3/h$ and since after applying DR solution operating pump units became one. The energy-saving effect through the year is determined by whether how much of the load flow rate change occurs in how much of the frequency, since circulation flow rate is constantly changing in the actual operation.

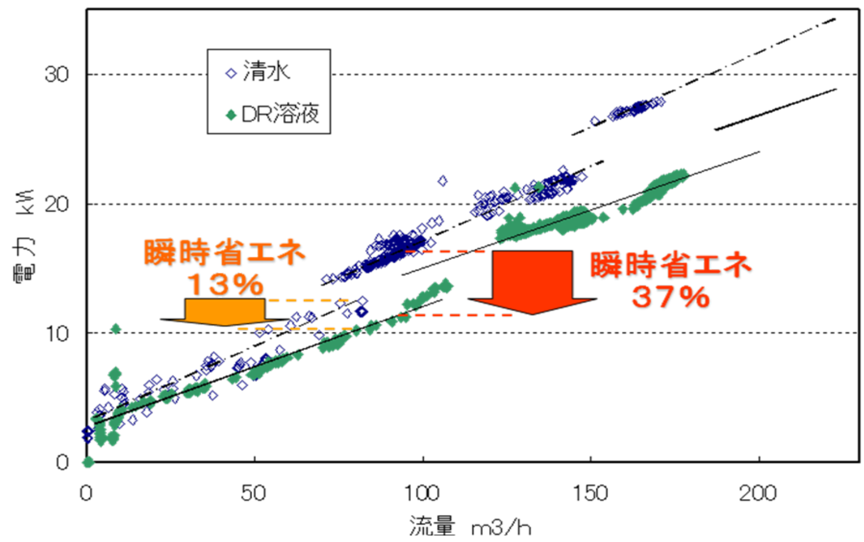


Figure 8 actual measurement result of the circulation water and the pump power consumption

In Figure 9, the occurrence of each load flow rate (in every 10%) when the maximum flow rate designed to be 100% are shown in the bar graph by a respective measurement of one year before and after the introduction, in the case of the same building that was introduced case above. Total operating time of year was a 5,475h, one pump operation time after application was increased to 3,534h, where an operating time of the before was a 2,776h, and 3 pumps operating time of the before was 557h was reduced to 37h against. In other words, it can be seen a number of operating unit reduction coming from the effect that the average number of operating units of the pump was decreased.

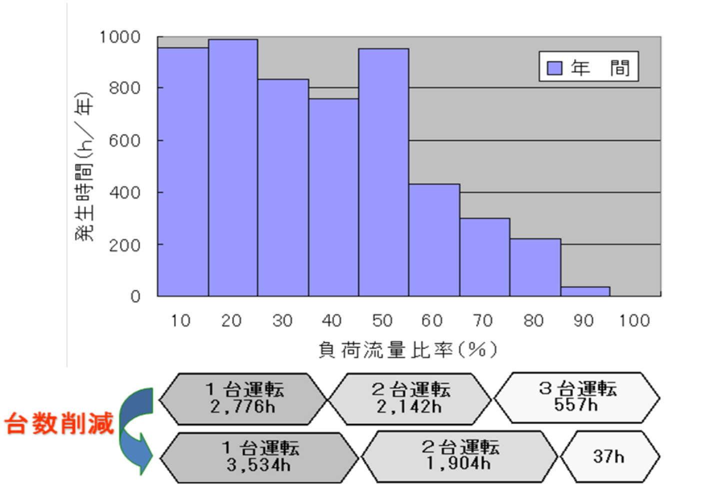


Figure 9　pump operating time with each load flow rate of year time occurrence

When we estimate the power consumption of the year for each load flow from Figure 8 and Figure 9, it is Figure 10. From this result, the annual power consumption 72.8MWh/year before application, it becomes 52.2MWh/year after the application, and energy-saving effect of the year was about 28%. In particular, it is read a large energy-saving effect in the load flow rate ratio of 40% to 50%.

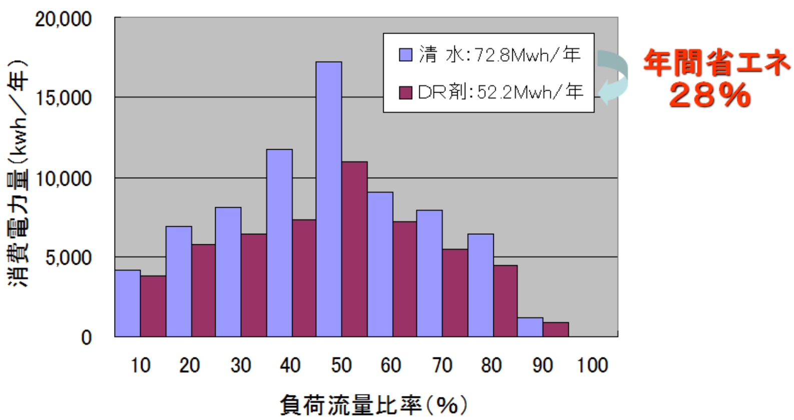


Figure 10 annual power consumption of each load flow rate

6. Summary

This paper is assumed the DR agent application to the air conditioning piping for the existing business building, the findings are summarized below.

(1) it is necessary to examine well the appropriateness of the target system before input.

(See "Conditions for DR agent application ① ~ ⑨")

(2) Energy saving effect can be easily obtained as the straight pipe section resistance ratio is large. (See Figure 5)

(3) energy savings can be obtained for the first time by carrying out appropriate pressure-flow rate adjustment.

(4) The proper pressure and flow rate adjustment is required overall engineering design based on actual measurement.

(5) hot water system has a possibility that the heat exchange performance degradation occurs. (See Figure 6)

(6) After application, the DR agent concentration management is important.

Nevertheless the auther’s understanding of the ILC is not sufficient, the challenges of adopting the DR agent in this project are listed three below;

(1) Acquisition of basic characteristics data in the case of DR agent charged into a large diameter pipe.

(2) Design of the resistance ratio of the straight pipe part and the optimum pipe size in consideration of the energy-saving effect.

(3) Verification and its counter-measure to radio-activation of DR agent.

Reference

[1] Iguchi, Kudo: Evaluation of piping resistance-reducing agent (the 1-3 Report), air conditioning and sanitary engineering Association, academic lecture Papers (2000-2003)

[2] Iguchi: practical evaluation of the pipe friction resistance reducing agent, piping technology October 2003 issue (Nihonkogyoshuppan)

High efficiency operation of Data Center
(Osamu Takehisa, NTT facilities)

1. Introduction

Data center that houses the computer and data communication equipment has become an important infrastructure that is essential not only for the company but for the entire society. However, power consumption of the data center is increasing year by year. Figure 1 shows the amount of heat generated per rack of ICT equipment by the investigation of ASHRAE. According to the 2012 the latest survey results, the amount of heat generated by the ICT equipment is further increased, it has become a 40 ~ 50kVA per rack with a maximum, and there is a prediction that extends to about 10-fold in 2000 to 2020. Power consumption of the data center will consume the power of 5-10 times more compared to the same scale of the office building.

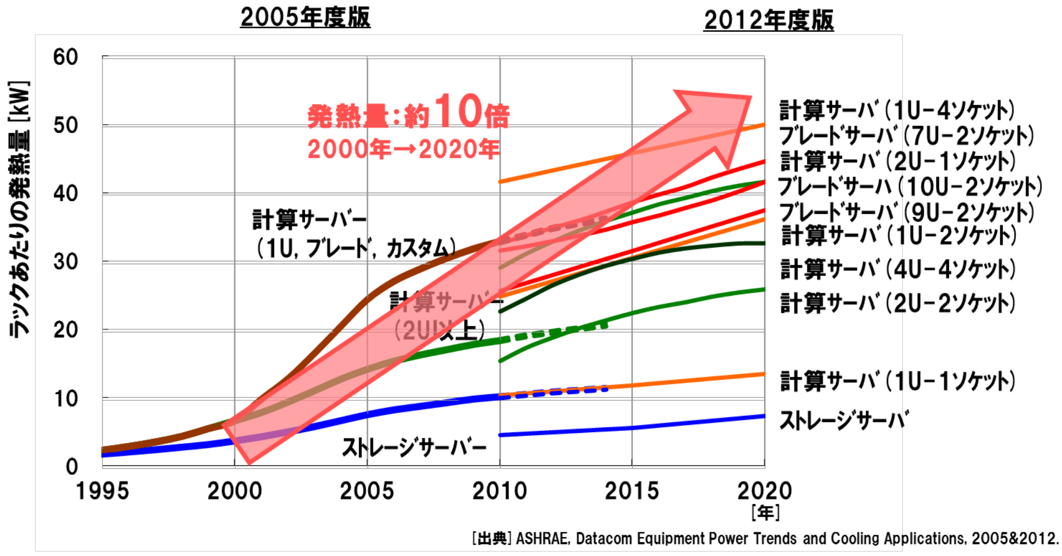


Figure 1 calorific value trend of ICT equipment

More recent price hike of electricity prices is multiplied by the final blow, power cost reduction has become the greatest challenge of data center business operations. (Figure 2)

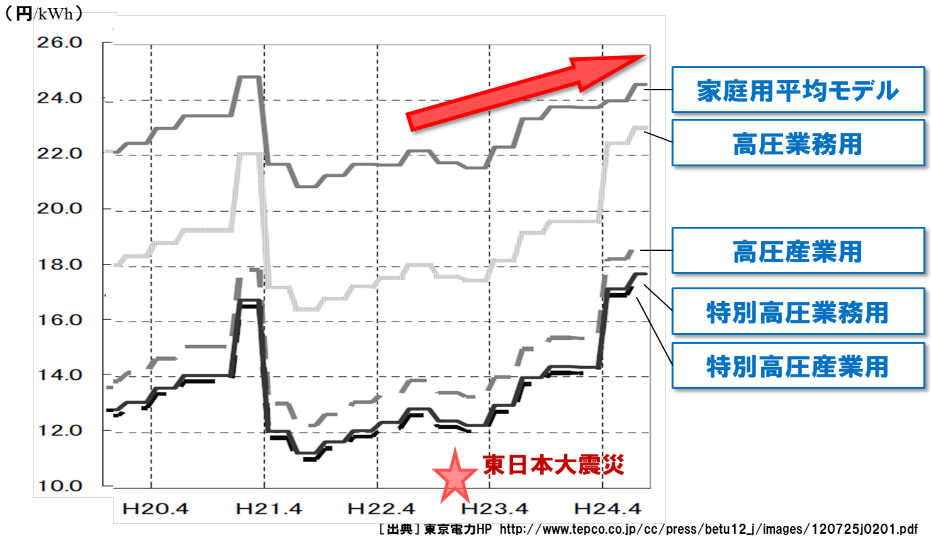


Figure 2 Changes in model electricity prices in TEPCO

The power consumption breakdown example of a data center by the Uptime Institute and the McKinsey survey is shown in Figure 3 (The Uptime Institute, The Invisible Crisis in the Data Center 2007). ICT equipment is 56%, the air-conditioning power is 33%, the power supply loss, lighting and others become 11%. To reduce power consumption in this situation, the following three points are important. First, to improve the air conditioning efficiency. Second, to improve the power conversion efficiency. The third is to do optimization throughout total system including ICT equipment, air conditioning, and the power supply system.

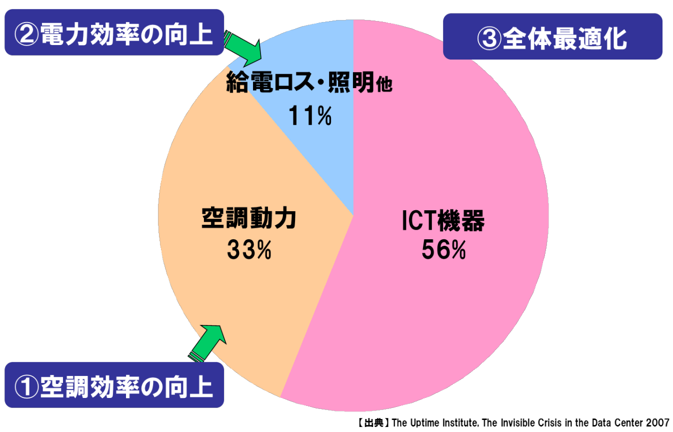


Figure 3 power consumption breakdown example of a data center

In Figure 4, it shows the breakdown of the data center facilities investment. This is the average for conducted hearings on the data center operators by ourselves. It finds that about 75 percent of the capital investment is being used to maintain the existing data center (surveyed 38 companies in December 2012 implementation). The old data centers faced many challenges, because they are unable to stop the service to the equipment specification renewal, and can not be extended by the power capacity shortage despite a space in the server room, etc.

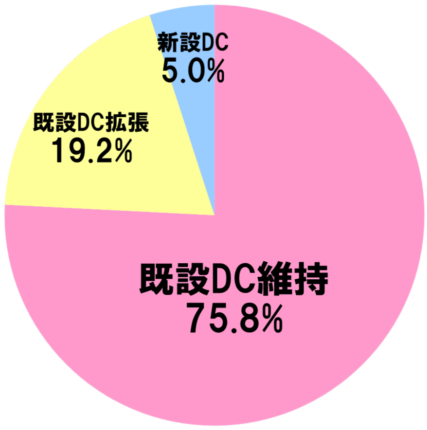


Figure 4 the capital investment breakdown of the data center

NTT Facilities will maximize the value of the data center from the multilateral point of view, by a combination of technology that has supported the communication of Japan and building and energy technology, and by solving the issues for reduction of power costs and personnel expenses, equipment and buildings of aging measures, the issues such as response to the scalability. In addition, we support cost reduction for electricity charges and equipment of the data center, and provide a variety of solutions from the power-saving products such as LED lighting, system development to realize the energy saving, and to consulting, since the data center is to continue to operate a long time, especially energy-saving and cost reduction becomes important. NTT Facilities has carried out about 30% of the design and construction of the entire domestic data center, in 2000 or later, there are building experience about 40 buildings of large-scale data center of more than 5,000 square meters. Also, in addition to the 24 hours operation a day and 365 days a year by the advanced systems that make full use of ICT, we have maintenance staff of experienced professional, which is located across the country about 260 locations of maintenance bases, to deal with rapidly and eligibility at the time of trouble. Overseas, we have the local subsidiary in the United States West Coast and in Beijing, the branch in Singapore, the partner construction company of the data center in Thailand. There are consulting experience at about 120 sites in the world 30 countries, the design, construction and O&M records in Singapore.

This time, focusing on the energy and cost savings from a variety of solutions, we introduce the solutions for improving the power efficiency and improvement of the air-conditioning efficiency. For the solution for air conditioning efficiency, airflow control system for ICT equipment "aisle capping", smart air-conditioning control system for the data center "Unified Cooling", introduction of efficiency improvement of air-conditioning system by outside air use "indirect outdoor air cooling type of FMACS hybrid", are introduced. For the solutions of power efficiency improvement, high-voltage DC-current system for ICT equipment "HVDC (high voltage DC power supply)" is introduced.

2. Solutions for improvement of the air-conditioning efficiency

There is different cause that is not able to efficient air conditioning in the actual data center. As a typical example, the following three are mentioned. The first one, that cold air to cool air for cooling is inhibited, and does not reach to the server. The recent years of data center take the method which is often supplying the cold air from the double floor in the double floor system, however, in the double floor, it has been laying the cable to the ICT equipment, and is often stacked high. Also, the cables being made replacement of ICT devices often can not be removed and buried in another cables. As a result, when the replacement of ICT equipment is followed by cable is piled high, it has often occurred that cold air to the ICT equipment is unable to supply. (Figure 5)

Figure 5 inhibition of airflow (cold)

The second one, adverse heat effects to ICT equipment will occur, by the hot spot and heat accumulation where required cold air can not be placed and the exhaust heat of ICT devices are wrapped around (when it severe, server is down). (Figure 6)

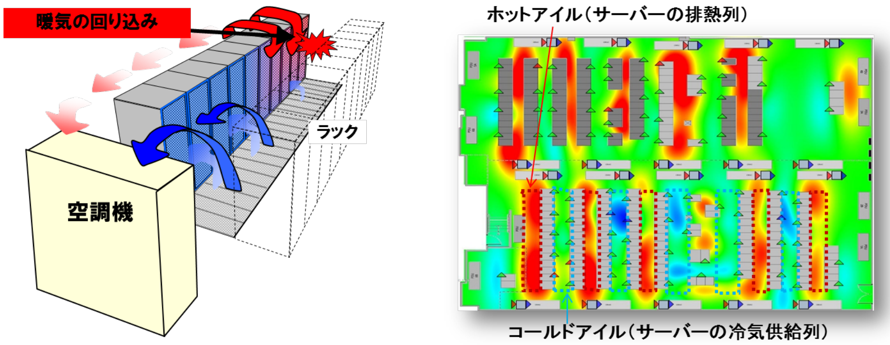


Figure 6 inhibition of airflow (cold)

The third one, the server often become hot at the top, being made of good cooling in the bottom, since it has about 2m height. (Figure 7)

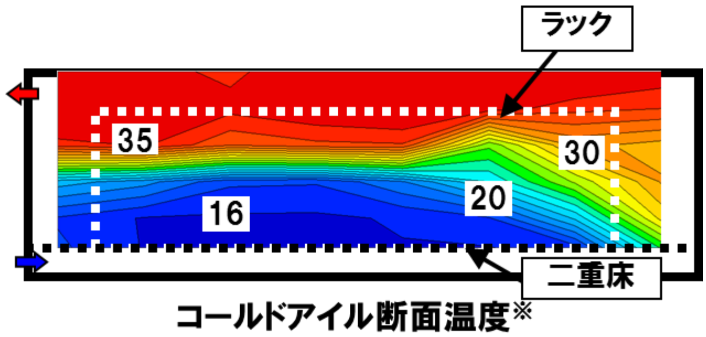


Figure 7 the upper and lower temperature difference at the suction surface

To eliminate hot spots, as a countermeasure 1, is a method of increasing the air volume of the air conditioner cooling, however, energy saving as a whole can not be achieved for sending cooling air flow more than necessary in other locations. As a countermeasure 2, there is a method of lowering the set temperature of the air conditioner, however, energy saving can not be achieved to lower the temperature in the same or also required elsewhere. (Figure 8)

Therefore, here we will introduce the solutions that lead to cost reduction and energy saving.

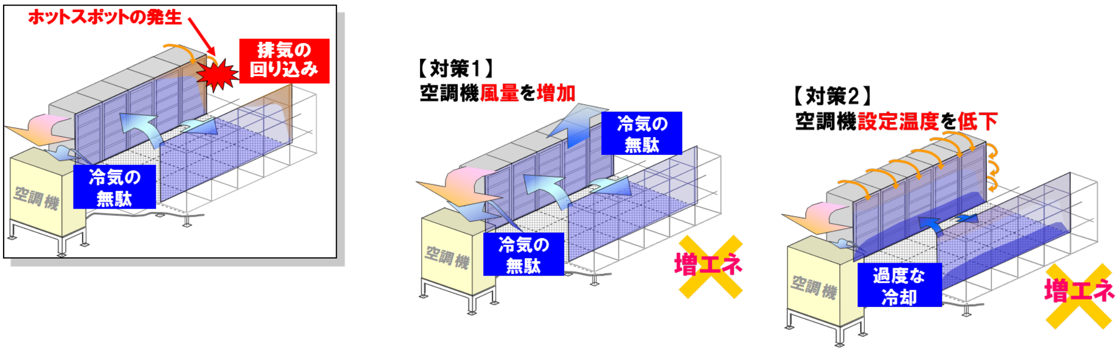


Figure 8 countermeasures for hot spot

2-1. Airflow control system for ICT apparatus "aisle capping"

The aisle capping, is an airflow control technology to realize the efficient air conditioned environment and is a solution that can be both energy-saving and high reliability in the data center, by partioning a rack passage by walls and roof, and by separating physically the exhaust the (high-temperature) of the IT equipment from the air supply (low-temperature) to the IT equipment. As energy saving effect as a feature, by improving the supply air volume reduction and operational efficiency from the air conditioner, the air conditioning power can be reduced up to 20 percent. In addition, by eliminating the hot spot of the cold aisle, a good air conditioning environment can be achieved. And it has a high seismic performance, mitigation of the supply temperature rise in the event of a power failure. The top panel is removable and can be easily maintained. (Figure 9) (Figure 10)

Figure 9 inhibition of airflow (cold)

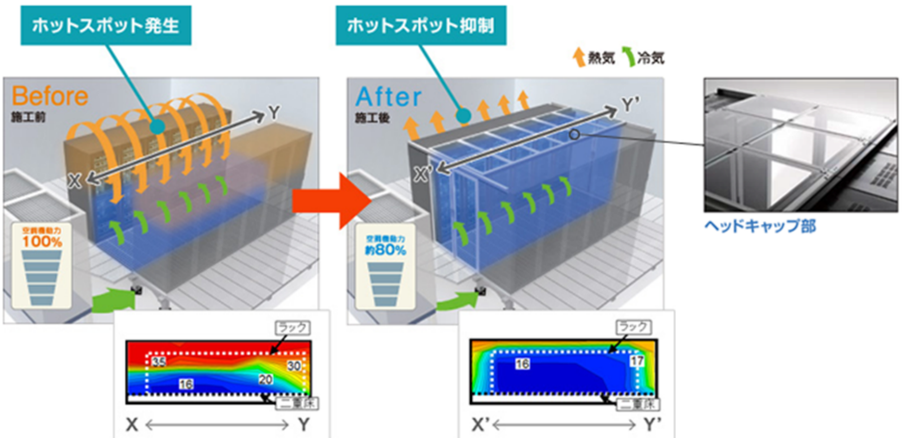


Figure 10 Inhibition of airflow (cold)

Also, by calculating the pressure distribution under the floor tailored to the air conditioner and underfloor availability, and by calculating the blow-off distribution commensurate with the airflow in need or with heating value of the equipment, the equipment necessary aperture ratio of the double floor panel and its deployment plan are obtained for properly cooling, and it will be able to suppress the air volume of the air conditioner. (Figure 11)

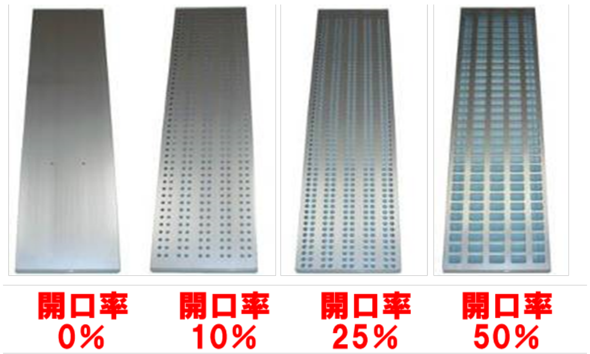


Figure 11 porous double floor panels with different aperture ratio (aperture ratio: 0% to 50%)

Then, by mounting the blank panel that blocks the hot air flowing through the gap in the rack to the cold aisle to the place of not mounted server equipment in the rack, it is possible to enhance the control efficiency of the aisle capping. (Figure 12)

Figure 12 inhibition of the air flow (cold air)

2-2. Data center for smart air-conditioning control system "Unified Cooling"

Since in large data centers scale power consumption increases, and for the air-cooled package air conditioning system there is a possibility that can not be installed outdoor unit to the outdoor space, there is a growing tendency for cold water use air conditioning system is adopted. In chilled water use air conditioning system, there is divided three functions, the chiller cooled the water (heat source system), a pump for circulating the water (water-based), and air conditioner which performs cooling installed in a server room. These chiller, pump, and air conditioner, it is often that consists of different manufacturers, it can not be cooperation operation between devices. Therefore, cold water temperature and water supply pressure (water amount) of cold water made by the chiller is operated at a constant set value assuming the maximum cooling load, if the load is not a maximum value, such as a low operation rate of the ICT device, it tend to consume power more than required and to decrease the efficiency. Power consumption of the chiller pump accounted for 60% of the power consumption of the entire water-cooled air conditioning system, energy conservation has become a major issue. Therefore, Unified Cooling® is ever performs chiller and pump integrated control that was operated at a constant set value, to reduce power by adjusting the flexible settings. The dedicated developed controller, regardless of the building new construction or old, unifies the information of chillers, pumps, and integrating information of the air conditioner into BACnet which is a standard communication protocol specifications of the BAS, and controls the settings of the chiller pump by monitoring the operating temperature and humidity and air conditioners in the data center. (Figure 13)

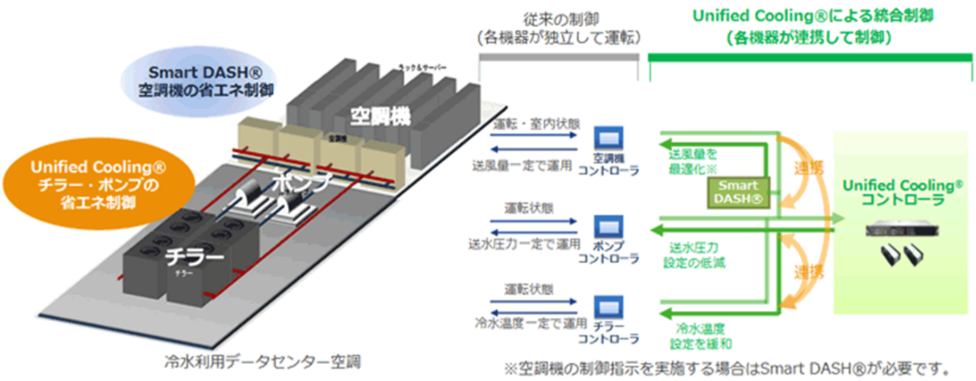


Figure 13 Overview of the Unified Cooling®

In addition, Smart DASH collect the suction temperature data of ICT equipment, by the wireless temperature sensor installed in the server rack and the server room, individually automatically controls each of the air conditioners on the basis of the analysis result of collected data. Until now adjustment of the temperature environment has been done manually by a technician-operator, etc., Smart DASH has a learning function, and precision of air-conditioning control is improved through the utilization of a continuous operation, by dynamically respond to the amount of heat change generated by the server, achieve a higher energy efficiency optimum air. It is noted that the air-conditioning control, wireless communication and BACNet, the communication protocol, such as MODBUS are used. (Figure 14) (Figure 15)

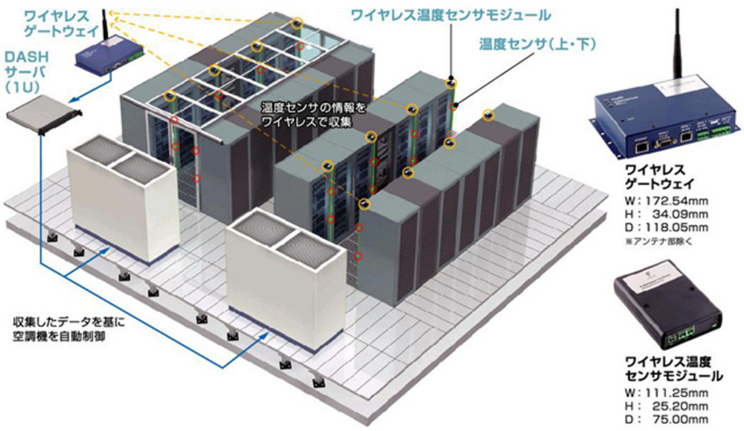


Figure 14 System configuration in Smart DASH

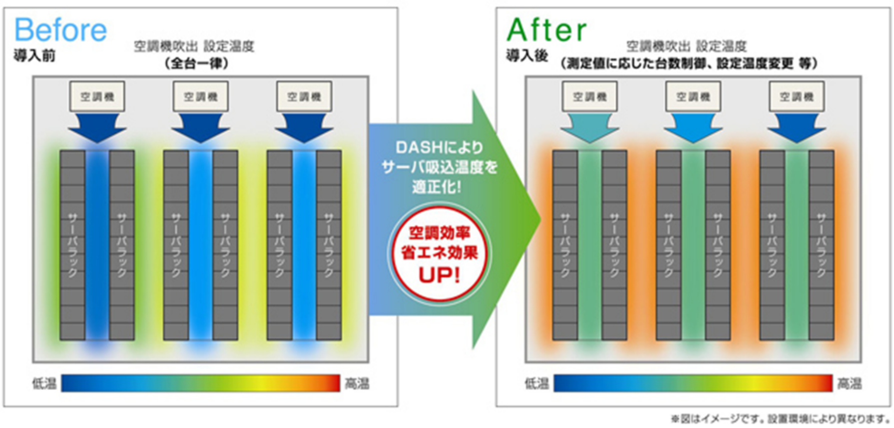


Figure 15 Benefits of Smart DASH

By these system, highly reliable and highly efficient integrated air conditioning control can be achieved, and up to 30% power consumption of the chiller and pump can be reduced. In addition, by combining the data center air conditioning automatic control system SmartDASH® of our products, it is possible to make all energy saving for air conditioners, chillers, pump, 2.5 times saving as compared in the case of use SmartDASH® only, it will reduce power consumption up to 30 percent of the entire system of air conditioning. (Figure 16)

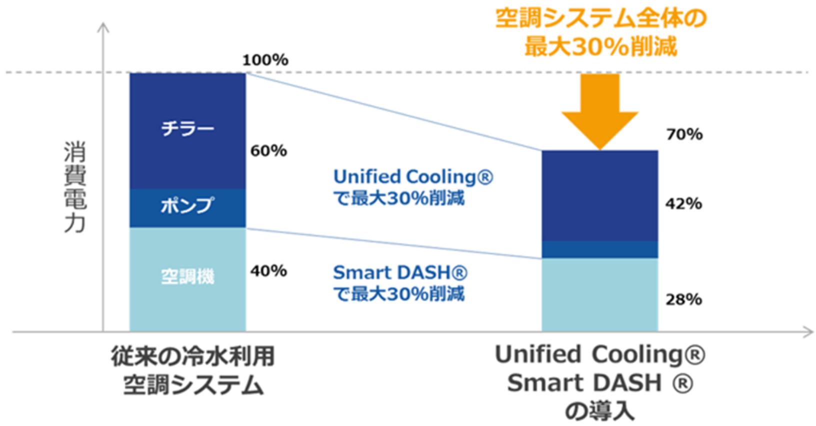


Figure 16 effect of reducing power consumption of the air conditioning system

2-3. High efficiency air conditioning system "indirect outdoor air cooling type FMACS hybrid" through the use of outside air

Generally, direct outdoor air cooling method using low temperature ambient air (Figure 17-1) has a case that it is necessary of humidity control to avoid corrosion of the electrical circuit board due to impurities, such as outside air dust and sea salt particles, and in accordance with air introduction amount. With clearing these challenges, we have developed FMACS hybrid (Figure 18) as an indirect outdoor air cooling type air conditioner suitable for data centers where high energy efficiency is required (Figure 17-2). This air conditioner comprises a compressor and a refrigerant pump, a less indirect outdoor air cooling to reduce the influence of external air quality, and high efficiency while ensuring high reliability and availability are realized. The compressor is stopped in winter and in the interim period when the outside air temperature is low, by performing the outside air cooling operation that circulates the coolant in the coolant pump, operation efficiency is greatly improved, since the power consumption of the coolant pump is much smaller than compressor used in a conventional air conditioner. Using the present air conditioner, the annual power consumption and annual CO_2 emissions related to the data center air conditioning are up to 54% reduction (estimated result by the standard meteorological data of Sapporo) as compared to the general computer room air conditioners.

Figure 17-1 direct outdoor air cooling system, Figure 17-2 indirect outdoor air cooling system

Figure 18 FMACS hybrid appearance

As a reference, for condition of the outside air environment of the location, possible year time of direct outdoor air cooling at 24℃ operation data center estimated from meteorological data of each city, is 5,000hours in Sapporo, 3,500hours in Tokyo. However, because it is necessary to adjust the humidity, it needs to be careful that it is not all for energy-saving time. (Figure 19)

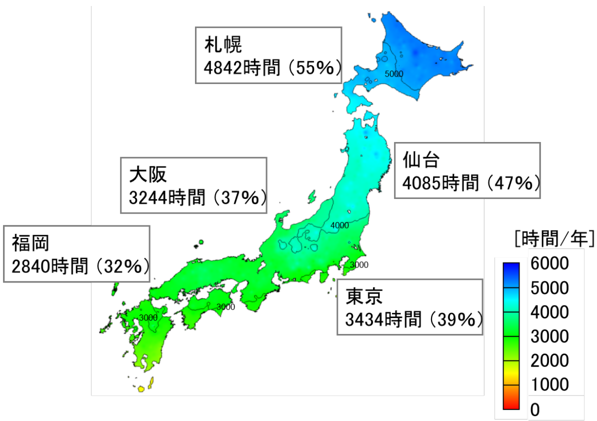


Figure 19 estimated operation time of outdoor air cooling

3. Solutions for improvement of power efficiency

Power supply system, which has been utilized in the central telephone office as a reliable power supply, are deployed in the data center, in recent years, in consumer electronics, also to distributed power supply, etc. Although previously mentioned, in which the power consumption of the data center is expected to increase more and more in the future, in the NTT Group, as part of the "DC power supply promotion of initiatives policy", as a friendly power supply system to the global environment we are promoting the further research of the DC power supply system. So, we will introduce the solutions related to power efficiency improvement.

3-1. ICT equipment high-voltage DC system "HVDC (high voltage DC power supply)."

General ICT devices converts AC power into DC, and operates by further converts the voltage. The ICT equipment in the data center is connected always via a UPS (uninterruptible power supply). Also, since in the UPS the conversion of the AC/DC, and the DC/AC performed, four times in total including conversion in the ICT equipment takes place in the data center. In contrast communication system used in NTT, by feeding the first from the DC 48V in order to reduce the power conversion to twice, a mechanism to reduce the cause of energy loss or damage has been employed for a long time. The company, applying this mechanism, in order to cope with recent ICT devices large power consumption, has provided the HVDC power supply system that enhances the voltage of the supply power to 380V since 2011. (Figure 20)

Figure 20 large-capacity HVDC rectifier system

Compared with conventional UPS systems, by introducing the HVDC power supply system, up to 20% energy saving and 40% space saving is achieved. Cost is also served at almost the same. (Figure 21)

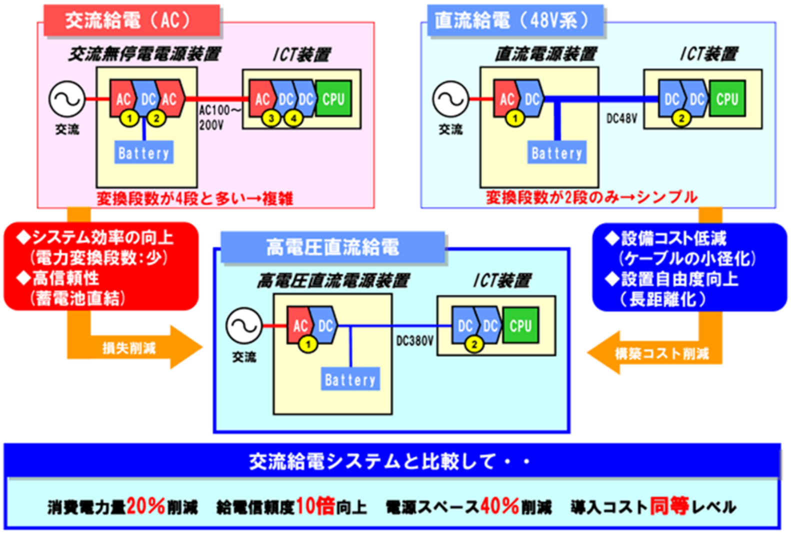


Figure 21 benefits of the high-voltage DC power supply

Mounting in a rack by the 2013, migration apparatus which can convert the voltage to fit existing ICT equipment (AC100V/200V, DC48V) is also on sale, and is to improve the flexibility of introduction for the spread of HVDC. On the other hand, we have been also promoted movement towards international standards, ICT equipment manufacturers to sell the HVDC-enabled products are gradually increasing. In addition, such as there is also a movement to standardize the connector or plug of the power, it is expected the spread in the future. (Figure 22) (Figure 23)

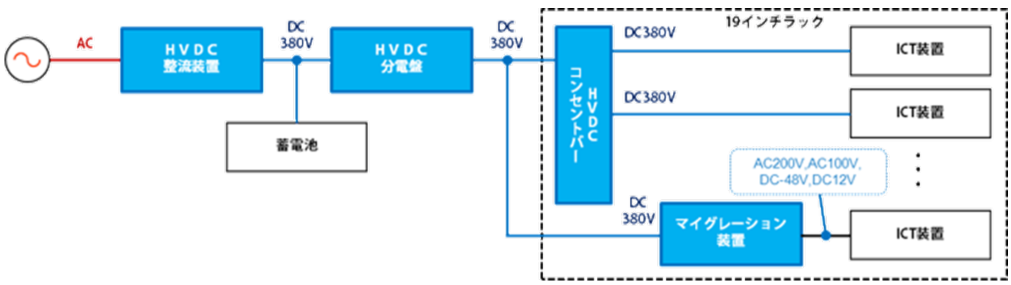


Figure 22 Overview of HVDC power supply system

Figure 23 migration devices, and HVDC outlet bar and power plug

As an example of an introduction effect of HVDC, in the system of Figure 24, comparing HVDC power supply system efficiency with the AC power supply system, it is improved by 11%, and there is a reduction of 108000kWh per year of power consumption. As a result, about 1.3-million-yen reduction in electricity rates over the years, and there is a reduction of CO_2 emissions by about 36.5t. This is equivalent to the CO_2 absorption amount of forest 10.2ha (2.2 times Tokyo Dome area). (Since this introduction example is one of the cases, at the time of the actual introduction system configuration quantity, etc. are different, then result might be different.)

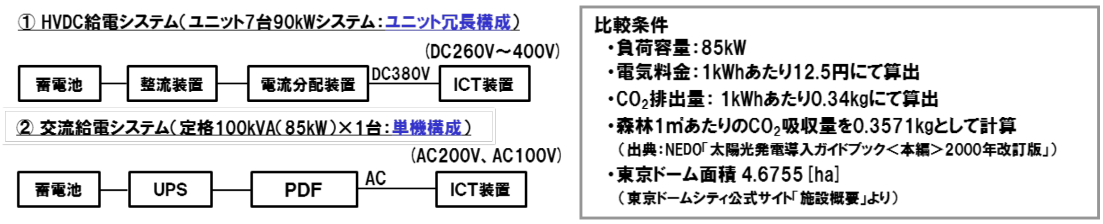


Figure 24 System Comparison (Example)

Table 1 power consumption and comparison of electricity prices

電源システム	HVDC 給電システム	交流給電システム (UPS)	差
年間消費電力量（万ｋWh／年）	85.2	96.0	10.8 万 kWh
年間電気料金（百万円／年）	10.7	12.0	130 万円
年間 CO_2 排出量（ｔ／年）	289.7	326.2	36.5 ｔ

4. For the future

In recent years, we often hear DCIM as data center-related keywords (Data Center

Infrastructure Management). Data center operators, by DCIM introduction, has the advantage of energy conservation and cost reduction. The DCIM is integrated management method for ICT equipment, power supply equipment, air-conditioning system, the resources that make up the data center such as rack space etc., and for facility management techniques to support the optimal operation of the data center. In our company regarded the followings as "DCIM", that is, from the design, construction and procurement, to operation, maintenance, and analysis, and the "management cycle" itself, including the planning and consulting. From "Connecting", "Accumulate", "Showing (the show)" various data to the "Use (to find customer value)", and further to realization of the "Prediction", "Action", we have strength to realization of DCIM where no other companies having, then we will further study and as able to offer.

Smart Community
(Takahumi Shimokochi, Takenaka)

1) ILC and smart community

Although there is no clear definition against smart community, in the "Basic Energy Plan" [1] of Japan, it is marked as "a certain scale of the community, while using a distributed energy such as renewable energy and cogeneration, and building through energy management systems that utilize technology such as IT and storage batteries, comprehensively manage the energy demand in distributed energy systems, as well as optimize the utilization of energy, a new social system incorporating also other life support services. " In addition, Figure 1 is shown as an image [2].

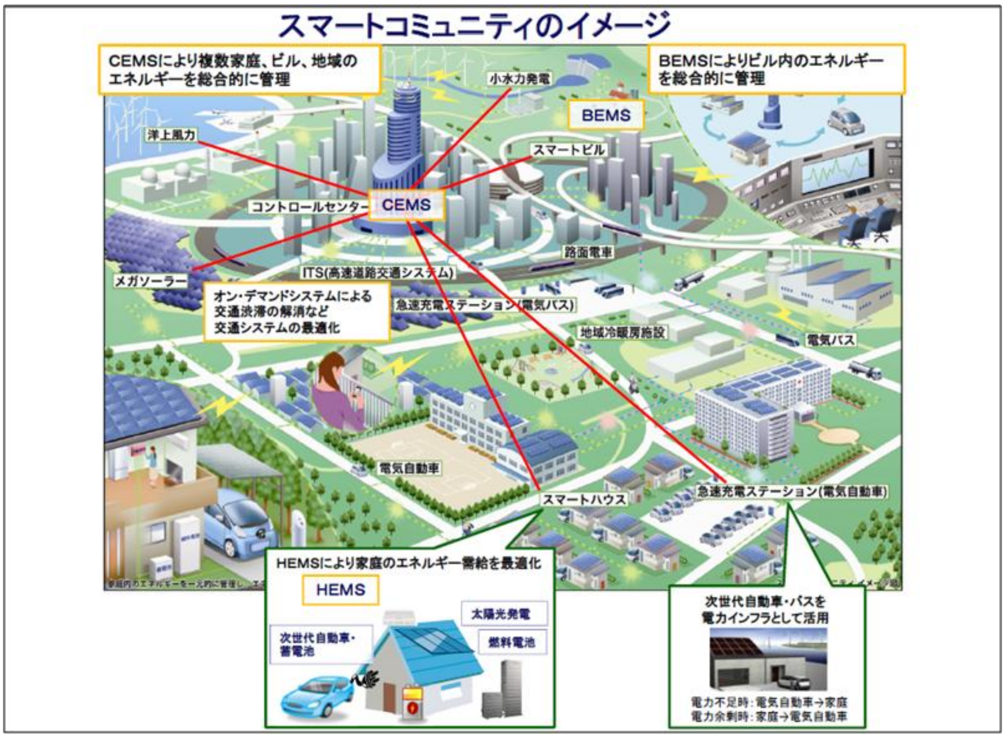


Figure 1 image of smart community [2]

In the ILC, about total floor area in the central campus and the experimental site 254,000m^2 of ground facilities have assumed, international science and technology research sphere, such as shown in Figure 2, is envisaged [3]. Campus building with smart community, town planning is an important point of view also in the ILC. We will introduce a demonstration cases and building cases which Takenaka is doing in the following.

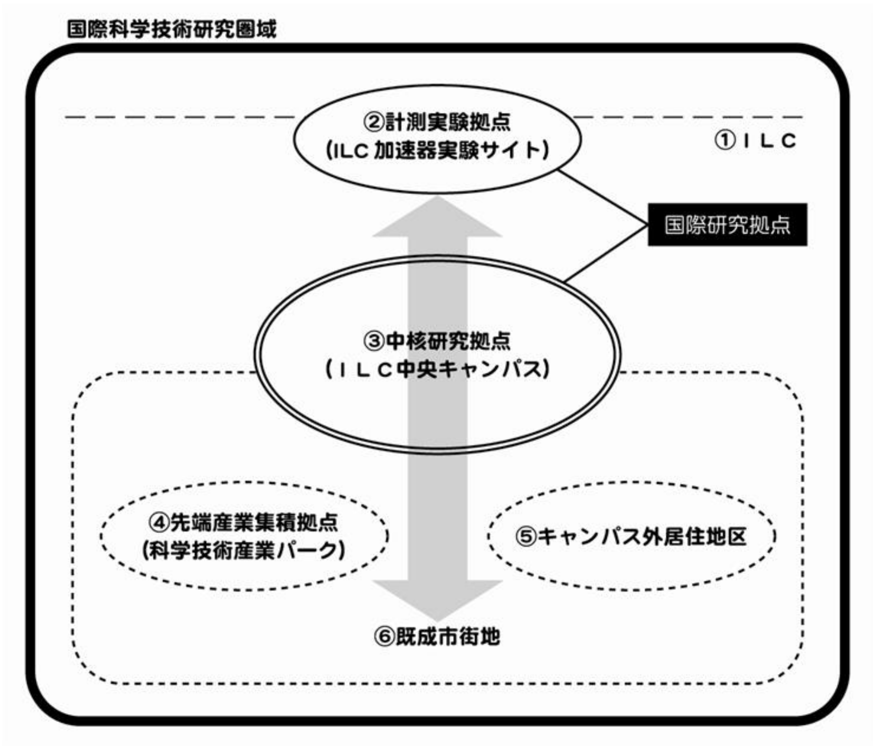


Figure 2 Deployment image of ILC international science and technology base to construct a research area and District [3]

2) Energy management that utilize cloud

"Building communication system", information and control platform of building equipment that was developed by Takenaka, is a system to capture the changes in the building and out of the environment and information, to create the cooperation of the building and "people" by lobbying to users, and to activate the activity of the "people" and the "town".

"Building communication system", creates added-value such as the automation of control to realize the energy saving and demand response and productivity improvement by analysis and show of various sensor information, and aims the creation of convenient and attractive space for the user.

In addition, not only the building itself, it is possible to centralize the information of city block area, and to contribute to the rationalization of the various management, such as optimization of energy in the area, the formation and activation of the area within the community. Through this system, by cooperating people such as landowners, tenants, visiter, the system operator, a sustainable area management can be build. (Figure 3)

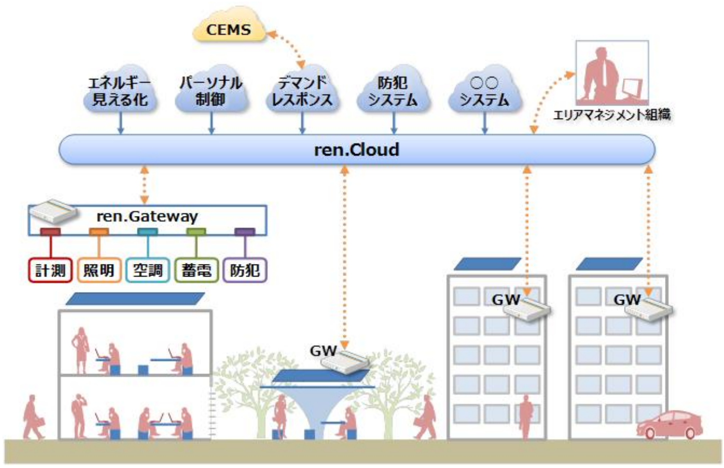


Figure 3 energy management that utilize cloud

3) Energy management by regional cooperation example: An Empirical Case Study in Osaka Business Park

(1) work style that utilize a shared space

Building distributed workspace outside or the indoor of the building with less energy consumption, the work styles free to choose space depending on the preference of worker and comfort were realized. Also, by sending environment information and congestion level in real time to match the indoor or outdoor preference of the worker, the use of a variety of space to the worker was encouraged.

Thus, amount of moving to a distributed workspace is reduced the energy of the office room, but also workers for performing the activities even outdoors without staying office, the bustling of the city was created. (Figure 4)

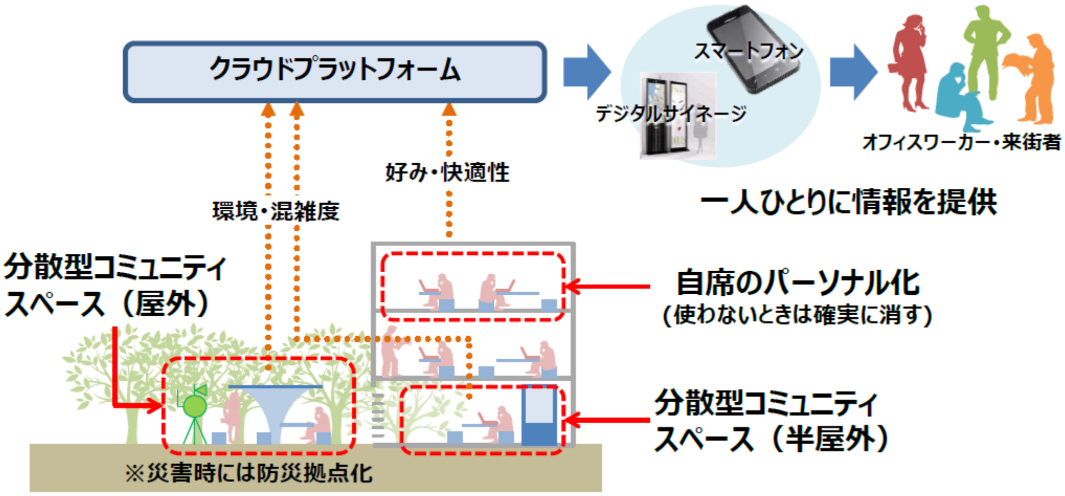


Figure 4 work style that utilizes a shared space

(2) Taking advantage of the EV in the region to demand response and BCP

For the realization of a low-carbon society, with a view to conversion to company's car to an electric vehicles (EV), and plug-in hybrid (PHV), we promote technology demonstration project of power supply system utilizing a battery of EV·PHV.

We have developed a new energy management system that leads to energy load control by EV·PHV and charging/discharging at the same time to EV·PHV, which are Japan's first five EV·PHV. (Figure 5)

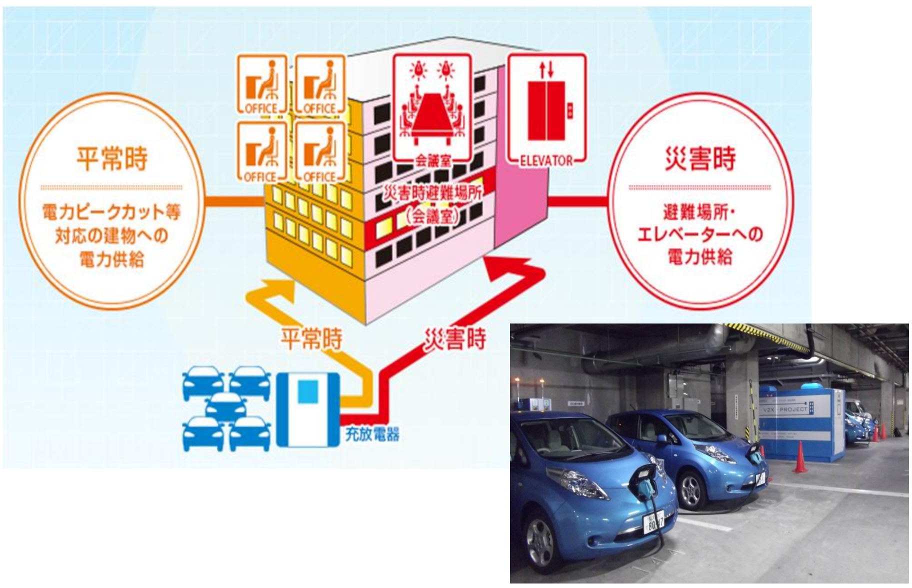


Figure 5, taking advantage of the EV in the region to demand response and BCP

4) three-dimensional urban Abeno-harukas [4]

"Abenobashi Terminal Building(Abeno-harukas)" is a building height of 300m that contains the stations and department stores, office, hotel, museum, observatory, such as a variety of applications, as shown in Figure 6. It aims to "energy-saving three-dimensional city", and various technologies have been applied.

Building Overview

Address Abeno-ku, Osaka Abenosuji 1-1-43

Applications Station, department stores, office, hotel, museum, observatory

Site area of approximately 28,700m^2

Total floor area of 353,000m^2

Height above ground 300m

Floor B5F · 60F · P1F

Structure steel reinforced concrete, steel frame

Owner Kintetsu Corporation

Design and supervision Takenaka Corporation

Construction Takenaka JV

外観＜昼景＞

Figure 6 building outline and appearance

(1) using the natural energy ventilation and lighting system: Eco-void

Void provided in the building each place, it becomes a light and for air passage, are in gently connecting the external and internal. (Figure 7)

VOID1 hotels Void

«Hotel daytime and night»

In the four seasons, it leads a comfortable outside of the air in the spring and autumn to Eco-void. Air that has passed through the void flows gently to the hotel hallway. Air in the void is deprived corridor heat, and is exhausted from the top.

VOID2 office Void

«Office daytime and night »

Comfortable outside of the air in the first half, gently flowing to the office, such as refresh corner through the void.

«Office night»

To introduce the night of cool air to the office, to cool the offices by night purge, to reduce the air conditioning energy for the next day.

VOID3 department store Void

«Department store daytime and night»

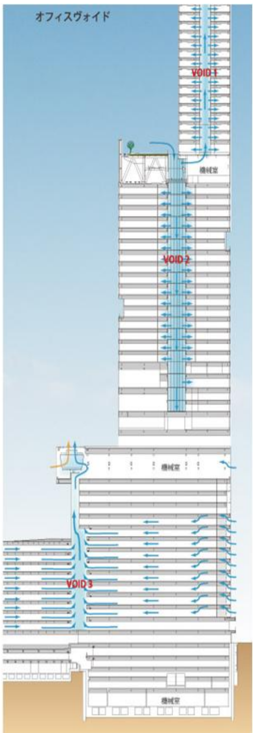
There are a lot of air, which is air conditioning in the department store where people gather many. Through the void without discarded as it is reused to cool the machine room.

«Department store night»

Department store cooling is required even in winter, in a night of cool air, cool the precursor enough by night purge, to reduce air conditioning energy for the next day.

(2) Comfort and energy saving and space by two glass: double skin

By the glass curtain wall for the outer wall of the building, a great view has spread. A double skin structure by the float laminated glass and Low-e double-glazed glass, we have adopted the air flow window system that does not leak the outside of the heat into the room. A high heat insulating shade is installed between the glass and the glass, thereby reducing the air conditioning load. (Figure 8)



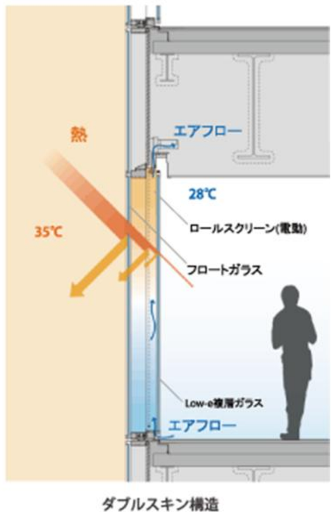


Figure 7 Eco-void

Figure 8 double-skin structure

(3) Power generation utilizing the garbage generated in the building: biogas power generation

From garbage such as department stores and hotels, a bio-gas as a fuel is produced. As well as reduce the amount of waste discharged outside of the building to 0, the generated biogas is used, such as in power generation and hot water as a fuel.

It was introduced a state-of-the-art energy-saving technology that make the biogas power generation by using the garbage generated in the hotel and department store restaurant, for the first time in high-rise buildings in Japan. (Figure 9)

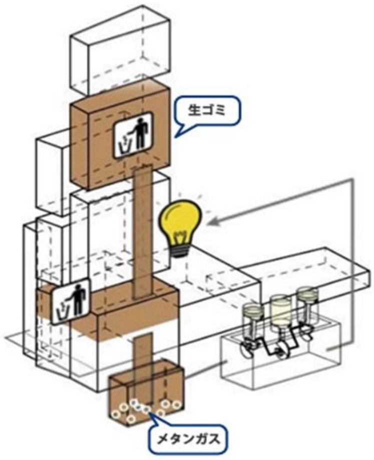


Figure 9 biogas power generation

(4) Energy saving in the comfortable office lighting: toning-dimming LED lighting

In Abeno-harukas Building, it is an important theme to be a comfortable for people while achieving energy saving. Depending on the season and time of day, it captures the natural light well, to illuminate gently with LED lighting (toning-dimming). In energy saving, in fact we are aiming to expand the pleasant "new comfortable area". (Figure 10)

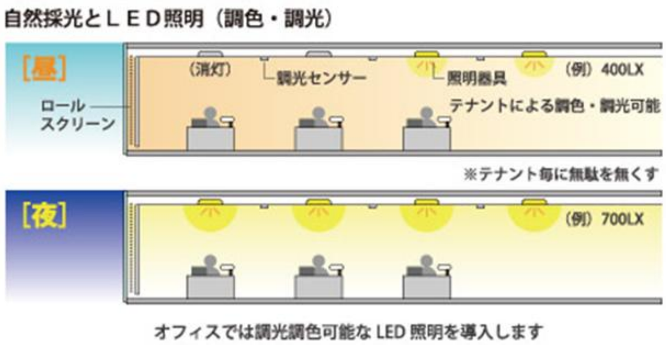


Figure 10 toning-dimming LED lighting

(5) High-efficiency energy system

By a combination of equipments with small environment load of high efficiency, we are building an energy system that can be friendly to the redundancy and safety relief and excellent maintainability in a space-saving. When there is a room and transportation benefits, we performs heat interchange to aged existing heat source. Others, a high-efficiency heat pumps which collect cooling exhaust heat and biogas generation equipment for heat recovery were installed. To reduce the valuable energy such as electricity and gas, we utilize natural energy, such as ambient air. (Figure 11)

(6) Energy saving promotion system by making the energy visible: A-EMS

In the case of motor vehicles, we check the speedometer, then operate the brake. Similarly, in the case of the building, there is a need for energy meter. The A-EMS, is a system making energy visible, and making everyone involved for performing management of participants. By interact with it, we are aiming to continue a reducing of CO_2 activities and reducing waste of energy. (Figure 12)

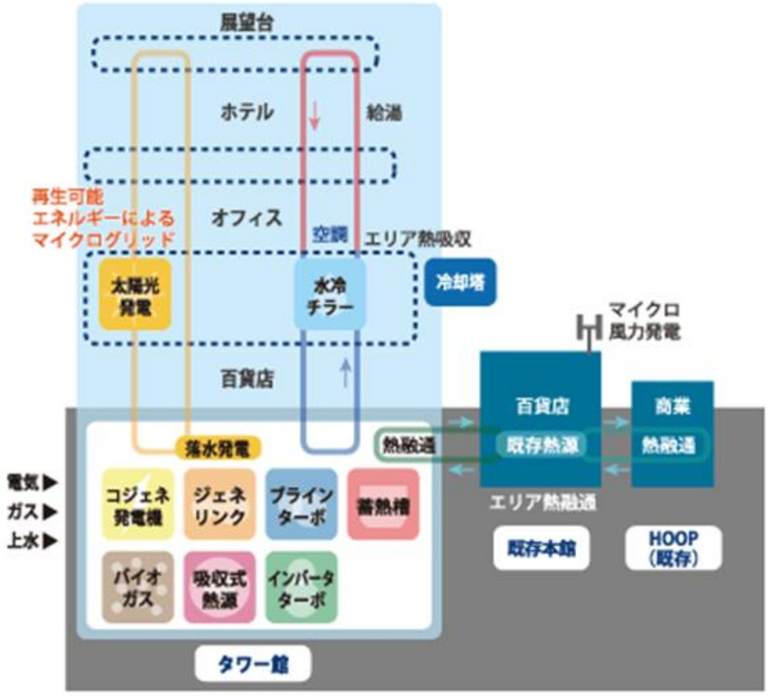


Figure 11 highly efficient energy system

Figure 12 A-EMS

(7) Leveling of energy load using the store-hours difference: peak cut

The hotel at night, the office on weekdays at day, department stores on holiday use a lot of energy. The leveling of energy load using business time difference, contributing to energy conservation. (Figure 13)

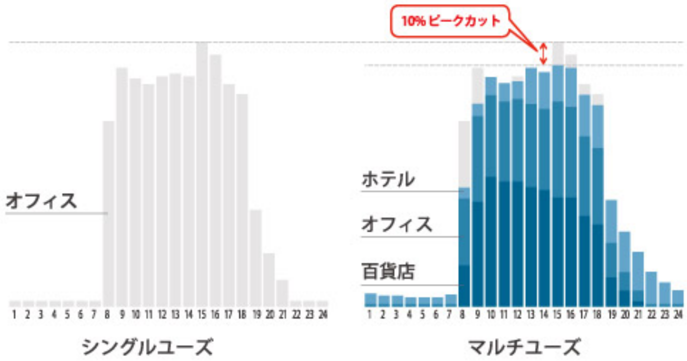


Figure 13 Leveling of energy load

(8) The energy conservation by heat exchange between applications: area heat recovery

Because a lot of people gather in the department store, cooling is required throughout the year. The exhaust heat for the cooling has also used for hot water supply of hotel rooms. The efficiency of energy by the exchange of heat between the area, contributing to energy conservation. (Figure 14)

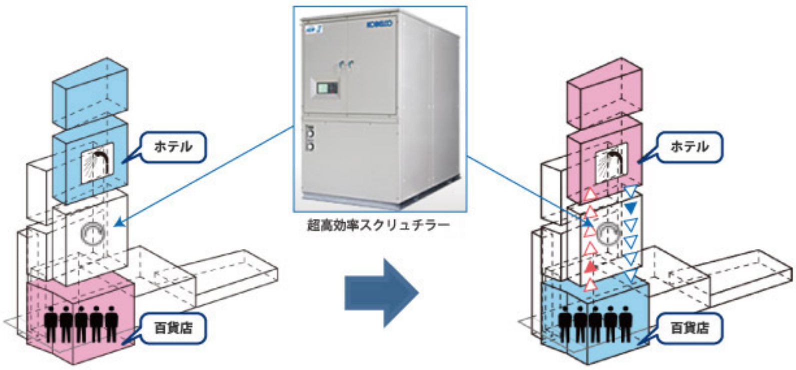


Figure 14　Area heat recovery

5) Summary

For smart communities, various initiatives are mentioned, demonstrated cases have also been reported. Here, we introduced the "Abenobashi Terminal Building

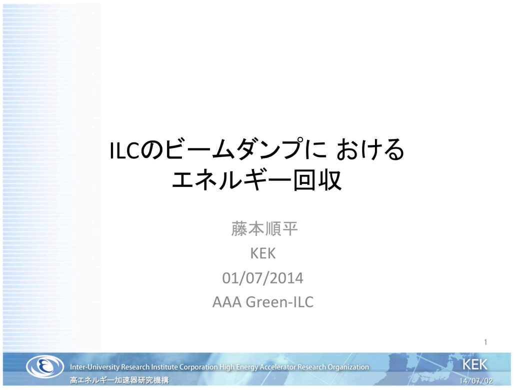
(Abeno-harukas)", as a demonstration cases and building cases in Osaka Business Park. In order to be inclusive green ILC of not only laboratory equipment and facilities, but around the facility, even in the ILC of the campus building and town planning, these systems and the technology might be made to the reference.

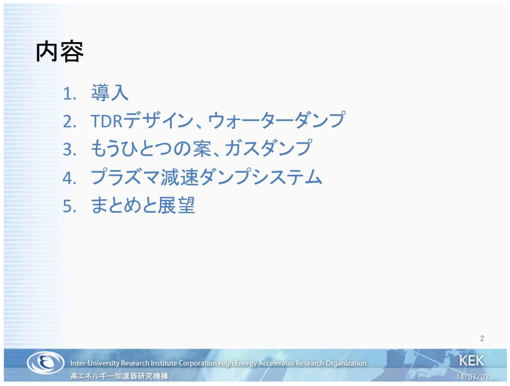
Reference
[1] http://www.enecho.meti.go.jp/category/others/basic_plan/pdf/140411.pdf
[2] http://www.meti.go.jp/policy/energy_environment/smart_community/doc/smartcommu.pdf
[3] http://lcdev.kek.jp/LCoffice/OfficeAdmin/Test/images/KEK_Report2013_5.pdf
[4] http://www.abeno.project-takenaka.com/

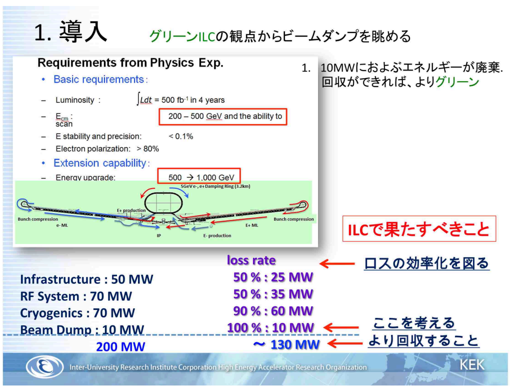
5 Energy recovery, Energy storage,

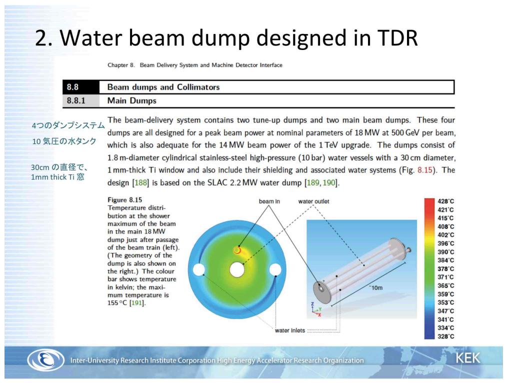
Energy control of Accelerator

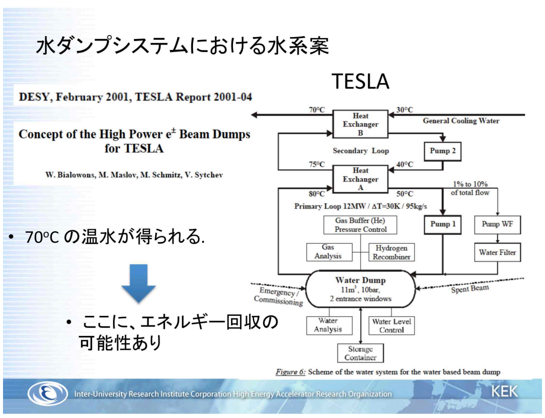
Energy Recovery from ILC beam dump
(Junpei Fujimoto, KEK)

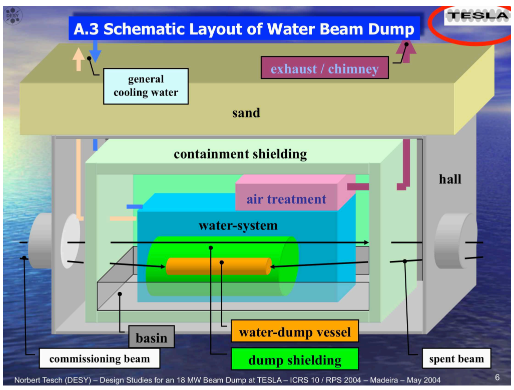










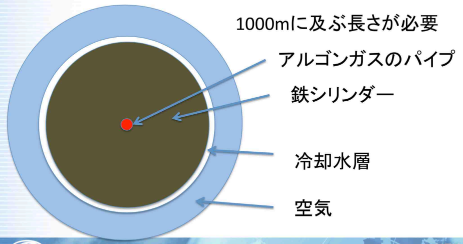


3.もうひとつの案、ガスダンプ

Based on “Another idea of a LC dump”
by Albrecht Leuschner 16/09/2003

ダンプトンネルの断面図

1000mに及ぶ長さが必要



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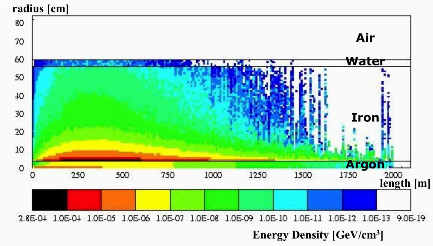
Albrecht Leuschner

400 GeVの電子を入射したときのエネルギー分布



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長所・短所

	水ダンプ	ガスダンプ
長さ	10 m	1000 m
窓にかかる圧力	10 bar static, 0.5 bar dyn.	1 bar static, 0.01 bar dyn
窓の直径	30 cm	8 cm
水素ガスの生成量	Several liter/sec @ 20 MW	no

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4.プラズマ減速ダンプシステム

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **13**, 101303 (2010)

Collective deceleration: Toward a compact beam dump

H.-C. Wu,[1] T. Tajima,[1,2] D. Habs,[1,2] A. W. Chao,[3] and J. Meyer-ter-Vehn[1]
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[2]*Fakultät für Physik, Ludwig-Maximilians-Universität München, D-85748 Garching, Germany*
[3]*SLAC National Accelerator Center, Stanford University, Stanford, California 94309, USA*
(Received 10 December 2009; published 5 October 2010)

Bethe-Bloch formula for stopping power in material

$$-(dE/dx)_I = (F/\beta^2)[\ln(2m_e\gamma^2v^2/I) - \beta^2], \quad (1)$$

where E is the electron kinetic energy, $F = 4\pi e^4 n_{e,m}/m_e c^2 = e^2 k^2_{pe,m}$, $n_{e,m}$ is the electron density in the stopping material, $k_{pe,m} = \omega_{pe,m}/c$ is the plasma wave number, and $\beta = v/c$ is the normalized electron velocity.

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The collective stopping power for wakefield deceleration of the electron bunch is large;

$$-(dE/dx)_{\text{coll-wave break}} = m_e c\omega_{pe}(n_b/n_e). \quad (5)$$

Equation (5) is exact for the resonant excitation of a wakefield with bunch length $\sigma_L/\lambda_{pe} \approx 0.5$, transverse size $\sigma_T/\lambda_{pe} \geq 0.3$, and modest density ratio $n_b/n_e < 10$

where λ_{pe} is the plasma wavelength of the background plasma with density n_e, n_b is the bunch density.

For a long beam $\sigma_L/\lambda_{pe} \gg 1$, the stopping power decreases exponentially with the factor $k_{pe}\sigma_L \times \exp(-k^2_{pe}\sigma^2_L/2)$. For a narrow beam $\sigma_T/\lambda_{pe} \ll 1$, the stopping power decreases with the factor $k^2_{pe}\sigma^2_T$.

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σ_L/λ_{pe} = ½ なので $\sigma_L = \pi\ c/\omega_{pe}$ と $n_b = N_b/(\sigma_L\sigma_T^2)$となる。
ここで、N_b はバンチ中の電子の数なので、

$-(dE/dx)_{coll\text{-}wave\ break}$ [GeV/cm] = 5.74 × N_b/σ_T^2[cm]

結局、

L_{dump}[m] = 1.7 ×10¹³ σ_T^2/N_b E_0[GeV], w/ $\sigma_T > 0.6\ \sigma_L$

ILCでは、それぞれ、N_b=2×10¹⁰, E_0=500 GeVなので、

L_{dump}[m] = 4.3 ×10⁵ σ_T^2[cm]
= 130 m w/ σ_L= 300 μ m, σ_T= 0.6×σ_L= 180 μ m
= 10 m w/ σ_T= 50 μ m, σ_L= σ_T/0.6 = 83 μ m

< 1000 m

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プラズマ航跡場からのエネルギー回収の可能性

- 論文では、“in principle, the energies from the decelerated beams deposited in the form of organized plasma wakefield may be recovered into electricity.”との指摘がある。
- “Any electric circuit such as a metallic loop in the plasma picks up coherent electric currents caused by the plasma collective oscillations. Then, external circuit extract electric energies rather than heat.”
- “Because the energy of the plasma electrons is much less than that of the beam electrons, the collisions do not give rise to excessive radioactivation.”

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6. まとめと展望

- TDRでの水ダンプシステムはよく考慮されていて、シミュレーションもよくされている。
- が、以下の考慮すべき点があることもわかっている。

(1) 耐10気圧のダンプ窓
(2) 発生する水素ガスの排出
(3) 70°C の温水が得られる。

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- ガスダンプ案では、
  (1) 1気圧でよいので、ダンプ窓の耐圧問題はない
  (2) 水素ガスの発生がない
  (3) 全長が長い、(1000 m の 4 ダンプシステム)
- プラズマ減速ダンプシステム
  (1)ダンプ窓の耐圧問題はない
  (2)水素ガスの発生がない
  (3) ガスダンプ案よりは、短い
  (5) 電力エネルギー回収の可能性あり

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- Green-ILC, の観点から、プラズマ減速ダンプシステムを考察することは意味がある。
- ただ、ILCのような細長いビームで働くかの検証が必要。
- 例えば、衝突点のあと、バンチコンプレッサーなどを入れてプラズマ減速ダンプに適したビーム形状にするなどの工夫が必要かもしれない。
- Green-ILCの観点からは、どのシステムによってエネルギー回収が効率的に行えるかが鍵。

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Status of charged particle acceleration and deceleration by Plasma
(Mituhiro Yoshida, KEK)

プラズマによる荷電粒子の加速・減速に関する研究の現状

第6回AAA グリーン-ILC WG 会合
2015.02.18
吉田　光宏 (KEK)

Novel Accelerator (新奇加速) の技術開発

・超高電界加速器の技術開発:
- 高Q ⇔ THz
  THz : レーザー、電子ビーム、非線形光学素子
- 光伝導スイッチ

加速器の電界を大幅に上げるには

- 耐圧の高い媒質
  - ×金属
  - ◎プラズマ
  - ○誘電体

$$W(\text{蓄積エネルギー}) = \int \frac{\varepsilon E^2 + \mu H^2}{2} dV$$

$$E = \sqrt{\frac{2W}{\varepsilon V}} \sim f\sqrt{W}$$

E : 電界、H : 磁界
V : 体積
f : 周波数

- 体積を小さくする or 蓄積エネルギーを上げる

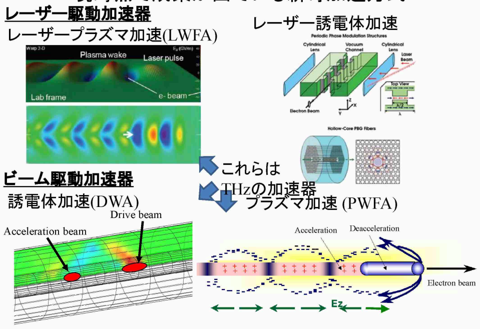
$$Q = \frac{\omega W}{P_{wall}}$$

周波数の高い加速器 : THz
- 従来のGHz帯加速方式
  → 20GHz以上の高周波源が無い
- **100 fs　程度の超短パルスとプラズマ or 誘電体による変換**
  - ・レーザー駆動　レーザー高強度化は著しく速い
  - ・電子ビーム駆動　SLAC/KEK等で可能&世界最高電圧の実績
  - ・陽子ビーム駆動　CERN/J-PARC等で可能→バンチ圧縮が問題

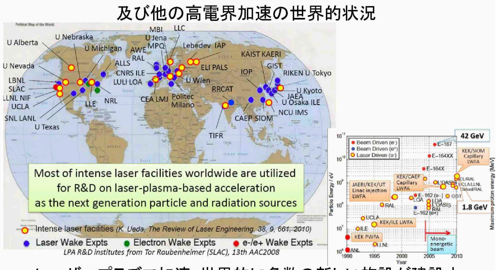
Q値の高い材料
- 常伝導Cu : Q～10,000
- 超伝導Nb : Q～10^{10} しかし電界<40MV/m
- 誘電体　: Q～10^6

私の最近の研究テーマ

現時点で成果が出ている新奇加速方式



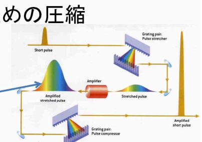
レーザープラズマ加速及び他の高電界加速の世界的状況

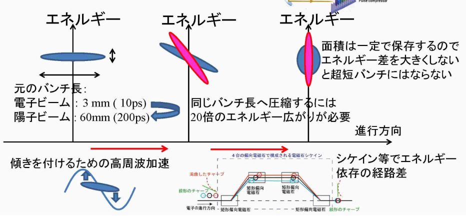


- レーザープラズマ加速 :世界的に多数の新しい施設が建設中
  - 30fs 程度で 1 PW というThales の商品
  - 500fs 程度で 1PW の超大型施設(低繰り返し)
- ビーム駆動の超高電界加速 : SLAC/FACET が唯一の大型施設

超短パルスを作るための圧縮

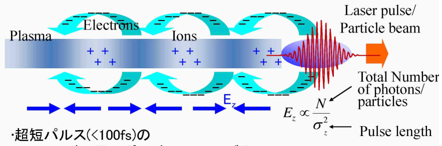
- バンチ圧縮には
  エネルギー差が必要
  - ーレーザー : CPA(チャープパルス増幅)
  - ービーム : 位相回転





THzのプラズマ振動による加速

- 何故プラズマが必要か？
  - 電磁波(レーザー)は横波なので進行方向の電界が無く加速できない
  - ビームも相対論的になると後続のビームにエネルギーを渡せない
    （後続のビームが駆動ビームを減速しないと変換できない）



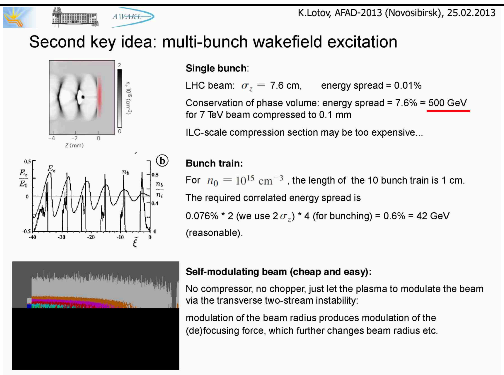
$$E_z \propto \frac{N}{\sigma_z^2}$$

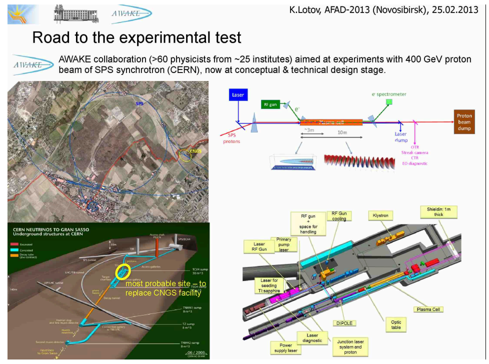
・超短パルス(<100fs)の
- レーザー場のポンデロモーティブ力
- または電子・陽子バンチのクーロン力

がプラズマ電子を排除。
・プラズマイオンの復元力で電子を引き戻す。
・プラズマ振動が起こる　→　このプラズマ振動の周波数が THz

エネルギー源と電界

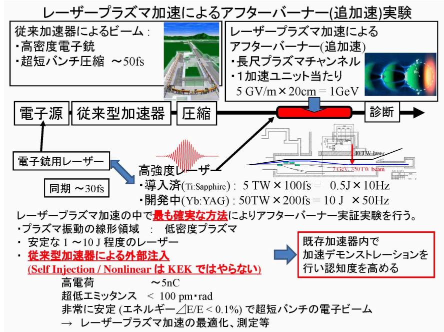
	常伝導	超伝導	電子ビーム駆動	レーザー駆動	陽子ビーム駆動
	6/12GHz	1.3GHz	5THz (50fs)	5THz (50fs)	? THz (後述)
駆動エネルギー	20J [/m] = 40MW × 500ns	200J [/m] = 300kW × 700μs	70J (SLAC) =23GeV × 3nC 35J (KEK) =7GeV × 5nC	40J (→ 1kJ)	**15kJ (SPS)** = **450GeV** × 30nC 150kJ (LHC) = 7TeV × 20nC 300kJ (J-PARC MR) = 40GeV × 8μC
電界	40/80MV/m 放電限界	40MV/m クエンチ	20GV/m × 2m = 40 GV	10 GV/m	?
繰り返し	50Hz	5Hz	50Hz	10Hz	1/18 Hz (SPS) 0.3 Hz (J-PARC MR)
ビーム電力/駆動/AC	400W / 1 kW / 8 kW (1m辺り)	10 MW / 23 MW / 150 MW (ILC)	? / 3.5 kW / 70 kW	4 W ? /400W /4kW(LD)	? / 833W/75MW (SPS) / 300kW/25MW (J-PARC)
効率	5% ?	8%	5%(電子生成) × η(e→e)	現状 0.1 % ?	1%(陽子ビーム生成) × η(p→e)

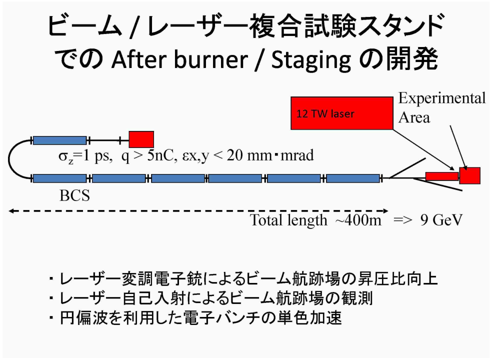


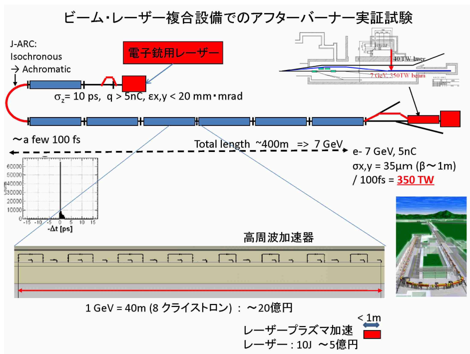


KEK固有の展開
(FY2011 からの活動状況)

- レーザープラズマ加速
  - * レーザー移設(東大より)
  - * レーザー開発
  - * プラズマチャンネルの開発
- 誘電体加速

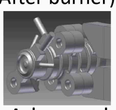






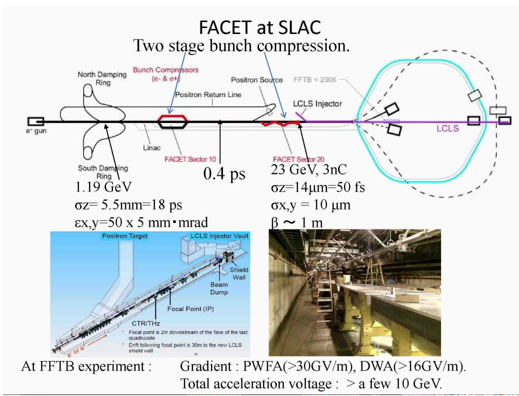
High density electron beam in KEK LINAC

- Injection for the SuperKEKB (5nC, 7GeV)
- Ultra high field experiment
  - Beam driven accelerator (DWA, PWFA)
  - Injector for laser plasma accelerator (After burner)
- Photon generation

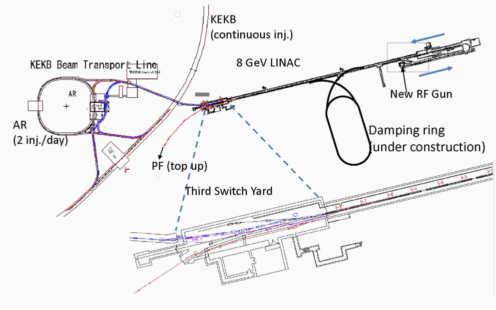


- Low emittance (< 10 mm mrad)
- High charge (> 5 nC)
- Short bunch length (fs)
  - 4-stage bunch compression
  - → Bunch shape control / precise syncronization

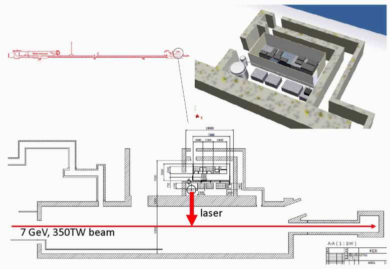
Advanced RF-Gun



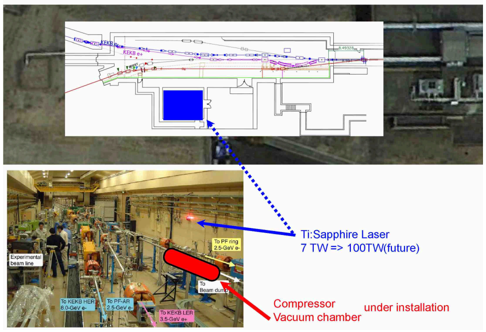
8 GeV LINAC Third Switch Yard



Experimental area for laser plasma after burner



Experimental area for laser plasma after burner



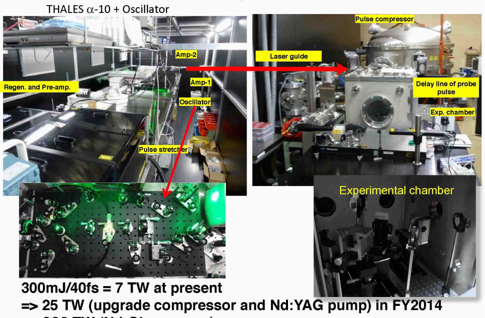
第三スイッチヤード電源室

- 以前水没 → 排水口と空調は改良

密閉されたレーザーハットを構築

Ti:Sapphire Laser from U-Tokyo Uesaka-lab for Phase-1

THALES α-10 + Oscillator



300mJ/40fs = 7 TW at present
=> 25 TW (upgrade compressor and Nd:YAG pump) in FY2014
=> ??? TW (Nd:Glass pump)

Ex. DWA

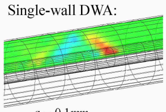
PRL 100, 214801 (2008) PHYSICAL REVIEW LETTERS week ending 30 MAY 2008

Breakdown Limits on Gigavolt-per-Meter Electron-Beam-Driven Wakefields in Dielectric Structures

13.8 ± 0.7 GV/m.

Fused silica, THz range, ~psec exposure

Single-wall DWA:



$a = 0.1mm$

$b = 0.324mm$

$\varepsilon = 3.0(SiO_2)$

$q = 5\ nC$

$\sigma_z = 30\mu m(0.1ps)$

- Mode wavelengths

$$\lambda_n \approx \frac{4(b-a)}{n}\sqrt{\varepsilon - 1} = 0.7mm$$

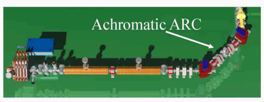
- Peak decelerating field

$$eE_{z,dec} \approx \frac{-4N_b r_e m_e c^2}{a\left[\sqrt{\frac{8\pi}{\varepsilon-1}}\varepsilon\sigma_z + a\right]} = 2GV/m(\sigma_z = 0.1ps)$$

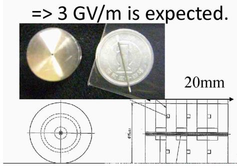
- Transformer ratio

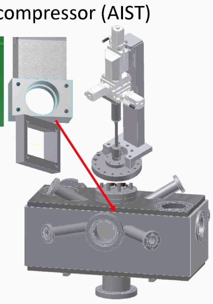
$$R = \frac{E_{z,acc}}{E_{z,dec}} \le 2$$

DWA test plan at 40 MeV LINAC & Achromatic ARC bunch compressor (AIST)



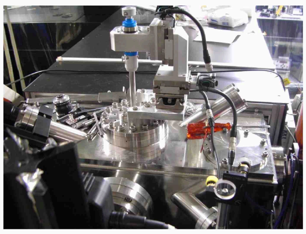
- 150 fs, 50um bunch size
  => 3 GV/m is expected.





0.2mm diameter ceramic pipe

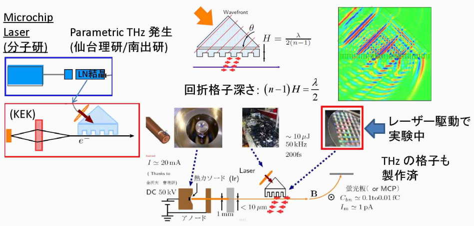
産総研での DWA の試験



- 非軸放物面鏡による THz 波の観測
- ビームの減速は今後の課題

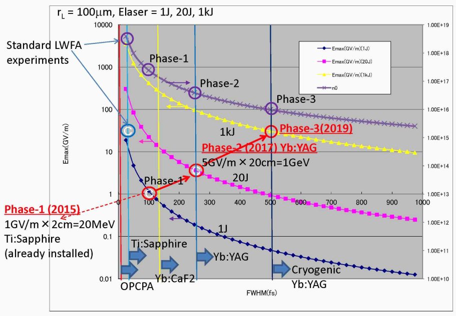
THz 誘電体加速

- THz での誘電体加速
  - 10mJ (1.2THz) と現行加速器の 100J (12GHz) が同じ加速電圧
  - 高強度 THz はシングルサイクル～数サイクル → 垂直入射は不可 → プリズム入射方式



Low density and long plasma waveguide for LWFA afterburner experiment

Possible experimental region for LWFA

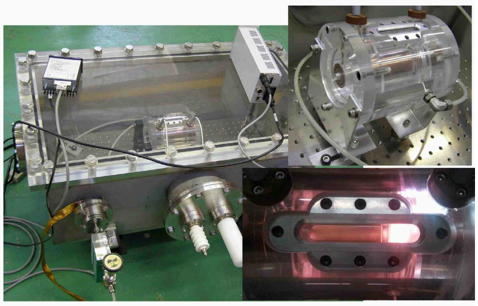


Plasma waveguide

- Gas filled capillary with electric discharge :
  - Slow mode (Simon's method)
    Simmer Discharging (100µs)
    => 200～300A, a few 100 ns
    Capillary diameter = 200-500µm
  - Fast Z-Pinch mode (Hosokai's idea)
    1kA, 10ns
    Capillary diameter = 1mm

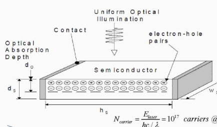
=> Pulsed HV power supply for both mode is required.

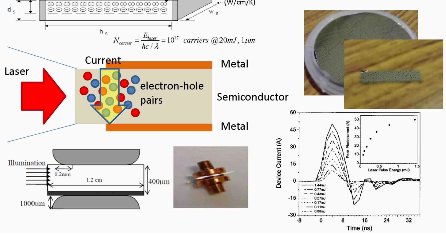
Preliminary test for Electric Discharging Plasma Channel



Photoconductive switch for Fast Z-Pinch

	GaAs	Si	InP	4H-SiC
Bandgap(eV)	1.43	1.12	2.25	3.26
Withstanding(kV/cm)	250	300	200	3000
Dark current(Ωcm)	2×10^7	2×10^3	3.6×10^7	10^{11}
Mobility(cm^2/Vs)	6000	1350	6500	300
Thermal conductivity (W/cm/K)	0.55	1.40	0.7	4.9

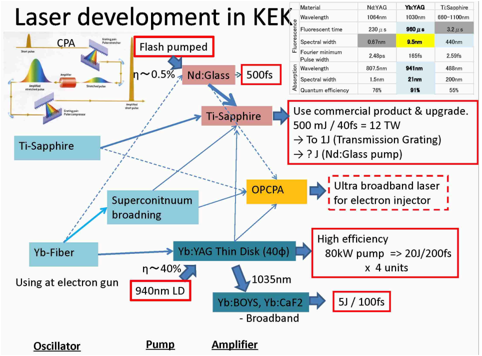




Laser development toward high energy sub-picosecond LWFA afterburner experiment

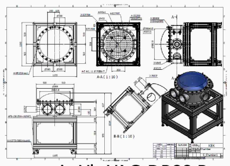
Laser development in KEK

	Material	Nd:YAG	Yb:YAG	Ti:Sapphire
Fluorescence	Wavelength	1064nm	1030nm	660-1100nm
	Fluorescent time	230 µs	960 µs	3.2 µs
	Spectral width	0.67nm	9.5nm	440nm
	Fourier minimum Pulse width	2.48ps	165fs	2.59fs
Absorption	Wavelength	807.5nm	941nm	488nm
	Spectral width	1.5nm	21nm	200nm
	Quantum efficiency	76%	91%	55%



Upgrade of Ti:Sapphire Laser

- New compressor using transmission grating

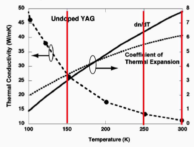


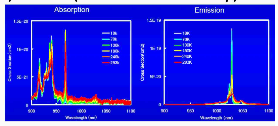
- Cryogenic Yb:YAG DPSS Pump
  - 1.5 inch Yb:YAG disk
  - 150K Yb:YAG with He-gas cooling
  - 9kW × 40 = 360kW
  - 10J/module

Cryogenic Yb:YAG

- Improvement of thermal and emission property

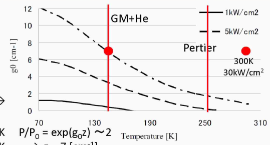
(Thermal lens effect) (Excitation density)





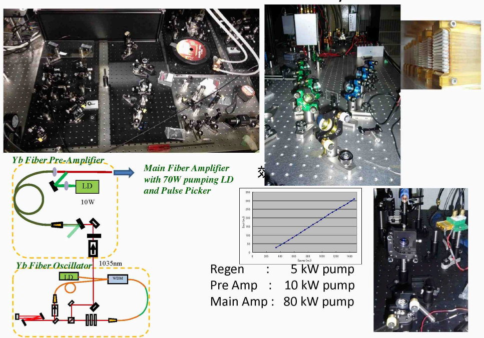
10 W/m/K , dn/dT = 8ppm/K @ 300K
25 W/m/K , dn/dT = 3ppm/K @ 150K
↑150K 1/6 Thermal lens

Same gain @ 1/3 excitation density →
↓
150K => 1/20 thermal lens

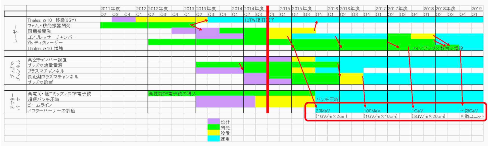


300K $P/P_0 = \exp(g_0 z) \sim 2$
150K → $g = 7\ [cm^{-1}]$

Yb Fiber + Yb:YAG Disk Laser system



スケジュール(FY2011-2018)



- 完了：
  - フェムト秒発振器開発
  - 12TW レーザー移設 (東大との共同研究+名大)
- 進行中：
  - レーザーの増強
    - 高強度Ybディスクレーザー開発 (>10J)
    - 透過型グレーティングによるコンプレッサー
  - 長距離プラズマチャンネル開発
  - アフターバーナーの評価

Plasma Beam Damp for ILC

Plasma Damp

- 250 GeV のビームを数10m で減速する
- ダンプにおける高エネルギーミュオンの生成を抑える
- プラズマのエネルギーを回収する？

Collective stopping power

（ビームから航跡場のエネルギー）

$$-\left(\frac{dE}{dx}\right)_{CWB} = m_e c \omega_{pe} \left(\frac{n_b}{n_e}\right)$$

H.C-. Wu, et al, PR-STAB, **13**, 101303 (2010).

m_e；電子の質量 c；光速 $\omega_{pe} = \left(4\pi e^2 n_e/m_e\right)^{1/2}$ ；電子プラズマ周波数
$= 5.64 \times 10^4 n_e^{1/2}$ rad/s

n_e；標的電子の数密度 $n_b \simeq N_b/\left(\sigma_L \sigma_T^2\right)$; バンチの数密度

N_b；バンチ内の粒子数, σ_L；バンチ長, σ_T；バンチの幅

線形共鳴条件

$$\frac{\sigma_L}{\lambda_{pe}} = \frac{\sigma_L \omega_{pe}}{2\pi c} \sim \frac{1}{2}$$

但し、 $\frac{\sigma_T}{\lambda_{pe}} \geq 0.3$ $\frac{n_b}{n_e} < 10$

- 長いバンチ $\frac{\sigma_L}{\lambda_{pe}} \gg 1$ の場合、
  $k_{pe}\sigma_L \exp\left(-\frac{k_{pe}^2 \sigma_L^2}{2}\right)$ で小さくなる
  短い方は問題ない
- 細いバンチ $\frac{\sigma_T}{\lambda_{pe}} \ll 1$ の場合、
  $k_{pe}^2 \sigma_T^2$ で小さくなる

Collective stopping powerの試算

stopping powerの式と共鳴条件の式から

$$-\left(\frac{dE}{dx}\right)_{CWB} [\mathrm{eV/cm}] = 0.96 n_e^{1/2}\,[\mathrm{cm}^{-3}] \left(\frac{n_b}{n_e}\right) = 5.8 \times 10^{-7} \frac{N_b}{\sigma_T^2\,[\mathrm{cm}]}$$

$$L_{dump}\,[\mathrm{m}] \approx 1.7 \times 10^{13} \frac{\sigma_T^2\,[\mathrm{cm}]}{N_b} E_0\,[\mathrm{GeV}]$$

但し、 $\sigma_T \geq 0.6\sigma_L$ & $\sigma_T \geq 1.9 \times 10^{-6}\sqrt{N_b \sigma_L}$

ILC $N_b = 2 \times 10^{10}$ $E_0 = 500\mathrm{GeV}$

$$L_{dump}\,[\mathrm{m}] \approx 4.3 \times 10^5 \sigma_T^2\,[\mathrm{cm}]$$

$$\sigma_T \geq \begin{array}{ll} 0.33\sqrt{\sigma_L} & ,\ 0 \leq \sigma_L \leq 0.25\mathrm{cm}\ (8.3\mathrm{ps}) \\ 0.6\sqrt{\sigma_L} & ,\ \sigma_L \geq 0.25\mathrm{cm} \end{array}$$

バンチサイズを小さく

$$L_{dump}\,[\mathrm{m}] \approx 4.3 \times 10^5 \sigma_T^2\,[\mathrm{cm}]$$

長さを10mにするには $\sigma_T \approx 50\mu\mathrm{m}$

$$\sigma_L \approx 3\sigma_T \approx 150\mu\mathrm{m}$$

(510fs)

プラズマの電子密度と初期水素分子の密度は、

$$n_e = 3.1 \times 10^{15}\mathrm{cm}^{-3}$$

$$P\,(\mathrm{RT}) = 0.1\mathrm{mbar} - \mathrm{H}_2$$

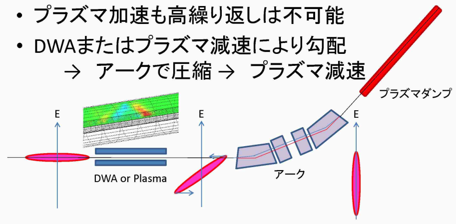
ILCでのバンチ圧縮の可能性

- 衝突後のエネルギー分布：

↓

- 高周波空洞の勾配では不可能
- プラズマ加速も高繰り返しは不可能
- DWAまたはプラズマ減速により勾配

→ アークで圧縮 → プラズマ減速



Utilization of Stored Energy in Iron
(Kenji Hosoyama, KEK)

鉄を利用したエネルギー貯蔵による エネルギーの有効利用

- はじめに
- 深夜電力の有効利用
- 鉄は蓄冷材として優れている？
- 熱機関（カルノーサイクル）とエネルギーの質
- 電気エネルギーの貯蔵
  熱、水の位置、磁場
- 揚水、風力、地熱、圧縮空気、太陽光、太陽熱発電
- 鉄による熱エネルギー貯蔵によるエネルギーの有効利用

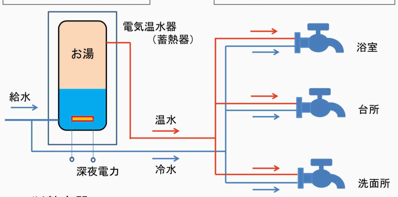
KEK
K. Hosoyama

はじめに

- 地球温暖化防止の CO_2 排出抑制の実現に向けて、世界的な規模で、水力、風力、太陽光、地熱、バイオなどの再生可能なエネルギーへの関心が高まっている。わが国では大震災よる福島原子力発電所の事故によって原発への信頼が大きく失われ、今後のエネルギー政策の大きな見直しが迫られ、再生可能なエネルギーの利用が真剣に検討されている。
- 我が国に建設が計画されている大型加速器装置 ILC は大電力を必要とし、エネルギー問題をも含めた形で建設計画を推進していかなければならない。
- 風力、太陽電池等による再生可能なエネルギーは、出力が天候に左右されるため不安定で、その実用化の大きな障害となっているが、電気エネルギーを熱エネルギーに変換して貯蔵し、必要に応じて電力として再び、取り出すより容易に解決される。

電気温水器と給温水配管

セントラルヒーテイング ⟷ クライオジェニック　システム

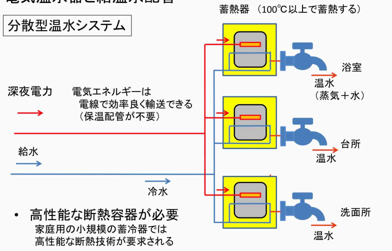


- 断熱容器
- 断熱配管

お湯が出るまでに時間がかかる
無駄な水を消費する
温水の温度が下がる

電気温水器と給温水配管

分散型温水システム



- 高性能な断熱容器が必要
  家庭用の小規模の蓄冷器では
  高性能な断熱技術が要求される

使用中に温度が下がる → 蓄熱温度を100℃以上にする

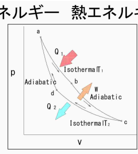
蓄熱材としての　　水と金属（鉄）の比較

- 水は比熱が1と大きく、蓄熱材として優れている
- 100℃で沸騰するため、高い温度で使用出来ない
- 100℃以上で使用する場合は高圧容器が必要

機関車	350℃	16 ata
火力発電	600℃	250 ata
原子力発電	284℃	68 ata

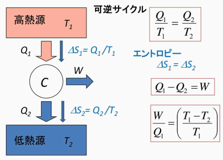
- 金属（鉄）は比熱が約 0.1と小さく、蓄熱材としては劣っているが、
  比重が約8と大きいため、単位体積あたりの熱容量は水とほぼ同じ（0.8倍）
- 高い温度での 100℃以上（800℃）での使用が可能
- 断熱が重要
- 装置が重くなる

有効な熱エネルギー　熱エネルギーの質



理想的な熱機関
カルノーサイクル

熱機関を運転するには高熱源と低熱源が必要で、取り出すことが出来る仕事は熱源の絶対温度によって決まる。



理想的な熱機関の例
高熱源　100 ℃　373 K
低熱源　10 ℃　283 K

$$\frac{W}{Q_1} = \left(\frac{90}{373}\right) = 0.24$$

100 ℃の高熱源から熱 Q_1 (100%)を受け取って,76% の熱を低熱源に排出して、24% の仕事を生み出す。

熱エネルギーの質 （熱力学的な考察）

高温度での熱エネルギーの保存
1） 蓄積熱量 ＝ 比熱 x 温度 を大きくすることができる
2） 質の高い熱エネルギーとしての保存できる
　　電気エネルギーとして再利用する場合は重要

理想的なエンジン
カルノーサイクル

$$Q_1 - Q_2 = W$$
$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$
$$W = Q_1 \frac{T_1 - T_2}{T_1}$$
$$\frac{W}{Q_1} = \frac{T_1 - T_2}{T_1}$$

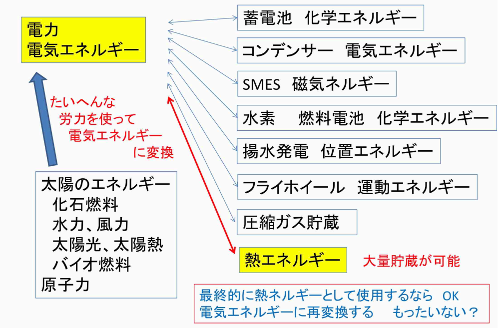
地熱発電
T_1 = 150℃
T_2 = 35℃
W/Q_1 = 0.27

火力発電
T_1 = 600℃
T_2 = 35℃
W/Q_1 = 0.65

汽車、原子力発電
T_1 = 350℃
T_2 = 35℃
W/Q_1 = 0.51

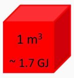
蓄熱発電
T_1 = 800℃
T_2 = 35℃
W/Q_1 = 0.71

電気エネルギーの貯蔵　　電気エネルギーの貯蔵は難しい



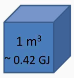
鉄と水の蓄積熱量の比較

鉄　　　　　　　　　　　　　水



ΔT = 500 ºC

$\Delta E = m \times Cp \times \Delta T$
= 8000 kg
x 0.1 kcal/kg/ºC
x 500 ºC
x 4.2k J/ kcal
= 1680000 k J
= 1.68GJ



ΔT = *100 ºC*

Heat Capacity of Water
Cc.c. = 4.2 J/c.c./ºC
C_L = 4.2 kJ/ L / ºC
C_{m3} = 4.2 MJ/m³/ ºC

Specific Heat Cp ~ 1/10 kcal/kg/ºC
Density ρ ~ 8 kg/L

Heat Capacity per Volume Cv

C_V = Cp x ρ

Heat Capacity of Iron/volume

= 0.8 x Heat Capacity of Water

Weight = 8 ton Very Heavy

Energy required to rise the temperature 1ºC of 1 m³ water

E = 4.2 MJ

Energy required to rise the temperature 1ºC of 1 m³ iron

E = 0.8 x 4.2 MJ = ~ 3.4 MJ

Energy required to rise the temperature 500 ºC of 1 m³ iron

E = 約 1700 MJ =~ 1.7 GJ

磁気エネルギーの貯蔵

(SMES: Superconducting Magnet Energy Storage)

- Stored Magnetic Energy E

$E = 1/\mu_0 \times B^2 \times V = 10/(4\pi)\, B^2 \times V$ [MJ]　　　　$E = ½\, L\, I^2$

Case 1: B = 5T, (V = 1 m³)
E = 20MJ

Case 2: B = 10T (V = 1 m³)
E = 80MJ

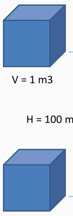
- Stored energy of LHC

15 GJ (including Detector magnets)

現在実用化されている10T 級の超伝導マグネットでは、磁気エネルギー貯蔵量は
熱エネルギーによる貯蔵量に比べてはるかに小さい。
瞬停対策用等の短時間での電力補償用に利用されている。

水の位置エネルギーを利用する　揚水発電

水の位置エネルギー



V = 1 m3

H = 100 m

U [J] = 9.8 W[kg] x H [m]

1 m3 の水、ΔH= 100 m 場合の位置エネルギー

U = 9.8 x 1000 x 100 [J] = 約 1 MJ

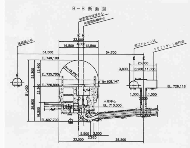
1.7 GJ の位置エネルギーを得るため必要な水の体積 V は？

落差が100 m の場合	体積 V = 1700 m3
落差が300 m の場合	体積 V = 570 m3
落差が1000 m の場合	体積 V = 170 m3

注）
1 m3 の鉄を ΔT = 500℃温度を上げるのに必要な
熱エネルギーは？

E = 約 1700 MJ =約 1.7 GJ

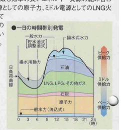
揚水発電の仕組みと特徴



■ 限られた資源のベストミックス

日本は世界の一次エネルギーの約5%を消費する世界第四位のエネルギー消費大国ですが、エネルギー資源の約80%を海外からの輸入に頼るエネルギー資源小国です。

今後の世界的なエネルギー需要を踏まえたグローバルな視点から、電気を長期に渡り安定してお届けするために、燃料の安定調達、経済性、環境への影響などを総合的に考えて、最も効率の良いエネルギー資源の組み合わせをめざしています。ベース電源としての原子力、ミドル電源としてのLNG火力、石油火力、ピーク電源としての水力というように、それぞれの特徴を生かしたバランスの良い発電設備づくりを進めています。



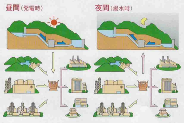
※LNG:液化天然ガス

■ 揚水発電の仕組みと特徴

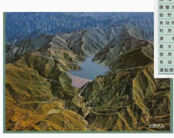
電気の使用量は1日の内でも大きな変動があり、深夜には昼間の半分程度に下がり発電設備に余裕ができます。揚水発電はこの余裕分を有効利用するものです。

揚水発電は発電所を挟む上と下の2つの調整池を利用し、昼間の電気の需要の多いときは上部調整池から下部調整池に水を落として発電し、電気の需要の少ない夜間に水車を逆回転させて下部調整池から水を汲み上げ、再び昼間の発電に使うというように一定量の水を繰り返して使用する発電方式です。また、運転開始から最大出力までわずか数分という出力調整の早さで急激な電力消費量の変化にすばやく対応します。

揚水発電は、貴重な水資源の有効利用がはかれると共に火力、原子力発電所と組み合わせて運転することにより、電気の供給コストの低減もはかれます。



神流川発電所



上部ダム

【計画諸元】

	上部調整池	下部調整池
河川名	信濃川水系南相木川	利根川水系神流川
流域面積	6.2km²	31.2km²
調整池面積	0.59km²	0.56km²
総貯水量	1,917万m³	1,840万m³
有効貯水量	1,267万m³	
利用水深	27m	29.4m
満水位	EL（海抜）1,527m	EL（海抜）843.4m
最大出力	282万kW（47万kW×6台）	
使用水量	毎秒510m³	
有効落差	653m	
運転開始予定	2005年12月（初号機47万kW）	

上部ダム		中央土質遮水壁型フィルダム 高さ 136.0m　堤頂長 444.0m　堤体積 730万m³
下部ダム		重力式コンクリートダム 高さ 120.0m　堤頂長 350.0m　堤体積 72万m³
1号水路系	導水路	内径 8.2m　延長 2,445m
	水圧管路	内径 8.2m～2.3m 延長 1,397m（1,2号発電電動機側） 延長 1,365m（3,4号発電電動機側）
	発電所	高さ 51.4m　幅 33.0m　長さ 215.9m（地下式）
	放水路	内径 4.1～8.2m　延長2,270m
	ポンプ水車	立軸フランシス型ポンプ水車4台
	発電電動機	立軸三相交流同期発電電動機4台

最大出力　282万kW （47 万kW x 6 台 ）
使用水量　510 m3 / sec
有効落差　653 m
有効貯水量　1,267万m3

発電時間　1267/653 x 10000 /3600 hr
~ 5.4 hr

下部ダム

電力ネットワーク

効率的な電力ネットワークの構築には、
揚水発電所が欠かせません。

■日本と東京電力における水力発電の最大出力合計

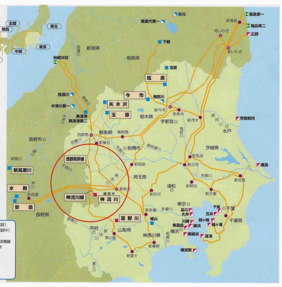
	箇所数	最大出力 合計(万kWh)
日本の一般水力発電	1,221	4,313.5
東京電力の一般水力発電	160	898.5（日本の20.8%）
日本の揚水式発電	41	2,514.4
東京電力の揚水式発電	9	680.8（日本の27.1%）

2008年3月末 現在

■東京電力の揚水式発電所一覧

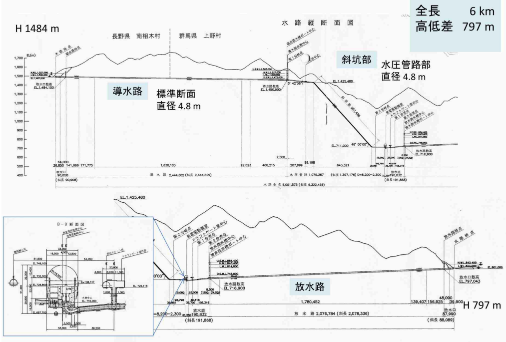
	発電所名	出力(万kW)	運転開始年	揚水型式
東京電力	矢木沢	24.0	1965年	混合揚水
	安曇	62.3	1969年	〃
	水殿	24.5	1969年	〃
	新高瀬川	128.0	1979年	〃
	玉原	120.0	1982年	純揚水
	今市	105.0	1988年	〃
	塩原	90.0	1994年	〃
	葛野川	160.0	1999年(1)	〃
	神流川	282.0	2005年(2)	〃

(1) 2000年 6 月　80万kW運転開始
(2) 2005年12月　47万kW運転開始



水路縦断面図

全長　　6 km
高低差　797 m

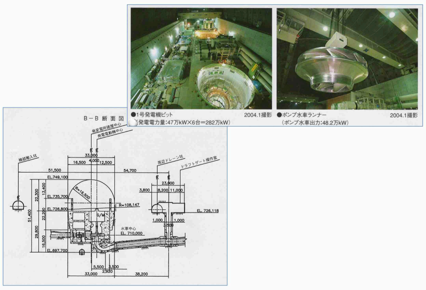


神流川揚水発電所


●上部ダム下流面（上空より撮影）　2003.10撮影　●上部ダム湛水池（右岸側より撮影）　2005.8撮影
（堤頂長:444m　高さ:136m　堤体積:730万m³）

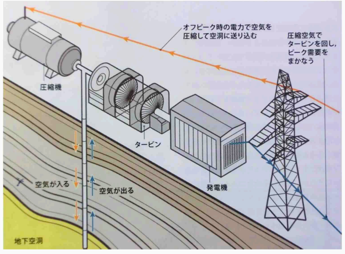

●下部ダム下流面（上空より撮影）　2003.9撮影　●下部ダム湛水池　2005.11撮影
（堤頂長:350m　高さ:120m　堤体積:72万m³）

地下発電所と発電機



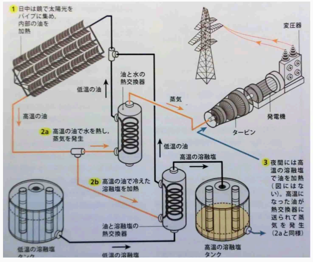
圧縮空気貯蔵発電

余剰の電力を使って空気を圧縮して高圧のガスとして地下の廃坑などの空洞に貯蔵し、必要に応じて取り出して膨張タービンで動力として取り出して電力に変換する。

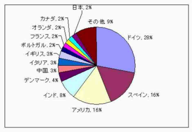


太陽熱利用の熱貯蔵発電

太陽からの熱輻射エネルギーは反射鏡で集められ、高温の油として熱エネルギーが取り出され、一部は熱交換器で高圧蒸気に変換され、発電に利用される。残りの熱エネルギーは別の熱交換器で溶解塩に渡されて高温の溶解塩の貯蔵タンク内に貯められて、夜間の発電に利用される。



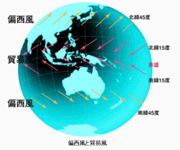
風力発電



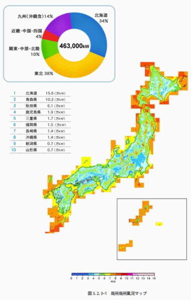
日本の風力発電の特徴と問題点

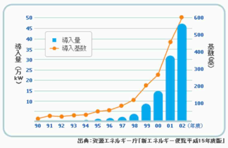
- 安定した偏西風が期待できないので多様な風を利用できるようにする。
- 台風などの強風に耐える構造にする(強い風のエネルギーを利用する)
- 欧州の風力発電よりも出力が不安定になるので、平準化のためのシステムが重要。

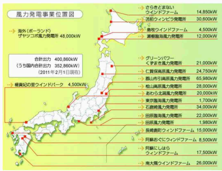
風力発電をベースロード電源に
近づける努力が必要



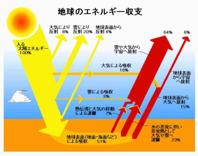
日本の風力発電

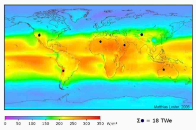






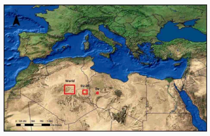
太陽光の利用





DESERTEC 計画
SSB (Sahara Solar Breeder) 計画

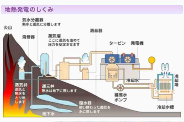
砂漠での大規模太陽光発電
長距離電力輸送(直流超伝導送電)



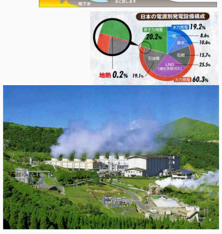
地熱発電

地球内部の熱エネルギーを利用する

- 地球誕生の過程で取り込まれた隕石の運動エネルギーが熱として蓄積された
- 地球内部の放射性物質の崩壊に伴う熱



日本の地熱発電所

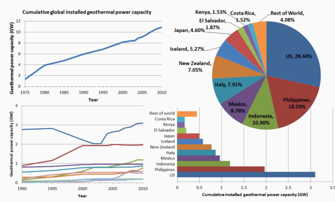


世界の地熱発電

「火山大国」の日本は地熱発電の開発が遅れている

海外では多くの国で地熱発電は行われている

米国カリフォルニアの地熱発電所

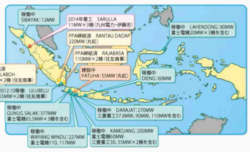


世界最大の地熱発電所は日本製

富士電機
- ニュージーランドのナ・アワ・プルア地熱発電所（14万kW, 2010年に運転を開始）を含め4か所を完成、合計出力 40万kW

三菱重工
- 九州電力八丁原地熱発電所（2基で合計11万kW）、東北電力澄川地熱発電所（5万kW）、アイスランドのネシャベトリル地熱発電所（4基で合計12万kW）、フィリピンのミンダナオ地熱発電所（2基で合計11万kW）、ケニアのオルカリア地熱発電所（2基で合計7万kW）、合計300万kW

日本は地熱発電技術の
世界の最先進国！



鉄に電気エネルギーを熱として蓄積する

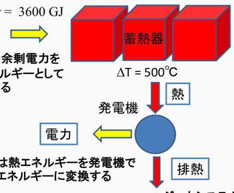
人工的な地熱貯留層

電気エネルギー E
100 MW x 1 0 hours

E = 100 M J / sec x 3600 sec / hr x 10 hr = 3600 GJ

鉄 1 m^3, ΔT = 500℃
E = ~ 1.7 GJ
鉄 3000 m^3, ΔT = 500℃
E = 1.7 GJ x 3000 = ~5100 GJ

鉄の蓄熱器の寸法
10 x 10 x 10 [m^3] x 3 units



夜間の余剰電力を熱エネルギーとして貯蔵する

日中は熱エネルギーを発電機で電気エネルギーに変換する

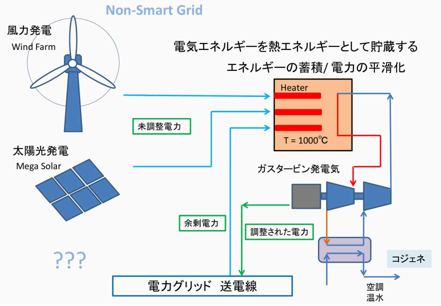
コジェネシステム
暖房、空調、
温室、・・・・

鉄の蓄熱器 重い
基盤にかかる圧力 80 ton/m^2

人工的な地熱貯留槽を利用した「地熱発電装置」

この規模の地熱発電は既に、国内は勿論のこと世界中で実用運転されている。

電気エネルギーの熱エネルギーとしての蓄積

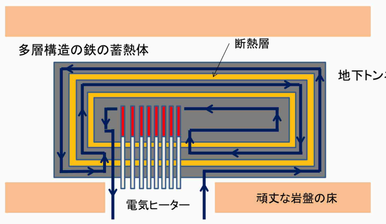


熱エネルギー貯蔵システムの特徴

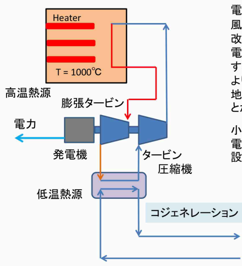
- 「熱エネルギー貯蔵システム」のヒーターに供給する電力は平滑化などの調整は不要で、供給された電気エネルギーは自動的に熱エネルギーに変換され、蓄熱器に熱エネルギーとしてトッピングすることができる。
- 蓄熱器は層間が断熱された多層構造で。加熱用の電気ヒーターを中心層に設置することにより断熱性能が向上させることが出来る。
- 高温で良質の熱エネルギーを大量に貯蔵できるため、電力の平滑化と同時にエネルギーの蓄積が可能で、発電機の回転速度を制御することにより、完全に制御されて電力となる。
- タービン発電機から放出される比較的高温の排熱は熱交換器で回収してコジェネレーションシステムとして、空調（冷暖房）、温水供給設備等に利用することができる。

蓄熱器の構造と機能

蓄熱器はエネルギーの蓄積、質の良くない電力の改善、商用電力の遮断時には予備電源として威力を発揮する。



タービン発電機の排熱や余剰電力の利用



電力の地産地消
風力、太陽光発電等による不安定な電力を改質すことにより、再生可能なエネルギーを電力として安定に供給することが可能となる。すなわち生産した電力を遠距離の送電線により遠く離れた工業地帯へ送るのではなく、地場産業のエネルギー源として活用することが可能となる。

小型のタービン発電機を利用すれば、余剰電力を利用した補助電源としてビルなどに設置することも可能。
（燃料の供給が不要）

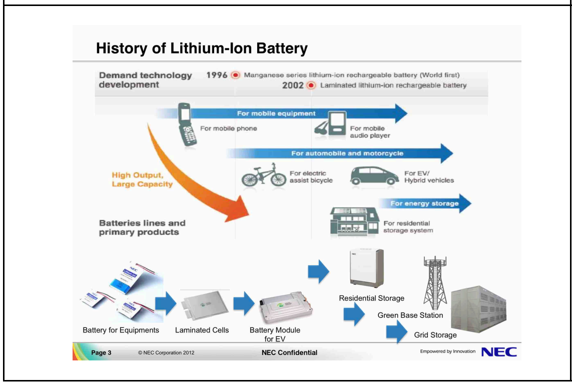
注）
ヘリウム圧縮機の冷却に使用した排熱も地域の農業や養殖の熱資源として利用することができる。

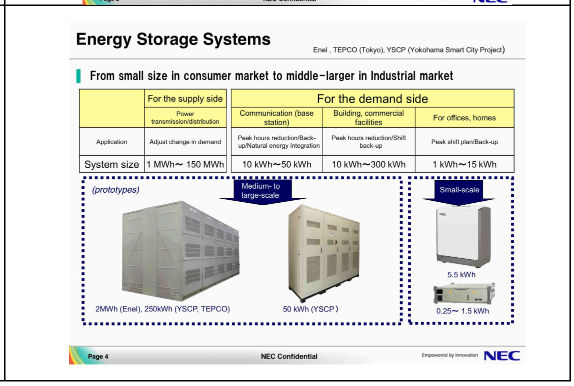
比較的高温の排熱は研究施設の冷水、温水の製造や空調装置に再利用すると同時に地域暖房や農業等の熱源として利用する。

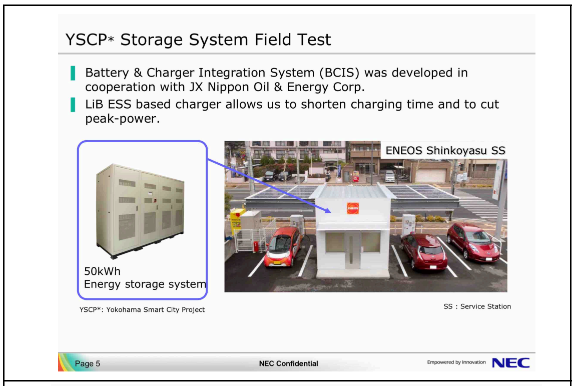
まとめ

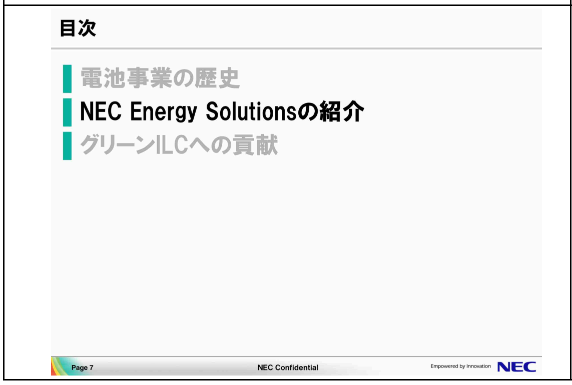
- 再生可能なエネルギーの風力、太陽光発電等による不安定な電力を熱エネルギーとして貯蔵し、再発電することにより安定な電力として利用できる。
- このグリーン電力は山岳トンネル内に建設が予定されている ILC 加速器用」の電力として利用できる。
- この発電システムを ILC 加速器に採用し、魁として実証することにより、この再生可能なエネルギー発電システムが将来、重要な社会インフラに発展することが期待できる。
- この熱貯蔵による発電システムを完成させるためには、要素技術の開発研究が必要となる。特に、システム全体の効率の向上が重要であると考えられる。

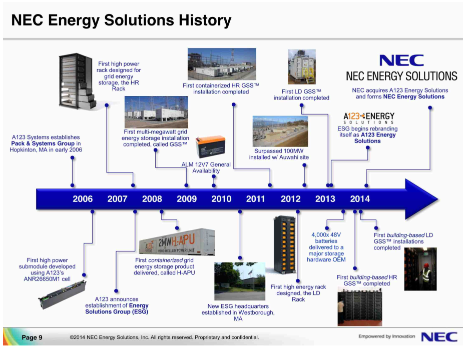
Power-line storage system and Green-ILC
(Hajime Sakuma, NEC)










NEC Energy Solutions History
First high power rack designed for grid energy storage, the HR Rack
First containerized HR GSS™ installation completed
First LD GSS™ installation completed
NEC
NEC ENERGY SOLUTIONS
NEC acquires A123 Energy Solutions and forms NEC Energy Solutions
A123 Systems establishes Pack & Systems Group in Hopkinton, MA in early 2006
First multi-megawatt grid energy storage installation completed, called GSS™
ALM 12V7 General Availability
Surpassed 100MW installed w/ Auwahi site
A123 ENERGY SOLUTIONS
ESG begins rebranding itself as A123 Energy Solutions
2006 2007 2008 2009 2010 2011 2012 2013 2014
First high power submodule developed using A123's ANR26650M1 cell
A123 announces establishment of Energy Solutions Group (ESG)
2MW H-APU
First containerized grid energy storage product delivered, called H-APU
New ESG headquarters established in Westborough, MA
First high energy rack designed, the LD Rack
4,000x 48V batteries delivered to a major storage hardware OEM
First building-based HR GSS™ completed
First building-based LD GSS™ installations completed
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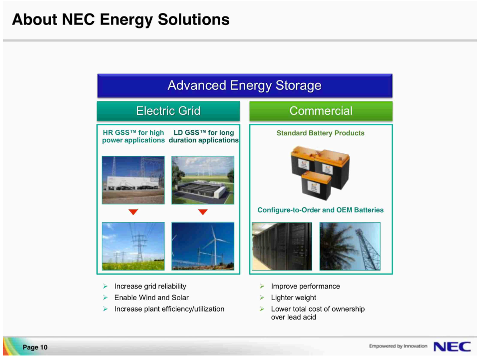
About NEC Energy Solutions
Advanced Energy Storage
Electric Grid
Commercial
HR GSS™ for high power applications
LD GSS™ for long duration applications
Standard Battery Products
Configure-to-Order and OEM Batteries
Increase grid reliability
Enable Wind and Solar
Increase plant efficiency/utilization
Improve performance
Lighter weight
Lower total cost of ownership over lead acid
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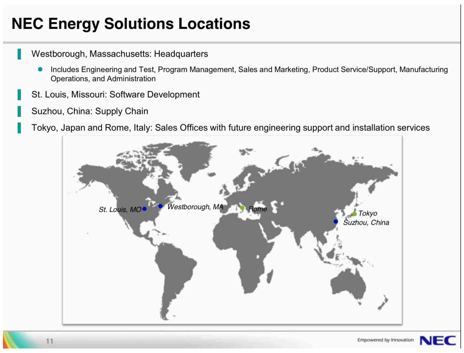
NEC Energy Solutions Locations
Westborough, Massachusetts: Headquarters
Includes Engineering and Test, Program Management, Sales and Marketing, Product Service/Support, Manufacturing Operations, and Administration
St. Louis, Missouri: Software Development
Suzhou, China: Supply Chain
Tokyo, Japan and Rome, Italy: Sales Offices with future engineering support and installation services
St. Louis, MO
Westborough, MA
Rome
Tokyo
Suzhou, China
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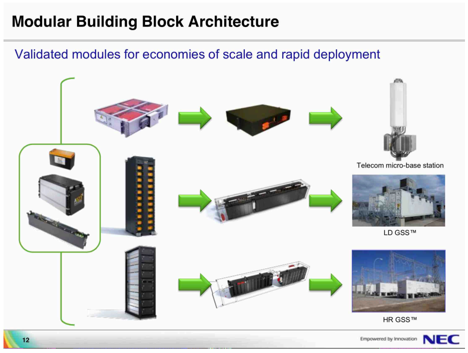
Modular Building Block Architecture
Validated modules for economies of scale and rapid deployment
Telecom micro-base station
LD GSS™
HR GSS™
12
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GSS™
An Integrated System
The GSS™ is a fully integrated, turnkey energy storage plant ready to interconnect to the grid
Designed and manufactured by NEC Energy Solutions, and includes
Rack-integrated energy storage with BMS and controls hardware
Enclosures (standard containerized, but custom enclosures possible)
Power conversion hardware (inverters)
Command and control software suite
Configured to order from factory assembled & tested standard modular components
Building-based 8MW, 32MWh GSS
Containerized 32MW, 8MWh GSS
13
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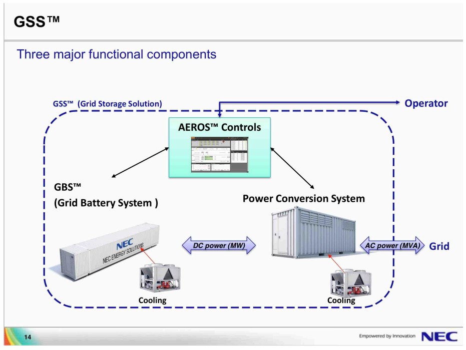
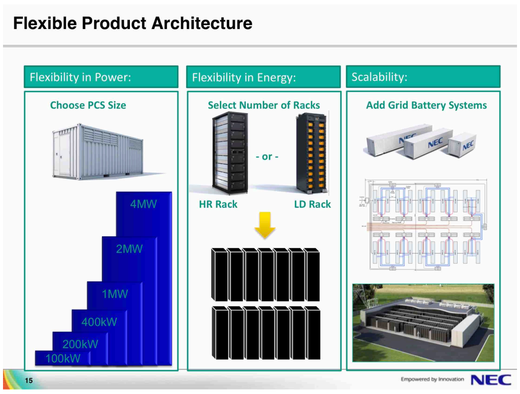
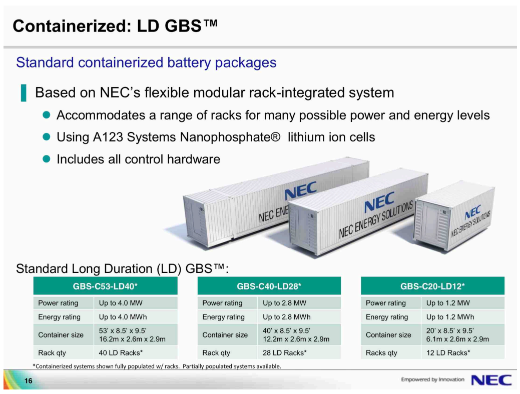

GSS™
Three major functional components
GSS™ (Grid Storage Solution)
Operator
AEROS™ Controls
GBS™
(Grid Battery System)
Power Conversion System
DC power (MW)
AC power (MVA)
Grid
Cooling
Cooling
14
Empowered by Innovation NEC


Flexible Product Architecture
Flexibility in Power:
Flexibility in Energy:
Scalability:
Choose PCS Size
Select Number of Racks
Add Grid Battery Systems
- or -
HR Rack
LD Rack
4MW
2MW
1MW
400kW
200kW
100kW
15
Empowered by Innovation NEC


Containerized: LD GBS™
Standard containerized battery packages
Based on NEC's flexible modular rack-integrated system
Accommodates a range of racks for many possible power and energy levels
Using A123 Systems Nanophosphate® lithium ion cells
Includes all control hardware
NEC ENERGY SOLUTIONS
Standard Long Duration (LD) GBS™:
GBS-C53-LD40*
Power rating Up to 4.0 MW
Energy rating Up to 4.0 MWh
Container size 53' x 8.5' x 9.5' 16.2m x 2.6m x 2.9m
Rack qty 40 LD Racks*
GBS-C40-LD28*
Power rating Up to 2.8 MW
Energy rating Up to 2.8 MWh
Container size 40' x 8.5' x 9.5' 12.2m x 2.6m x 2.9m
Rack qty 28 LD Racks*
GBS-C20-LD12*
Power rating Up to 1.2 MW
Energy rating Up to 1.2 MWh
Container size 20' x 8.5' x 9.5' 6.1m x 2.6m x 2.9m
Racks qty 12 LD Racks*
*Containerized systems shown fully populated w/ racks. Partially populated systems available.
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Containerized: HR GBS™

Standard containerized battery packages

- Based on NEC's flexible modular rack-integrated system
  - Includes all control hardware
  - Based on A123 Systems Nanophosphate® lithium ion
  - Standard High Rate (HR) GBS:

GBS-C53-HR20*	
Power rating	2.0 MW
Energy rating	575*kWh
Container size	53' x 8.5' x 9.5' 16.2m x 2.6m x 2.9m
Rack qty	Up to 20 HR Racks*
Integrated Fire Suppression	Included

*Containerized systems shown populated w/ 18 racks. Other rack quantities available . Capacity directly correlates with rack content. Power capability may be limited below 16 racks

Utility-scale grid energy storage

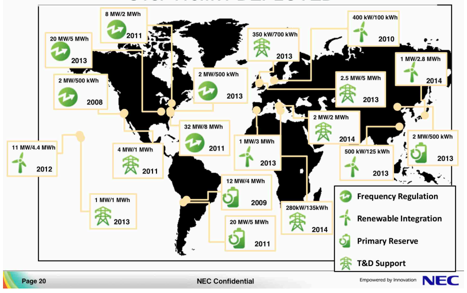
CASE STUDY

系統用蓄電システムの主要サービス・アプリケーション（米国の例）

サービス・アプリケーション名		概要
Bulk Energy Services		
	Peak shaving / Time shifting	消費ピーク時の電力を，余剰時に蓄えた電力で補う。再エネが発電した余剰電力を蓄えて、需要増大時に利用。
	Electric supply capacity	電力卸市場にて有利な調達再販を行うための貯蔵力。容量市場で適用。
Ancillary Services		
	Primary reserve/Spinning reserve	既存発電所の1次調整予備力(通常3-5%)を代替し、発電量と発電効率の最大化を図る。
	Frequency & voltage regulation	系統周波数・電圧変動の分単位補正。既設発電所に設置される場合はPrimary reserveで包含。調整市場で適用。
	Renewable ramp management	風力、太陽光発電の出力変動率を指定の範囲内に抑制する。
	Black start	停電等による電源喪失時に変電所配下のターゲット負荷に対して電力を供給する。
Transmission & Distribution Support		
	T&D deferral	送配電網の設備増強を延期するためのリソース支援

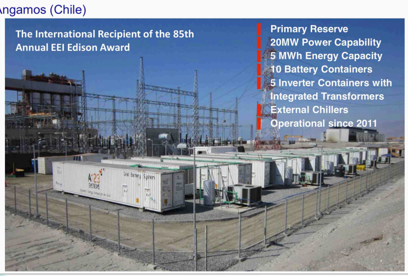
NEC Energy Solutions GSS™ Deployments Around the World

Over 110MW DEPLOYED



20MW/5MWh GSS™

Angamos (Chile)



32MW/8MWh GSS™

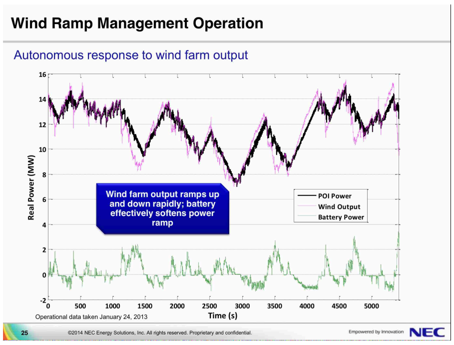
Laurel Mountain, WV

Auwahi project

- 21MW wind farm located in Hawaii on the island of Maui
- Interconnection requires wind farm output to be steady
- Change in wind farm output must be less than 1MW/minute

11MW/4.4MWh GSS™

Maui, HI


Wind Ramp Management Operation
Autonomous response to wind farm output
Real Power (MW)
16
14
12
10
8
6
4
2
0
-2
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time (s)
Wind farm output ramps up and down rapidly; battery effectively softens power ramp
POI Power
Wind Output
Battery Power
Operational data taken January 24, 2013
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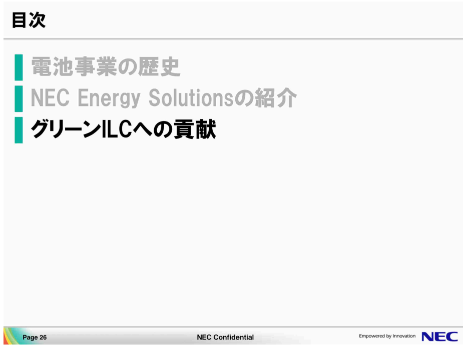
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電池事業の歴史
NEC Energy Solutionsの紹介
グリーンILCへの貢献
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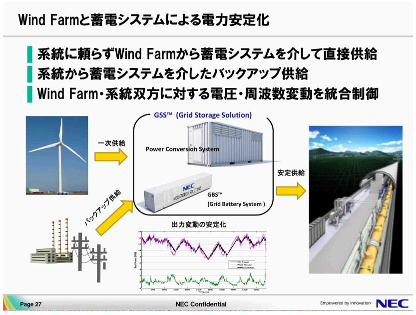
Wind Farmと蓄電システムによる電力安定化
系統に頼らずWind Farmから蓄電システムを介して直接供給
系統から蓄電システムを介したバックアップ供給
Wind Farm・系統双方に対する電圧・周波数変動を統合制御
GSS™ (Grid Storage Solution)
一次供給
Power Conversion System
安定供給
GBS™
(Grid Battery System)
バックアップ供給
出力変動の安定化
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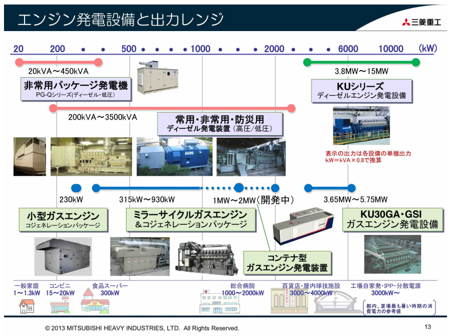
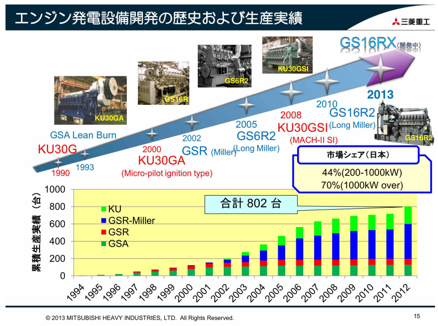
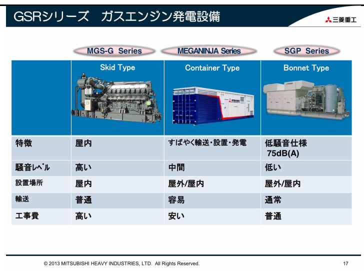
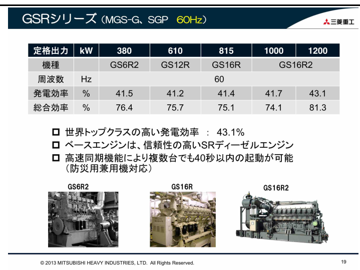
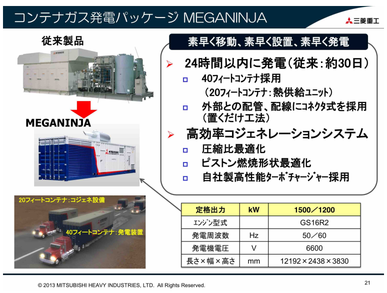
Introduction of high efficiency co-generation system using Gas-Engine (Ryusuke Osaki, MHI)

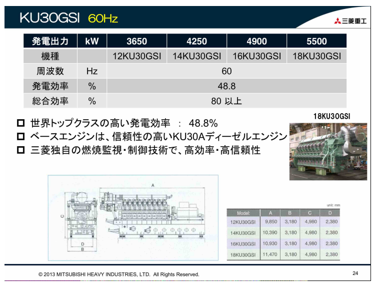




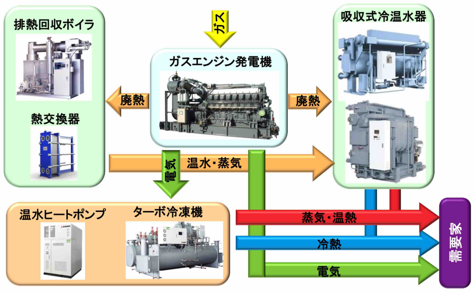








コジェネレーションシステムに使用される機器



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エネルギーソリューションの紹介

- 電力会社の系統の停電(瞬停)対策
- 電力会社からの節電要請(15%低減)対策
(将来の電力確保の保証)
- エネルギーコスト(電気代・燃料代など)セーブ
- 排熱の有効利用
- 既存の自家発電設備を最新鋭機に更新
- 全世界のCO2削減への寄与

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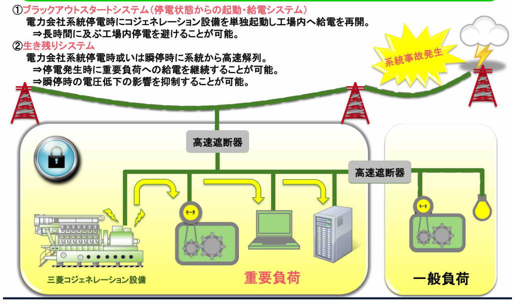
電力会社の系統の停電(瞬停)対策

電源セキュリティーの向上

①ブラックアウトスタートシステム(停電状態からの起動・給電システム)
電力会社系統停電時にコジェネレーション設備を単独起動し工場内へ給電を再開。
⇒長時間に及ぶ工場内停電を避けることが可能。
②生き残りシステム
電力会社系統停電時或いは瞬停時に系統から高速解列。
⇒停電発生時に重要負荷への給電を継続することが可能。
⇒瞬停時の電圧低下の影響を抑制することが可能。



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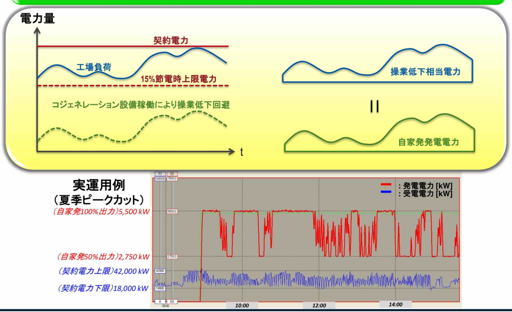
電力会社からの節電要請(15%低減)対策

電力会社からの節電要請による操業低下を解決します。



 30

エネルギーコスト(電気代・燃料代など)セーブ

排熱の有効利用によりガスエネルギーを最大限に活用でき, コストセーブに寄与します。

KU30GSIガスエンジンの一例を示します。

型式：18KU30GSI		発電効率仕様 50 Hz	発電効率仕様 60 Hz	備考
NOx排出濃度	ppm	320 (200*4)		O_2=0%換算時
燃料ガス消費量*1	m^3(N)/h	1,045	1,000	
(LHV)	kJ/m^3(N)	40,630	40,600	
発電端出力	kW	5,750	5,500	
蒸気量	kg/h	2,590	2,390	0.78 MPaG, 飽和蒸気, 給水温度60℃
高温水	m^3/h	303	290	83→88℃
低温水	m^3/h	16.2	15.5	20→60℃

注記) *1：ISO3046準拠(+5%裕度) 及び弊社標準ガス性状によります。発電機効率97%, エンジン付潤滑油ポンプ搭載時の効率です。
*2：エンジン付潤滑油ポンプの駆動動力を除いた場合の効率です。 *3：入熱は発電効率を48.8%として計算しております。
*4：200ppm仕様にも対応可能。効率が表記と異なります。

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排熱の有効利用

排熱有効利用の可能性は多岐に渡ります。

蒸気
- ORCタービン(ガスエンジンコンバインド発電)
- 蒸気タービン(ガスエンジンコンバインド発電)
- 蒸気吸収式冷凍機(冷水)
- アンモニア吸収式冷凍機(冷凍)
- デシカント空調機(除湿空調)
- 減容装置・乾燥機(汚泥乾燥等)
- 蒸気コンプレッサ(圧縮空気)
- 蒸気ヒーティング(暖房, 重油ヒーティング等)
- プロセス蒸気(洗浄, 殺菌等)

排ガス
- ORCタービン(ガスエンジンコンバインド発電)
- 排ガスボイラ(蒸気)
- 排ガス吸収式冷凍機(冷水)
- アルカリ排水処理装置(アルカリ性廃液中和)

温水
- 温水吸収式冷凍機(冷水)
- デシカント空調機(除湿空調)
- 減容装置・乾燥機(汚泥乾燥等)
- 温水ヒーティング(暖房)
- プロセス温水(洗浄, 殺菌等)

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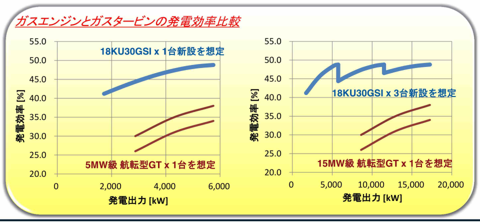
既存の自家発電設備を最新鋭機に更新

老朽化した既設GTをガスエンジンへ更新される例が多く見られます。

ガスエンジン　:電気需要の多いお客様
ガスタービン　:熱需要の多いお客様

という選択が一般的でしたが, 最近は構内の熱需要比を電気側へとシフトする傾向が見られます。

ガスエンジンとガスタービンの発電効率比較



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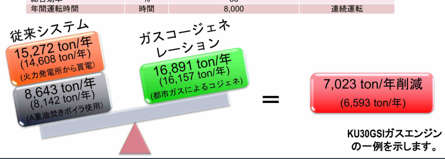
全世界のCO2削減への寄与

CO_2削減量の試算例

試算条件　()内は60Hz地区の数値を示す。

	単位	数値	備考
ガスエンジン導入台数	台	1	
ガスエンジン型式	-	MACH 18KU30GSI	
発電効率	%	48.8	ISO3046条件, 裕度：+5%
定格出力	kW	5,750 (5,500)	
排熱回収			
- 蒸気回収	kW	1,815 (1,673)	0.78MPaG, 飽和
- 高温水回収	kW	1,763 (1,686)	88℃
- 低温水回収	kW	753 (720)	60℃
- 排熱回収合計	kW	4,330 (4,079)	
総合効率	%	85	
年間運転時間	時間	8,000	連続運転



KU30GSIガスエンジンの一例を示します。

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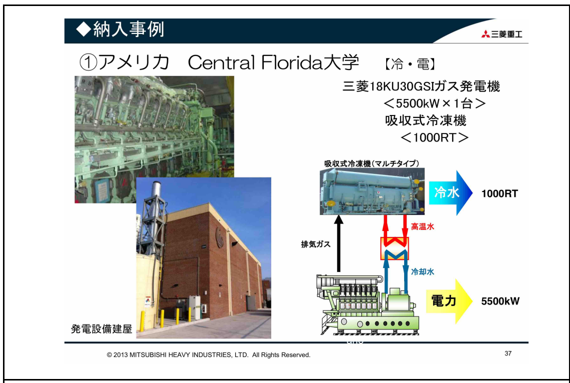
◆納入事例
①アメリカ　Central Florida大学　【冷・電】
三菱18KU30GSIガス発電機
＜5500kW×1台＞
吸収式冷凍機
＜1000RT＞
吸収式冷凍機（マルチタイプ）
冷水
1000RT
高温水
排気ガス
冷却水
電力
5500kW
発電設備建屋
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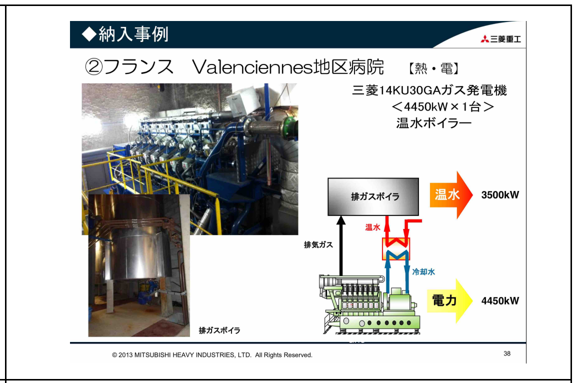
◆納入事例
②フランス　Valenciennes地区病院　【熱・電】
三菱14KU30GAガス発電機
＜4450kW×1台＞
温水ボイラー
排ガスボイラ
温水
3500kW
温水
排ガス
冷却水
電力
4450kW
排ガスボイラ
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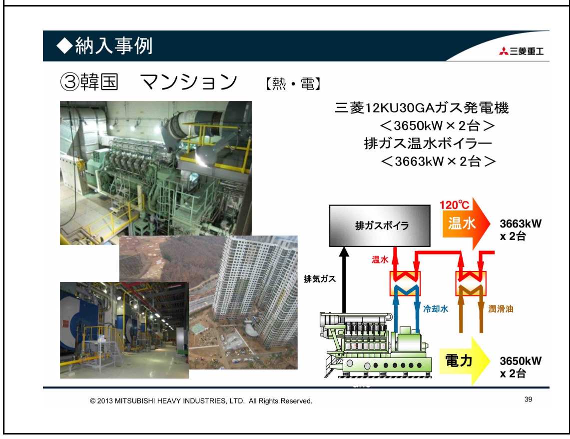
◆納入事例
③韓国　マンション　【熱・電】
三菱12KU30GAガス発電機
＜3650kW×2台＞
排ガス温水ボイラー
＜3663kW×2台＞
排ガスボイラ
120℃
温水
3663kW
x 2台
温水
排気ガス
冷却水
潤滑油
電力
3650kW
x 2台
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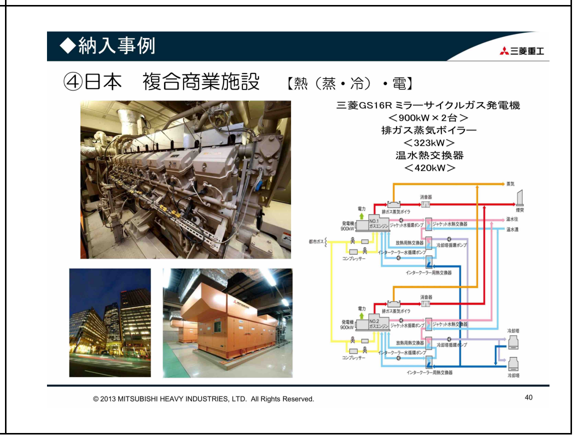
◆納入事例
④日本　複合商業施設　【熱（蒸・冷）・電】
三菱GS16R ミラーサイクルガス発電機
＜900kW×2台＞
排ガス蒸気ボイラー
＜323kW＞
温水熱交換器
＜420kW＞
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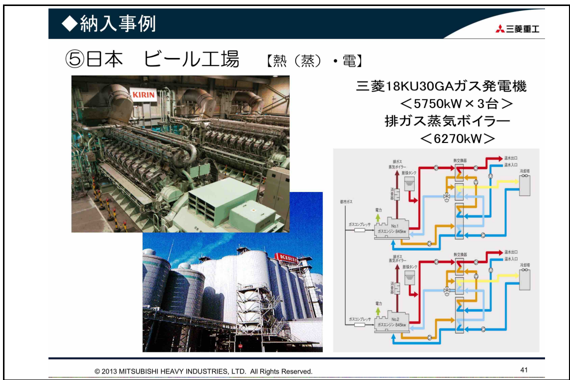
◆納入事例
⑤日本　ビール工場　【熱（蒸）・電】
三菱18KU30GAガス発電機
＜5750kW×3台＞
排ガス蒸気ボイラー
＜6270kW＞
KIRIN
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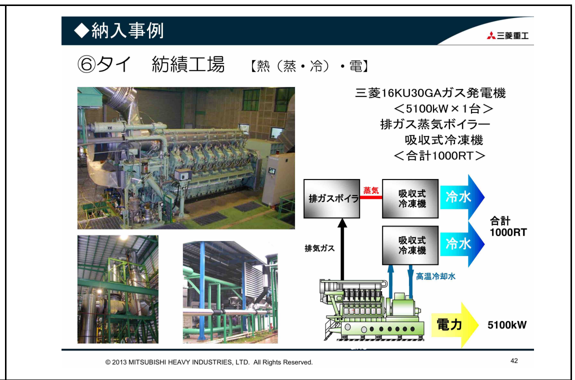
◆納入事例
⑥タイ　紡績工場　【熱（蒸・冷）・電】
三菱16KU30GAガス発電機
＜5100kW×1台＞
排ガス蒸気ボイラー
吸収式冷凍機
＜合計1000RT＞
排ガスボイラ
蒸気
吸収式冷凍機
冷水
合計
1000RT
排気ガス
吸収式冷凍機
冷水
高温冷却水
電力
5100kW
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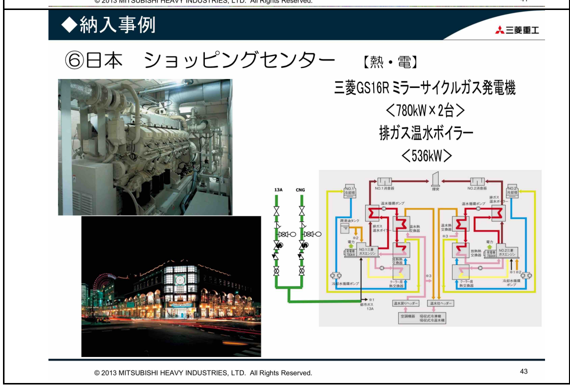
◆納入事例
⑥日本　ショッピングセンター　【熱・電】
三菱GS16R ミラーサイクルガス発電機
＜780kW×2台＞
排ガス温水ボイラー
＜536kW＞
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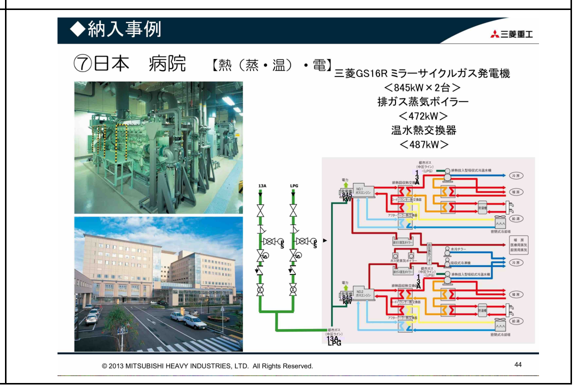
◆納入事例
⑦日本　病院　【熱（蒸・温）・電】
三菱GS16R ミラーサイクルガス発電機
＜845kW×2台＞
排ガス蒸気ボイラー
＜472kW＞
温水熱交換器
＜487kW＞
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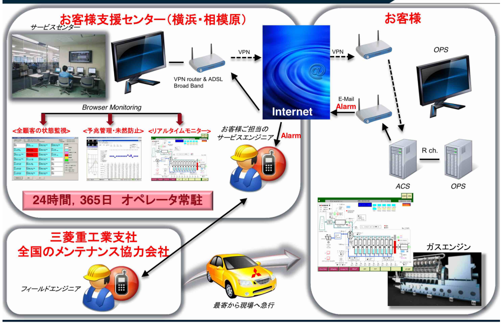
アフターサービス（遠隔監視・支援システム）



三菱ガスコージェネレーション導入メリット　まとめ

今後の情勢　⇒コージェネ導入メリットが増加する方向に推移

- 原子力発電の再稼動がなかなか進まない現状にあり，電気料金は上昇傾向。
- 日本のLNG購入価格は，現状では米国の約5倍，欧州の約3倍。
  シェールガス革命等の影響により，2016年頃を境にガス料金は低下の見通し。
  （現状の2/3が妥当なレベル）

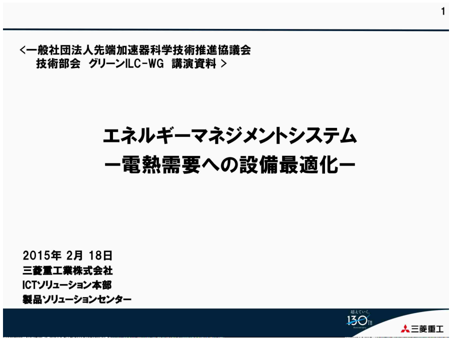
三菱ガスコージェネ導入のメリット

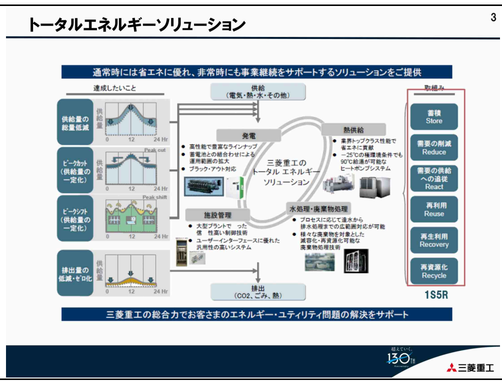
- 電力会社の系統の停電（瞬停）時でも単独運転にて重要負荷への電力供給が可能。
  （自社製制御装置により，電力製制御ニーズに合わせお客様毎の最適設計が可能）
- 節電要請を受けても操業への影響を最大限緩和可能。（安定電力の確保）
- 世界最高レベルの発電効率及び総合効率でコージェネメリット創出
- CO_2排出量の削減に寄与（CSR向上に寄与）
- 豊富な経験・実績，確かな技術に裏付けられた高信頼性で安定運用を約束します。
- 優れた機動性
  - KU30GSI：起動から5分以内に100%負荷到達。（同クラス世界最速）
  - GSR：複数台でも40秒以内に起動可能。（防災兼用対応）

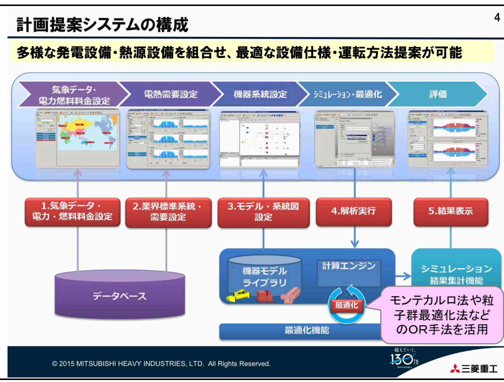
その他

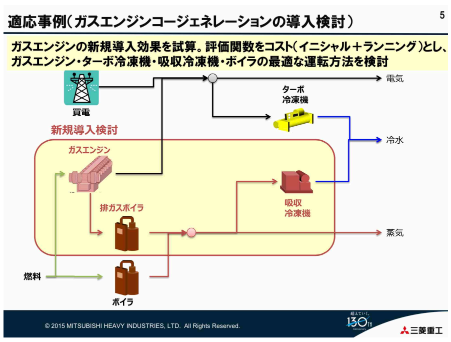
- 補助金制度利用により初期投資の低減が可能。
- 電力自由化により，余剰電力の売電も可能。

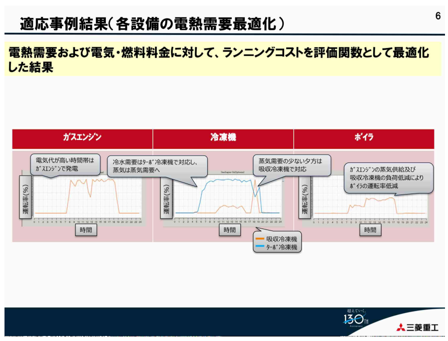
Energy Management System
(Manabu Miyamoto, MHI)

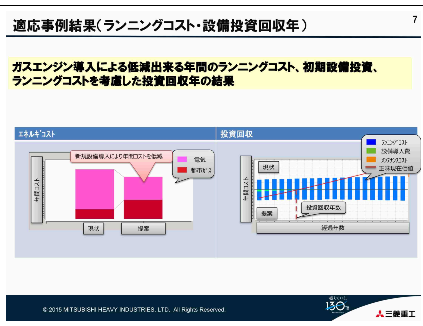


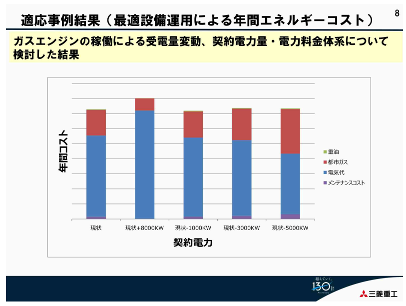













三菱重工
この星に、たしかな未来を

6 Installation of Renewable Energy into Accelerator

Examples of New Energy Power Plants for the Green ILC

(Tadashi Fujinawa, Riken)

1.Abstract

Construction of the International Linear Collider (ILC) in Japan will soon begin. This facility will be very large, so it will also consume considerable energy. It will operate continuously for 7,000hours per year. Thus, it is necessary not only to consider how to save energy, but also to introduce new kinds of energy, including renewable energy, for use in the ILC.

The government declared that renewable energy should account for between 23% and 25% of all electrical energy sources in 2030. However, renewable energy sources currently provide only 10% of all energy. A large portion of those sources are hydro-powered, but no suitable locations for additional hydro-power generation remain.

In this paper, forms of renewable energy that could be developed for ILC use will be described, namely, solar energy, wind energy, geothermal energy, hydraulic energy, biomass, and thermal energy obtained from a temperature difference or thermal recovery.

2.Solar cells (photo-voltaic systems: PV systems)

Solar power stations are among the easiest renewable energy systems to build, in contrast to wind power generators and geothermal power stations. However, PV systems are not reliable or stable power sources.

In this paper, we will discuss the solar park for the Green ILC (design date supplied by UNISUN JAPAN). The AC output capacity will be 200MW, and the DC capacity at installation will be 220MW. A similar plant is shown in Fig. 1.

The inverter will be a TMEIC 1500kW (750kW x 2)/unit. TMEIC has the largest market share in Japan at more than 70%, as well as more than half of the global share.

The output voltage will be 22kV, and the solar panels will each generate 265W.

A one (1) MW solar power station requires 15,000m^2 of land. The basic design is as follows.

Fig. 1 One of the largest solar plants, generating 145MW (Germany) and presented by UNISUN JAPAN.

Required land area: 15,000m^2/MW x 220MW = 33,000,000m^2 (3,300ha). This area corresponds to dimensions of 150m × 22,000m and does not include the 22kV/154kV substation and control building.

Array design: 23 panels/string, 6.095kW/string

Solar panel quantity: 220,000kW ÷ 6.095kW/string = 36,095 strings

36,095 strings × 23 panels/string = 830,185 panels (219,999kW)

In the subsequent discussion, the following symbols are used: V_{oc} (open circuit voltage), V_{mp} (maximum peak voltage), I_{sc}/A (short-circuit current), and I_{mp}/A (maximum peak current).

The reasons for choosing 23 panels/string are as follows, considering that we will use a JA solar JAM6 (BK) 60-265/SI, which has V_{oc} = 38.3V at 25°C and V_{ppm} = 31.1V at °C. In the case of 23 series, 984.7V < V_{oc} < 1000V at -10 °C and 554.2V > V_{ppm} > 540V at

80°C.

3,960 panels ÷ 23 panels/string = 172 strings

172 strings × 9A (I_{sc}/A) = 1,548A

1,548A ÷ 16 feeders = 96.75A/feeder

Please refer to page 6 of the GO-A5ES-2014-001-A specifications.

The rated current of the power fuse is 160A, and the recommended current is 102A (160 ÷ 1.25 ÷ 1.25 = 102A), according to NEC690.8 (US electrical STD).

97A < 102A

The actual current is 11 parallel/box × 15 array boxes + 7 parallel/box = 16 incoming for one 750kW inverter.

∴ 11 × 9A = 99A

99A < 102A

The required number of inverters is as follows: 200MW ÷ 1.5MW/inverter = 133 inverters.

Local governments will be essential in building such immense solar parks. These power stations should be built on the ILC grounds by a business partnership, and the land should be supplied by the government for this enterprise. The company will pay taxes as well. In case the land is farmland or is protected forest by law, the local government will provide the necessary documentation and change the land category so that the power station can be built.

All of the generated power will be consumed by the ILC, and therefore no transmission capacity issues will occur. Tohoku-epco claimed that solar power will overflow sooner or later; however, their estimate assumed that all solar parks approved by the Ministry of Economy, Trade and Industry (METI) would generate power.

All of the nuclear power stations (NPSs) shown in Table 1 are operable. METI estimates that only 40% of approved solar parks will actually be commissioned, while the other 60% will be given up for some reason. The NPSs in Table 1 are all boiling water reactors (BWRs), which is same type of NPS as the Fukushima Daiichi NPS. Furthermore, some of them are very old, and therefore it would be quite unlikely for them all to be simultaneously operable before they are decommissioned. Thus, it can be concluded that Tohoku-epco's concern is needless.

The key is that local governmental support is necessary for this type of renewable energy system to be implemented. The land should be free, not only that used for the ILC main body, but also that for the Green ILC power stations. The government will perform all necessary legal work, such as changing forest land or farmland to miscellaneous lands.

As mentioned previously, there are no transmission capacity issues since the ILC will consume all of the generated power.

STEP3：検討断面における出力の想定：原子力 NPS

p 6

安定供給のためには，ベースロード電源を一定量確保することが必要

↓

長期的な傾向を反映することとし，震災前過去30年（30年経過していない場合は運転開始後の全期間）［昭和56年度～平成22年度］の設備利用率平均を用いる 30 years capacity factor (CF) as average

Nuclear Power Station	
Available Capacity 供給力（10 MW）	※ 234．9
Installed Capacity 設備容量（10 MW）	389．3
Capacity Factor (CF) 利用率（%）	69．8

※ 福島第二は，東京電力の「新・総合特別事業計画」においても今後の扱いは未定としており，地元のご意向も踏まえて，接続可能量を算定する供給力には織り込んでいない。
仮に稼働した場合には，連系線に新たな南向き空き容量を確保できるため，その分を活用すれば，接続可能量には影響しない。 Fukushima Daini #3 & 4 are not include the capacity.

設備一覧［受電分］（10 MW）		
東通	57．0	Higashidori
女川1	52．4	Onagawa
女川2	82．5	
女川3	42．8	
柏崎刈羽1	52．6	Kashiwazaki Kariha
東海第二	21．1	Toukai Daini
大間	28．1	Ohma
福島第二3	26．4	Fukushima Daini #3
福島第二4	26．4	

Table 1. Nuclear power stations related to Tohoku-epco.

Concerning the economics, the feed-in tariff (FIT) price for solar power will be ¥27/kWh after June in FY2015. The FIT price has decreased from ¥42 in 2012 to ¥36 in 2013, ¥32 in 2014, and ¥29 until the end of June this year, after which it will be ¥27/kWh. In this paper, we will assume ¥20/kWh as the FIT price. The sunshine time in Iwate Prefecture is 1,888h/year, corresponding to a power generation of 234,110 MWh/year and an output price of 4.7 billion ¥/year. The Green ILC utility company will sell all of the power to Tohoku-epco, and about 10% of the income will be donated to the ILC. After the FIT has been paid off, control of the power plant will be transferred to the ILC, and thereafter, the ILC will be able to obtain free electricity for about 1,250 h/year.

The other government support requested of the METI Sendai office is that the licensed electrical engineer will maintain both the ILC and the Green ILC. Since the Fukushima Daiichi NPS disaster, there has been a heavy shortage of licensed electrical engineers.

3.Wind power generation

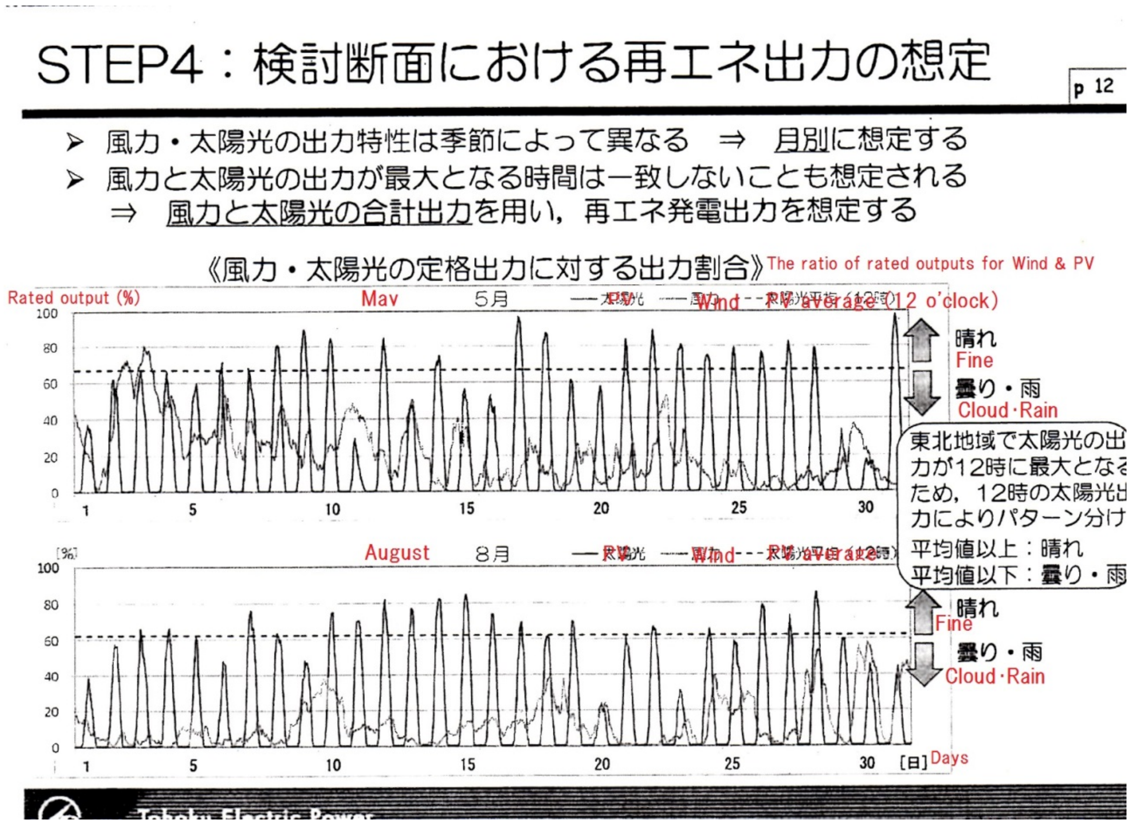
In the early stages of Japanese wind power generation, power stations were constructed by local governments with imported turbines. However, they did not well endure Japanese weather, and almost all were retired. The Japanese weather phenomena and problems that affect wind power are as follows.

1) The direction of the wind changes many times per day. For example, there may be sea breezes in the morning and mountain winds in the evening. Furthermore, mountain sides have irregular air flows.
2) Wind power generation requires an average wind speed of 6.5m/s. It is quite difficult for humans to live in locations that meet this requirement, so no access roads or transmission lines are available. Thus, utility costs will be high without a generator system. For instance, the Chiba Marine field is famous for its strong winds, and this baseball park has the only wind speed meter in Japan. However, the strong winds that are present at the ball park are not usable for power generations, as the winds that are defined as strong at this location only measure 3–4 m/s according to the wind speed meter. Figure 2 shows the Chiba Lotte Marines field.

Fig. 2 Home ground of Chiba Lotte Marines (QVC Marine field)

3) If people live nearby, low-frequency noise must be considered.
4) Typhoons and/or tornados generate winds over the design speed.
5) In Japan, thunderstorms occur more often than they do in other nations, and lightning may hit the turbine blades.
6) The center line of a turbine shaft is located very high (50–100m), making it difficult to maintain and repair.
7) Assessments of bird strikes and other environment factors take time (more than three years). Thus, it is difficult to judge whether or not to invest.

Even though there are many difficulties involved in wind power station construction, if locations are available that will yield more than 2MW/unit of power generation and if there is strong support from the local government, it is possible to build such stations. In addition, the FIT of ¥22/kWh will be maintained for 20 years, and according to Tohoku-epco, the peak power times of solar and wind power are different (Graph 1), so both generation systems can use same transmission lines and same locations. Thus, if a 200MW solar park is constructed at the ILC, then 72MW of wind power can be generated also. In this case, one generator unit would yield 6MW, which would be the greatest power generation in the world for a single unit. A total of 12 generator units will be located at the north end of the solar park. It is recommended that the local government study the average and maximum wind speeds at the ILC.



Graph 1. Peak output of solar cell and wind power generation reported by Tohoku-epco.

4.Geothermal power generation

Tohoku-epco and Toshiba explained geothermal power generation in another section of the Green ILC. Please refer to the above documents.

The Ministry of the Environment reported that the potential geothermal power generation is 33,100MW, while the recoverable amount is 14,200MW. This power is 17 times higher than that consumed by the ILC.

The author studied geothermal power generation at Japan Metals and Chemicals Co. Ltd. in Iwate Prefecture as a student 50 years ago. This company has more than 50 years of engineering knowledge and experience related to geothermal power generation.

The geothermal power generation capacity is 100MW in Iwate Prefecture, which is the second largest capacity in Japan. If an additional 100MW of geothermal energy were generated in Iwate, all of the power consumed by the ILC would be provided.

In addition, Japanese geothermal power generation manufacturers are very productive and get 70% of market share of the world. MHI (Fig. 3), Toshiba, and Fuji Electric always compete with one another to be the world’s most productive geothermal power manufacturer.

Fig. 3 From MHI Graphic.

5. Hydro-power generation

Hydro-power will be generated at the base load authorized by METI. However, water rights issues appeared when the construction plan was proposed. Thus, local government support will be required.

Here we present the calculations of the energy generated by a 1MW solar power station and the requirements necessary to generate the same amount of energy hydraulically.

The energy generated by a 1MW solar power station is as follows:

1MW × 1,800h/year (insolation time) × 0.6 (ratio of sunshine: from sunrise to sunset) = 1.08GWh.

The construction cost is ¥200,000/kW (for the solar cells only), yielding a total cost of ¥200,000,000.

To achieve the same output by hydro-power:

1.08GWh ÷ 24h/day ÷ 365 days/year = 123kW

The hydro-power generation *P* for a drop *H* and water volume *Q* is given by:

P (kW) = 9.8 × H (m) × Q (m^3/s)

In order to achieve 123kW of power generation, if Q = 1 m^3, then H will be 12.6m:

123kW = 9.8 × 12.6m × 1m^3/s.

Considering the efficiencies of turbines and generators, *H* should be about 14 m. The FIT price will be ¥34/kWh for 20 years (assuming a total output of not more than 200 kW), yielding a total income of ¥732,686,400 over 20 years. Hitachi and Toshiba also have catalogs of mine hydro-power.

6. Biomass power generation

MHI developed a biomass plant at the Koiwai ranch in Iwate Prefecture that uses methane gas from dung as fuel (Appendix 1). In addition, MHI and Hakutsuru Japanese Sake Brewing Industry Ltd. are researching how to produce liquid fuel from straws (Appendix 2).

In Japan, biomass generation is currently difficult economically; however, after the commissioning of the ILC, an international scientific project will be operational that will require a sewage treatment plant. Methane gas from this sewage treatment plant could be used as power-generator fuel. Biomass power centers can also produce fertilizer from sludge by using engine waste heat. The FIT for this system is ¥39/kWh for 20 years.

During construction, a great quantity of wooden boxes is generated as waste material. Similarly, forestry necessarily produces large amounts of wooden chips as waste. The best way to use these by-products is as raw material for the paper industry, and there are many paper factories in the Tohoku area. If they do not wish to receive these materials, the second option is to thermally recycle them. In this case, the waste would be used as fuel for boilers, turbines, and generators. This type of system is called a carbon-neutral power station. After construction, such a plant would be a waste-treatment plant for the city. The FIT for such as system ranges from ¥13/kWh to ¥20/kWh for 20 years.

7. Temperature-difference energy (waste heat recovery)

The author previously reported that the planned supply of waste heat from the Radioactive Isotope Beam Factory (RIBF) to the next-door 4th elementary school in Wako for heating in winter and for swimming pool temperature control was not working, demonstrating the difficultly of supplying energy outside.

Now we have a new technology, the binary turbine. Turbine systems are being introduced into the market by MHI and other companies. The energy sources will be RF power sources, He compressors, transformers, HVACs, and chillers for water-cooling systems. If the coolant outlet temperature is more than 60°C, and ideally as much as 80°C, electric power generation as well as waste heat recovery can be achieved. For this purpose, teams working on the accelerator and turbine should jointly consider and resolve the differences between the two arguments.

The 200MW electrical consumption of the ILC will be released as heat. If half of that amount can be controlled as waste heat and if the binary turbine system has an efficiency of 40%, the power generated by the turbine system will be 40MW, which is same as the consumption of the ILC control building. Furthermore, this amount is twice as high as RIKEN Wako campus's peak consumption from the utility company, Tokyo Electric Power Corporation (TEPCO).

8. Conclusion

The renewable energy sources that can be used in the ILC were explained in this paper. New energy plants cannot be established independently; they require support by local governments and/or utility companies. Without this support, it would be nearly impossible to build the Green ILC in addition to the ILC itself.

Only temperature-difference energy can be controlled by the team at the ILC, but the necessary system is one of most difficult to establish, as reconsideration of the decisions made by the accelerator builders would be required.

Nevertheless, there are numerous energy sources that could be implemented at the Green ILC. Therefore, only the selection of the preferred energy sources and concentration are necessary to realize the Green ILC.

9. Appendix

1) Mitsubishi heavy industry graph No.170 2013.1

2) Mitsubishi heavy industry graph No.163 2011.

Power saving and use of New Energy at Riken RI Beam factory

(Tadashi Fujinawa, Riken)

1 Introduction

RI Beam Factory (following RIBF) of RIKEN Nishina Center for Accelerator-Based Science (hereinafter RNC) is a heavy ion cyclotron of the top in the world, was commissioned three months earlier than expected in December 2006, the superconducting ring cyclotron (hereinafter SRC) succeeded the initial beam extraction, then, a lot of the research results has been continued to report in various fields.
This time, in the WG of Green ILC where we consider energy saving and new energy, the efforts for the RIKEN of advanced energy-saving technologies are reported, such as the world's first combined heat and power system (CGS) installed in accelerator facility.

2 Co-Generation System

For the introduction of CGS, environmental measures are the largest purpose, as well as Green ILC. When we explained the RIBF plan in RIKEN of the Board, we received a proposition, as physicist, to think something contribution to make "world best accelerator facilities, which, of course, it is specialty of RIKEN accelerator, however, while an accelerator uses electricity and water as if we use public water, something ecology in accelerator, considering about the Kyoto Protocol has been studied." And we, studied various new energy, and concluded that CGS (also referred to as cogeneration) with the introduction of the gas turbine generator (GTG) as the main engine is the best in the RIBF.

In this method, by supplying electricity and heat at the same time, efficiency is greatly improved compared with the supply of electrical only or heat only. The GTG body is shown in Figure 1. Figure 2 photo shows periodic inspections. Figure 3 shows a flow diagram of CGS.

Figure 1 GTG body, and the right side is the compressor, left turbine

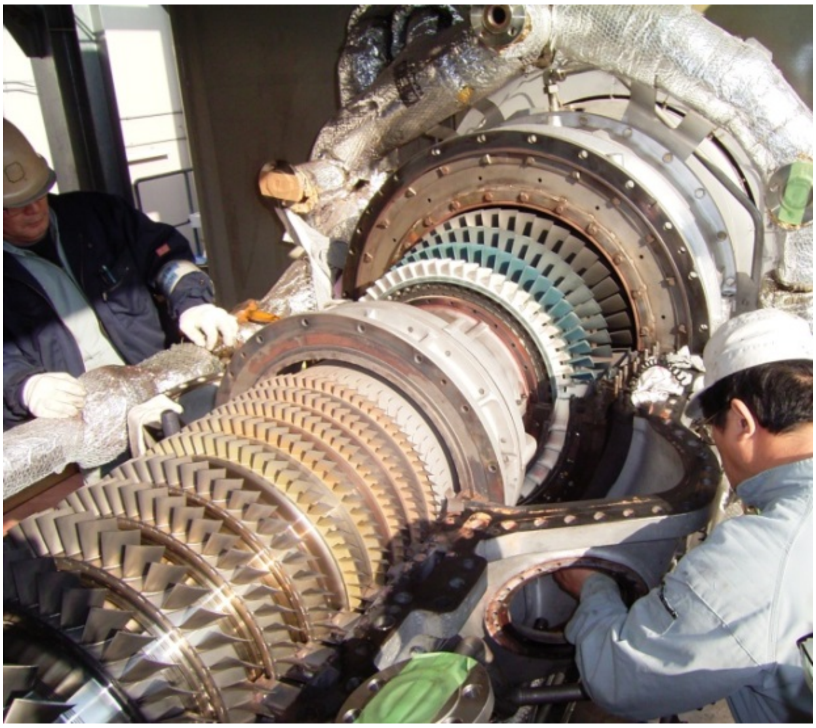


Figure 2 during annual inspection, the front is the compressor, rear is turbine

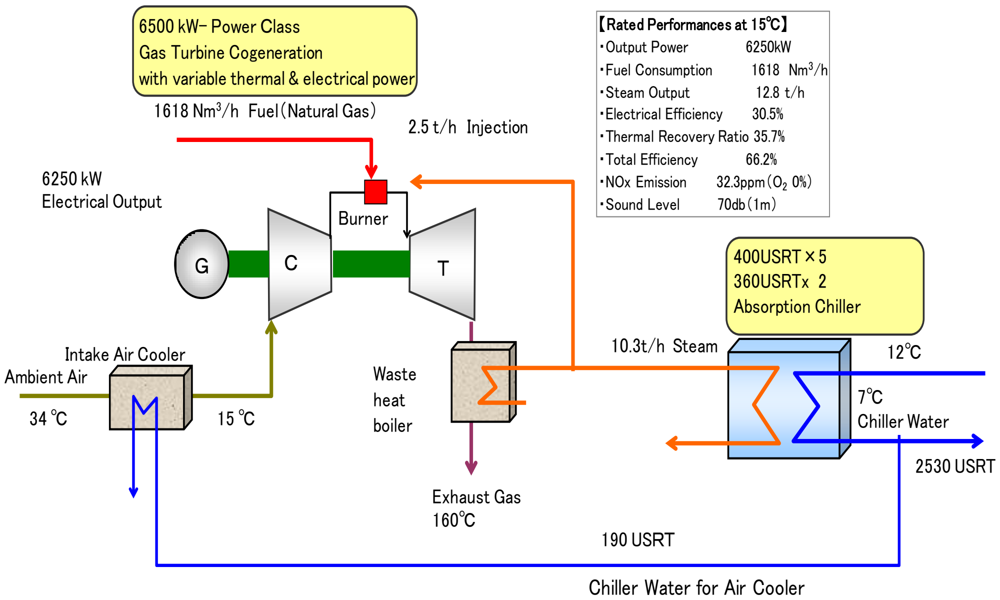


Figure 3 G is the generator, C shows the air compressor and a turbine, by generating saturated steam in the waste heat boiler, making it as a heat source of the absorption chiller cooling to make a cold water of 7℃, for the building cooling and the accelerator facility cooling, and is used for the intake-air cooling of the CGS.

This equipment has been introduced as an environmental measure, that is, as a response to the Kyoto Protocol as RIKEN. In fact, it also plays very important role into a function of accelerator facility as a large uninterruptible power supply at the same time.

CGS is using natural gas supplied from the Tokyo gas as fuel, the output of the generator is introduced and consumed in the RNC and the commercial lines of the Tokyo Electric Power Company (TEPCO) in parallel. If a problem in CGS has occurred, power is supplied to all of the accelerator from TEPCO uninterruptible.

If the instantaneous voltage drops (voltage sag) or power failure occurs in TEPCO, CGS disconnect the commercial line within one cycle, CGS provides power only to the critical loads such as helium refrigerator.

We believe that it is previous special situation to drive the accelerator, if the supply of TEPCO and Tokyo Gas will be disabled at the same time.

It should be noted that, for the power shortage due to the Fukushima Daiichi nuclear power plant accident in 2011, RIKEN CGS contributed to power supply to perform continuous operation until the end of the year.

For more information, accompanying CGS, you should refer the article in "accelerator" Vol.8, No.1, 2011(18-25) and "consideration of the large accelerator facilities for combined heat and power device as an uninterruptible power supply - RIKEN CGS-" [1].

For English article should be referred to a Proceedings[2] of ARW2013 and "RIKEN Accelerator Progress Report 36. (2003) ", "Cogeneration system for RI Beam Factory[3] ", Report 37 (2004) CGS operation[4].

Finally, as for the environmental effect, maximum efficiency is proud of the 68%, because the generator is located directly above the accelerator, there is no transmission loss. Natural gas is a very clean fuel compared to coal and oil. CGS absorption refrigerator is different from the typical refrigerator to repeat the compression-expansion by using a motor, there is an advantage of not using any ozone-depleting gas or greenhouse gases.

3. Energy saving and environment effect other than the CGS

It was already mentioned that minimization of transmission loss by placing the CGS just above the accelerator facilities. For commercial lines from TEPCO, the second special high voltage substation (the second extra-high voltage) was constructed at the top of the accelerator building, connected the 66kV underground line by the full-length 750 m from the first extra-high voltage substation in order to reduce the transmission loss. In the first floor basement, place the power supply room 2 to transform the high voltage (6.6kV) to low voltage (415, 220, 110V), further down below the power room 1 which houses the accelerator power was placed, in the next to the power room 1 the accelerator was arranged, in this way, the cable length was minimized.

In addition, high-voltage AC power supply of the experimental equipment SHARAQ (1MVA) and Rare-RI Ring (R3) 1.5MVA deployed to the accelerator room, with an effort to minimize the low-voltage cable length.

In the accelerator facilities, a lot of the electric motor in the cooling system being used, it is kept in mind the energy saving using a high efficiency electric motor actively.

It shows a photograph of a high-efficiency motor in Figure 4. Ordinary efficiency of the electric motor has a warship color in any manufacturer, gold color motor in the photo is made of Toshiba, a black color motor by Fuji Electric, they are descriptive.

Mitsubishi has two color motor, 31th US Navy warship color of GSI Creos Mr. HOBBY is high efficiency, 32th Japan Navy color (Yokosuka) is ordinary efficiency, to be difficult to determine the type. We suspect that there is a length of day advance in Toshiba and Fuji.

Figure 4 high-efficiency motors that are used in the cooling system (Toshiba)

Direct drive method was adopted for the motor start-up scheme considering helium compressor (315kW) as a main system, is a good start method for efficiency compared with the other start-up method (reactor, compared to Y- △ and inverter start-up).

High efficiency high/low voltage transformer is also adopted. Efficiency of the transformer are also advances year by year, the latest of a transformer for the RNC is the 99.4% of R3 (at rated 1.5MVA).

In addition, the transformer there is no worry of fire by using a dry-type transformers. As a result, carbon dioxide fire extinguishing equipment which has a risk of death is no longer needed. As harmonic voltage measures, we arranged the transformer alternately the winding △ - △ and the △ –Y, so as to obtain the same effect as three winding transformer. In CGS central control room, there is a harmonic monitoring device, and always shows the minimum value of the measurement limit. This is also that environment friendly design.

For more information, please refer to the English article [5) 6)].

4. New energy other not adopted

1) Solar cell: As the simplest new energy, solar power generation is raised. Since the energy density is low (a large area required), Wako of sunshine time is 1840 hours per year, even side-by-side solar cells on the existing Nishina Memorial Building roof, power generation capacity of about 40kW the maximum, there is unreasonable as the accelerator power. However, as a whole RIKEN, five places at the moment, we have total a 120kW of equipment. All generated power is a self-consumption, does not use fixed-price purchase system.

2) Wind power generation: suitable wind speed for wind power generation is 6 m per second, while average wind speed of Wako City is the 1 m. So it is not at all adapted.

3) Adsorption chillers: by changing the cooling water output temperature of the accelerator from 60 to 80℃, and making it as a heat source of the adsorption-type refrigerator, to give the cold water of 7℃ to be used for the air conditioning and cooling. As accelerator side, there is anxiety that the cooling water temperature is high, so we gave up.

4) Temperature difference energy[7)]: those are proposed in Wako City area new energy development committee, that waste heat of RIBF the (around 40℃), supplied to adjacent the Wako municipal fourth elementary school, for heating, hot water supply, and pool. It has been favorite proposal benefit to Wako areas as a result of the study over two years, however, a business entity did not appear, and did not reach to a realization, together with a problem of the education committee.

For more details, refer to the English documents.

5. Application to the ILC

High-efficiency equipment (electric motor, transformer, etc.) and so on, should be introduced for granted. It is necessary to note that it is slightly different even in the same high efficiency number by the manufacturer.

Next, as for the electric transmission and distribution, therefore it is very important and is described in a separate description. Please refer there.

Adsorption chillers with good improvement for performance in recent years, and worth considering because also possible to operate at a lower temperature.

CGS is an energy saving of the centerpiece of RIBF, but here it is necessary to pay attention.

The first, in planned construction site, there is no city gas, that is to lay the pressure pipe for CGS is required huge cost. In the case of RIKEN, because there was a medium pressure pipe next to the site of RIBF, so it was realized. Even if temporarily it is solved the problem of gas piping, because the ILC using 10 times the electricity of RIBF, by simply thinking, it requires 65MW of engine. For the gas engine it is too large, for the latest of composite power generation GTG it is too small.

Furthermore, absorption chiller which is key component of CGS has no noticeable progress in this more than 10 years. On the other hand, COP (Coefficient of Performance) of the motor drive refrigerators improving to 3 or more in the hot water supply, up to 6 or more in cooling, rather than a combined heat and power, combined cycle power generation (Combined Cycle; CC) can be used to convert to electricity, then to carry out the cooling and heating by the converted electricity. Those efficiency is good in the final end.

Temperature difference energy, it is to find a business entity who can build firstly with the investment.

6. Reference

1) "accelerator" Vol.8, No.1,2011 (18-25) record and consideration of the large accelerator facilities for combined heat and power device as an uninterruptible power supply - RIKEN RIBF of CGS-

2) ARW2013.Proceedings

3) RIKEN Accelerator Progress Report 36. (2003) Cogeneration system for RI Beam Factory

4) Report 37 (2004) CGS operation

5) WAO07. DESIGN, INSTALLATION, OPERATION AND MAINTENANCE OF ELECTRICAL POWER SUPPLY FOR RI BEAM FACTORY

6) RIKEN Accelerator Progress Report 46 (2013) AC power system for Rare-RI Ring.

7) New Energy Establishment Committee of Wako City District and RIBF; RIKEN Accelerator Progress Report

Solar Power
(Junichi Honda, Solar Power Association and Kyocera)

先端加速器科学技術推進協議会　技術部会
第2回AAA　グリーンILC・WG　会合

於；秋葉原UDXカンファレンス

太陽光発電について

―2030年、スマートカントリー日本を目指して―

第2回AAA グリーン - ILC WG 会合

2014年5月8日

一般社団法人　太陽光発電協会　幹事
京セラ株式会社　ソーラーエネルギー事業本部
主幹技師　本多潤一

Japan Photovoltaic Energy Association　1

内容

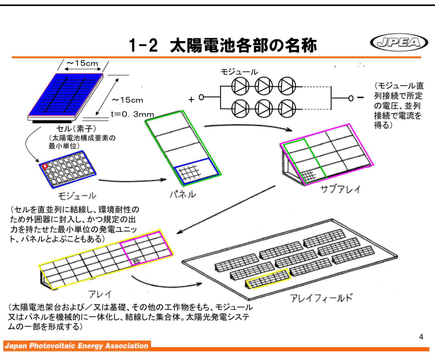
Japan Photovoltaic Energy Association　2

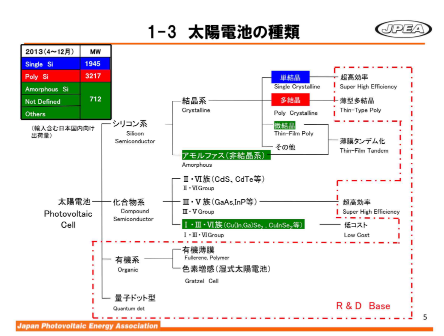
1-1　太陽電池の種類と特徴

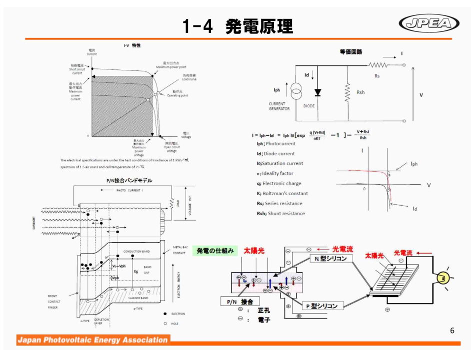
種類	シリコン（結晶系）				化合物
	結晶シリコン			薄膜シリコン	CIS（CIGS）
	単結晶	多結晶	ヘテロ接合	多接合	
特徴	単結晶セルで構成、最も歴史あり	多結晶セルで構成、世界で最も多く生産	結晶系基板にアモルファスシリコン層を形成	アモルファスシリコンと微結晶シリコンを積層	銅・インジウム・セレン等を原料とした薄型電池
平均的モジュール変換効率	15～17%程度	13～15%程度	16～19%程度	8～10%程度	11～12%程度
主なメーカー	シャープ、サンテック パワージャパン、三菱電機	京セラ 三菱電機 シャープ	パナソニック	シャープ カネカ （富士電機）	ソーラーフロンティア、（ホンダソルテック）
モジュール写真					
その他技術	CdTe系	GaAs系	色素増感	有機薄膜	

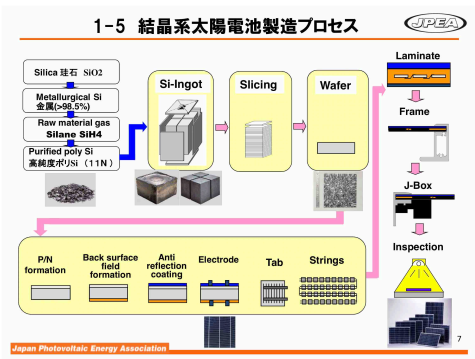
本表は、「NEDO再生可能エネルギー技術白書」およびJPEA「太陽光発電システム手引書」より合成。なお、各太陽電池の一般特性を示すもので、各性能については太陽電池メーカーにご確認要。

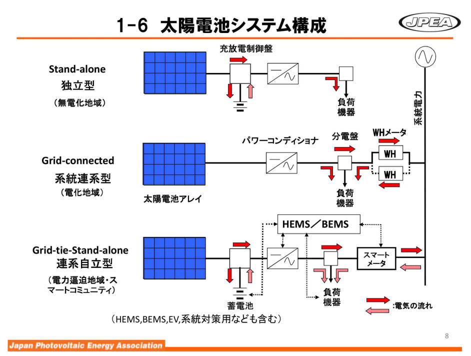
Japan Photovoltaic Energy Association　3

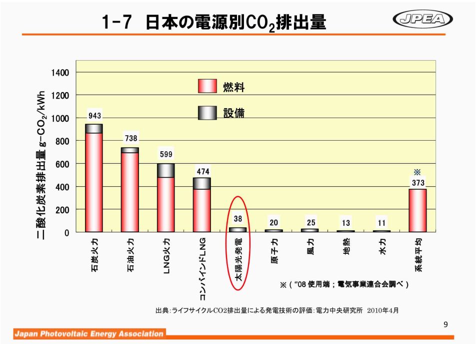




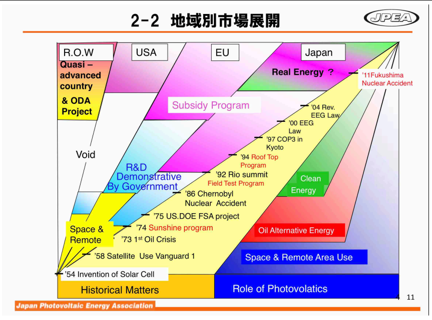


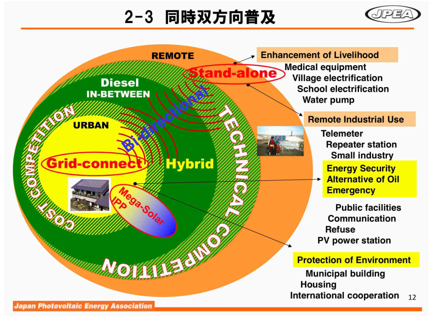





1-7 日本の電源別CO_2排出量
JPEA
燃料
設備
二酸化炭素排出量 g-CO_2/kWh
943
738
599
474
38
20
25
13
11
373
石炭火力
石油火力
LNG火力
コンバインドLNG
太陽光発電
原子力
風力
地熱
水力
系統平均
※（"08 使用端；電気事業連合会調べ）
出典：ライフサイクルCO2排出量による発電技術の評価：電力中央研究所 2010年4月
Japan Photovoltaic Energy Association
9


2-1 太陽電池の歴史
JPEA
'54 結晶シリコン太陽電池の発明（米国ベル研究所：ピアソン氏）
'58 人工衛星搭載（米：バンガード1号）
'73 第一次オイルショック
'74 サンシャイン計画開始（日本）
'75 地上用太陽電池開発計画開始（米国エネルギー省）
'76 アモルファス太陽電池開発（米国スピア・カールソン氏）
'86 チェルノブイリ原子力発電所事故
'92 国連環境サミット（リオ）
'94 公共産業用補助開始（日本）
'00 住宅用補助開始（日本）
再生可能エネルギー法（独）
'04 再生可能エネルギー法改正（独・フィードインタリフ）
時代 宇宙用 石油代替エネルギー 石油代替／クリーンエネルギー
米国 宇宙用 専門技術確立 地上用官プロジェクト ベンチャー参入 ベンチャー企業淘汰 州別補助施策へ
日本 無人灯台、無線電源 特定企業 地上用官プロジェクト 重電参入・基礎研究 実証研究・補助施策 重電撤退・応用技術
EU 基礎研究 地上用官プロジェクト イタリア・スイス 補助施策 ドイツ中心
途上国 援助プロジェクト NGOプロジェクト
Japan Photovoltaic Energy Association
10


2-2 地域別市場展開
JPEA
R.O.W
USA
EU
Japan
Quasi – advanced country & ODA Project
Real Energy ?
'11Fukushima Nuclear Accident
Subsidy Program
'04 Rev. EEG Law
'00 EEG Law
'97 COP3 in Kyoto
'94 Roof Top Program
'92 Rio summit
Field Test Program
Clean Energy
'86 Chernobyl Nuclear Accident
'75 US.DOE FSA project
'74 Sunshine program
Oil Alternative Energy
'73 1st Oil Crisis
Void
R&D Demonstrative By Government
Space & Remote
'58 Satellite Use Vanguard 1
Space & Remote Area Use
'54 Invention of Solar Cell
Historical Matters
Role of Photovolatics
Japan Photovoltaic Energy Association
11


2-3 同時双方向普及
JPEA
REMOTE
Stand-alone
Diesel IN-BETWEEN
URBAN
Grid-connect
Hybrid
Bi-directional
Mega-Solar IPP
COST COMPETITION
TECHNICAL COMPETITION
Enhancement of Livelihood
Medical equipment
Village electrification
School electrification
Water pump
Remote Industrial Use
Telemeter
Repeater station
Small industry
Energy Security
Alternative of Oil
Emergency
Public facilities
Communication
Refuse
PV power station
Protection of Environment
Municipal building
Housing
International cooperation
Japan Photovoltaic Energy Association
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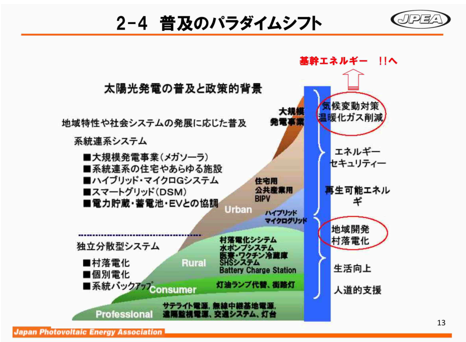
2-4 普及のパラダイムシフト
JPEA
基幹エネルギー !!へ
太陽光発電の普及と政策的背景
地域特性や社会システムの発展に応じた普及
系統連系システム
■大規模発電事業（メガソーラ）
■系統連系の住宅やあらゆる施設
■ハイブリッド・マイクロGシステム
■スマートグリッド（DSM）
■電力貯蔵・蓄電池・EVとの協調
独立分散型システム
■村落電化
■個別電化
■系統バックアップ
大規模発電事業
住宅用 公共産業用 BIPV
ハイブリッド マイクログリッド
Urban
Rural
Consumer
Professional
気候変動対策 温暖化ガス削減
エネルギー セキュリティー
再生可能エネルギー
地域開発 村落電化
生活向上
人道的支援
Japan Photovoltaic Energy Association
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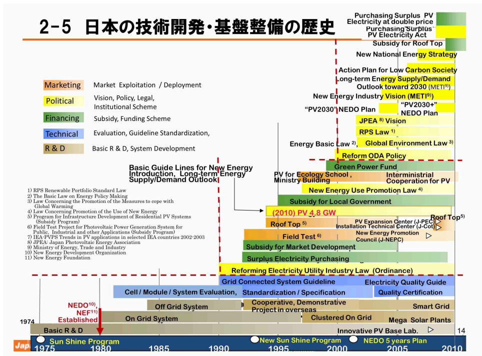
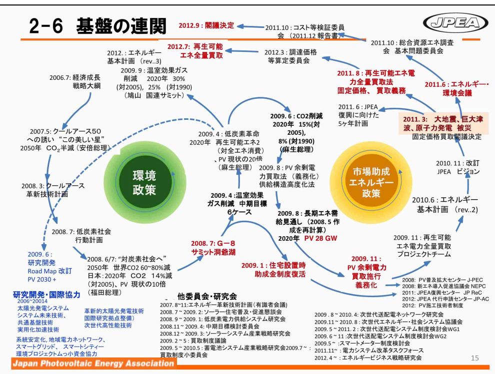

2-5 日本の技術開発・基盤整備の歴史
Marketing Market Exploitation / Deployment
Political Vision, Policy, Legal, Institutional Scheme
Financing Subsidy, Funding Scheme
Technical Evaluation, Guideline Standardization,
R & D Basic R & D, System Development
Purchasing Surplus PV Electricity at double price
Purchasing Surplus PV Electricity Act
Subsidy for Roof Top
New National Energy Strategy
Action Plan for Low Carbon Society
Long-term Energy Supply/Demand Outlook toward 2030
New Energy Industry Vision
"PV2030+" NEDO Plan
JPEA Vision
RPS Law
Global Environment Law
Energy Basic Law
Reform ODA Policy
Green Power Fund
Basic Guide Lines for New Energy Introduction, Long-term Energy Supply/Demand Outlook
New Energy Use Promotion Law
Subsidy for Local Government
(2010) PV 4.8 GW
Roof Top
Field Test
Subsidy for Market Development
Surplus Electricity Purchasing
Reforming Electricity Utility Industry Law (Ordinance)
Grid Connected System Guideline
Electricity Quality Guide
Cell / Module / System Evaluation, Standardization / Specification
Quality Certification
Off Grid System
Cooperative, Demonstrative Project in overseas
Smart Grid
On Grid System
Clustered On Grid
Mega Solar Plants
Basic R & D
Innovative PV Base Lab.
Sun Shine Program
New Sun Shine Program
NEDO 5 years Plan
1974
1975
1980
1985
1990
1995
2000
2005
2010
14


2-6 基盤の運関
JPEA
環境政策
市場助成エネルギー政策
研究開発・国際協力
他委員会・研究会
Japan Photovoltaic Energy Association
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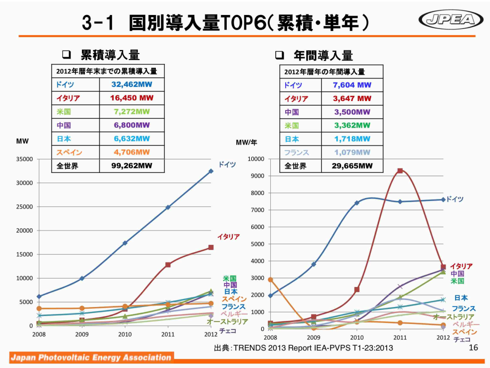
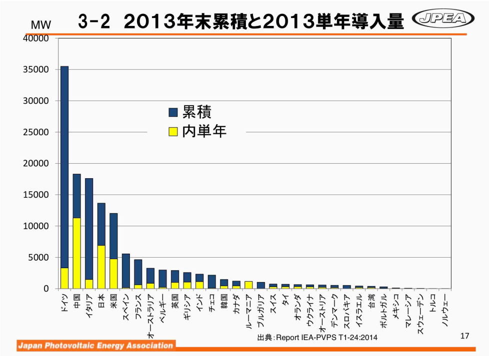

3-1 国別導入量TOP6（累積・単年）
JPEA
累積導入量
2012年暦年末までの累積導入量
ドイツ 32,462MW
イタリア 16,450 MW
米国 7,272MW
中国 6,800MW
日本 6,632MW
スペイン 4,706MW
全世界 99,262MW
年間導入量
2012年暦年の年間導入量
ドイツ 7,604 MW
イタリア 3,647 MW
中国 3,500MW
米国 3,362MW
日本 1,718MW
フランス 1,079MW
全世界 29,665MW
出典：TRENDS 2013 Report IEA-PVPS T1-23:2013
Japan Photovoltaic Energy Association
16


3-2 2013年末累積と2013単年導入量
JPEA
MW
累積
内単年
出典:Report IEA-PVPS T1-24:2014
Japan Photovoltaic Energy Association
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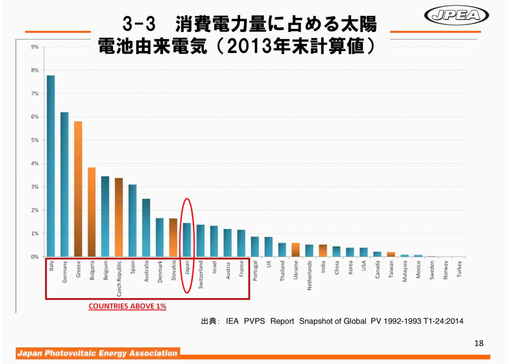
3-3 消費電力量に占める太陽電池由来電気（2013年末計算値）
JPEA
COUNTRIES ABOVE 1%
出典: IEA PVPS Report Snapshot of Global PV 1992-1993 T1-24:2014
Japan Photovoltaic Energy Association
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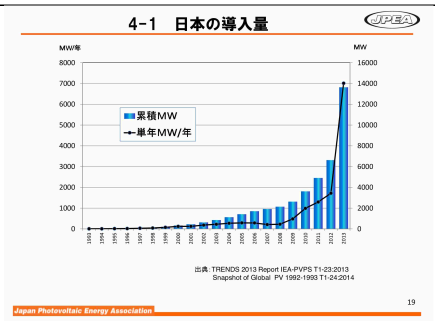
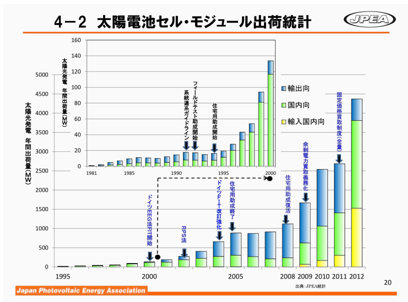
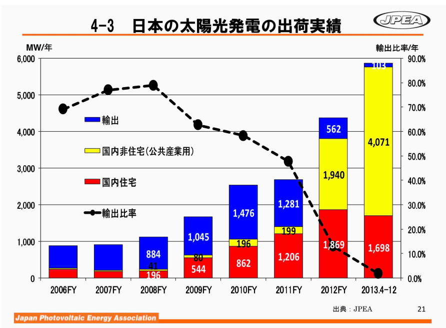

4-1 日本の導入量
JPEA
MW/年
MW
累積MW
単年MW/年
出典: TRENDS 2013 Report IEA-PVPS T1-23:2013
Snapshot of Global PV 1992-1993 T1-24:2014
Japan Photovoltaic Energy Association
19


4−2 太陽電池セル・モジュール出荷統計
JPEA
輸出向
国内向
輸入国内向
Japan Photovoltaic Energy Association
20


4-3 日本の太陽光発電の出荷実績
JPEA
MW/年
輸出比率/年
輸出
国内非住宅(公共産業用)
国内住宅
輸出比率
2006FY
2007FY
2008FY
2009FY
2010FY
2011FY
2012FY
2013.4-12
出典：JPEA
Japan Photovoltaic Energy Association
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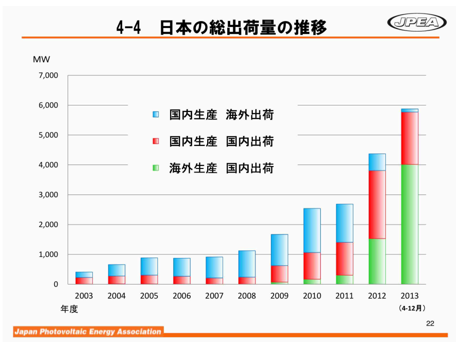
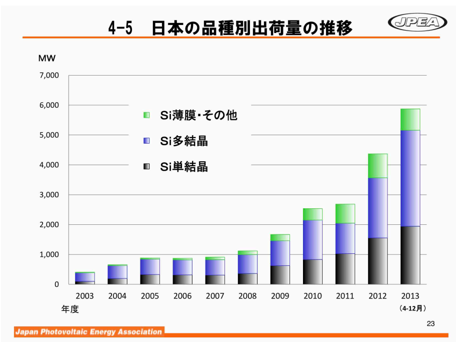
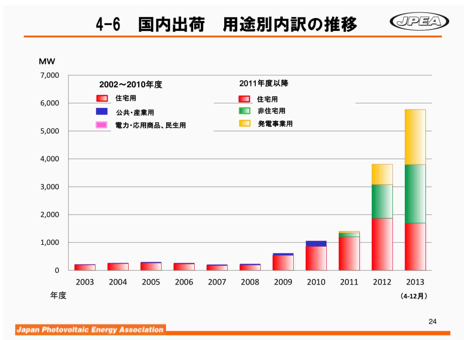

4-4 日本の総出荷量の推移
JPEA
MW
国内生産 海外出荷
国内生産 国内出荷
海外生産 国内出荷
年度
(4-12月)
Japan Photovoltaic Energy Association
22


4-5 日本の品種別出荷量の推移
JPEA
MW
Si薄膜・その他
Si多結晶
Si単結晶
年度
(4-12月)
Japan Photovoltaic Energy Association
23


4-6 国内出荷 用途別内訳の推移
JPEA
MW
2002〜2010年度
住宅用
公共・産業用
電力・応用商品、民生用
2011年度以降
住宅用
非住宅用
発電事業用
年度
(4-12月)
Japan Photovoltaic Energy Association
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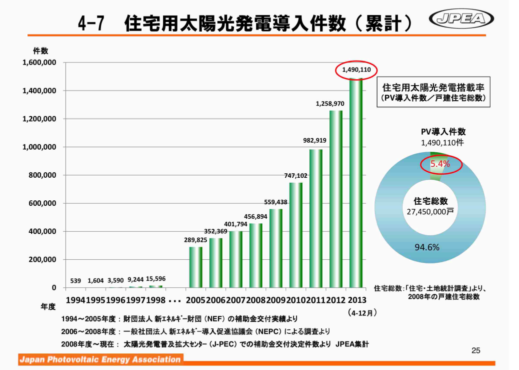
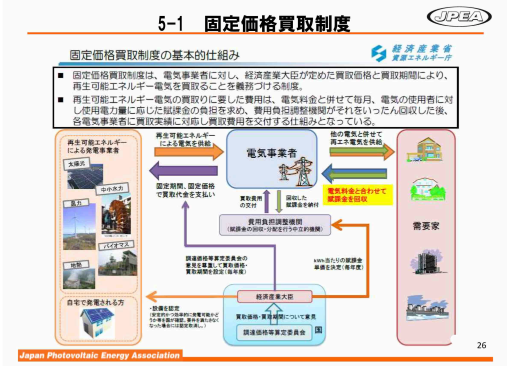


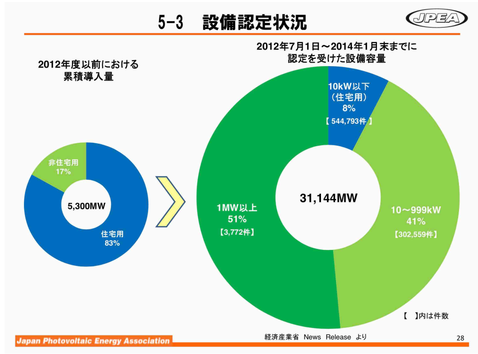


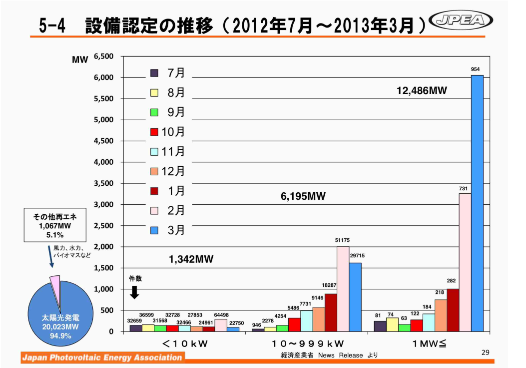
太陽光				風力			
年度	26	25	24	年度	26	25	24
10KW以上（20年間）	32円+税	36円+税	40円+税	20KW以上（20年間）	22円+税	22円+税	22円+税
10KW未満（10年間）	37円	38円	42円	20KW未満（20年間）	55円+税	55円+税	55円+税
10KW未満ダブル発電（10年間）	30円	31円	34円	洋上風力※（20年間）	36円+税		

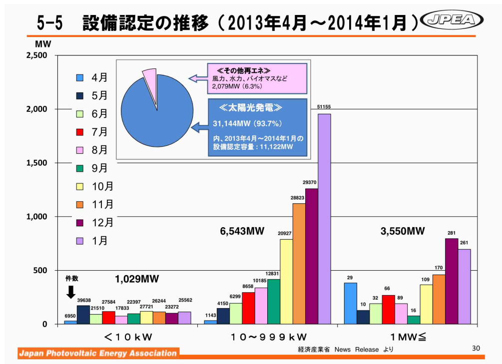
※建設及び運転保守のいずれの場合にも船舶等によるアクセスを必要とするもの

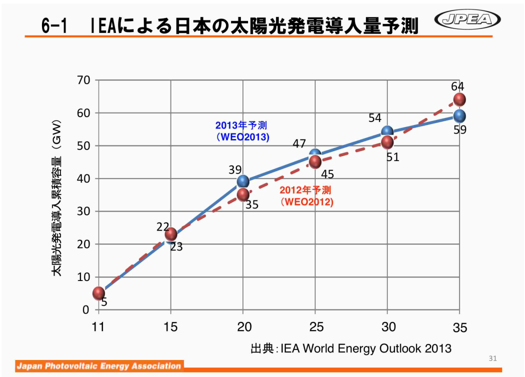
◆ 買取価格及び買取期間は、経済産業大臣が毎年度、当該年度の開始前に定める。
（施行の日から起算して三年間を限り、調達価格を定めるに当たり、特定供給者が受けるべき利潤に特に配慮するものとする。）
（エネルギー基本計画が変更されること又は少なくとも三年ごとに、・・・必要な措置を講ずる。）
◆ 経済産業大臣は、買取価格及び買取期間を定めようとするときは、調達価格等算定委員会の意見を聴き、その意見を尊重する。
◆ ・・・法律の施行後平成三十三年三月三十一日までの間に、この法律の施行の状況等を勘案し、この法律の抜本的な見直しを行うものとする。
●買取単価決定要素：年間発電量、発電劣化率、敷地造成費用、EPC価格、昇圧費用、電源線費用、O&M費用、土地リース代、販促費用、主任技術者人件費、貸付金利、償却年数、事業税、固定資産税、法人税、買取期間、撤去費、IRR（内部収益率）

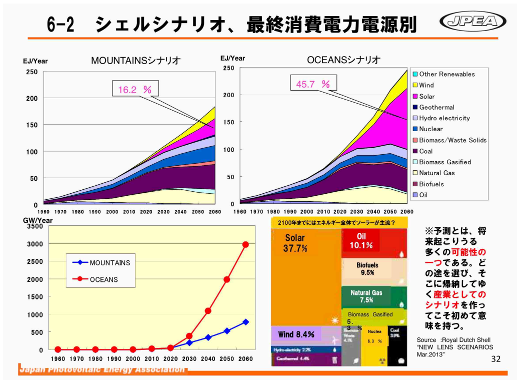
Japan Photovoltaic Energy Association　27

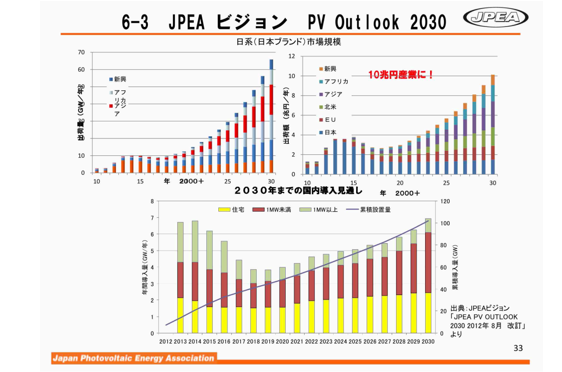
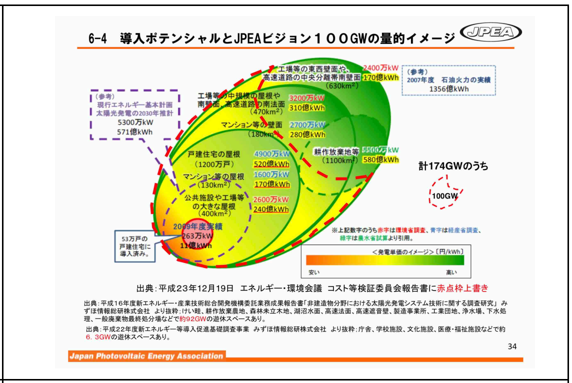











6-3　JPEA ビジョン　PV Outlook 2030
日系(日本ブランド)市場規模
10兆円産業に！
2030年までの国内導入見通し
出典：JPEAビジョン「JPEA PV OUTLOOK 2030 2012年 8月　改訂」より
Japan Photovoltaic Energy Association
33

6-4　導入ポテンシャルとJPEAビジョン１００GWの量的イメージ
計174GWのうち
100GW
出典：平成23年12月19日　エネルギー・環境会議　コスト等検証委員会報告書に赤点枠上書き
Japan Photovoltaic Energy Association
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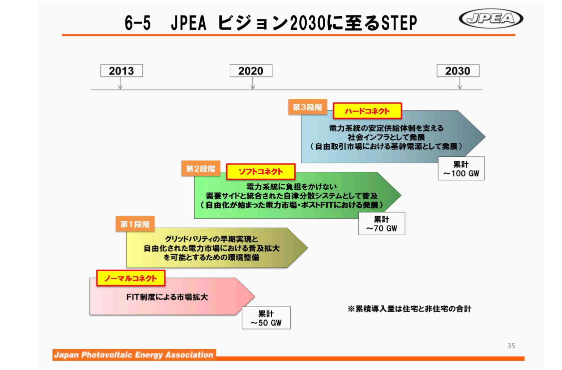
6-5　JPEA ビジョン2030に至るSTEP
2013
2020
2030
第3段階
ハードコネクト
累計 ～100 GW
第2段階
ソフトコネクト
累計 ～70 GW
第1段階
ノーマルコネクト
FIT制度による市場拡大
累計 ～50 GW
※累積導入量は住宅と非住宅の合計
Japan Photovoltaic Energy Association
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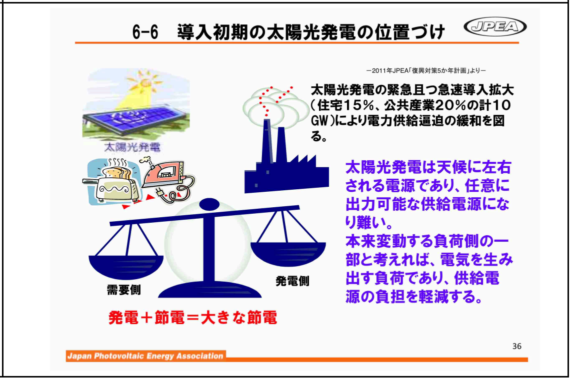
6-6　導入初期の太陽光発電の位置づけ
太陽光発電の緊急且つ急速導入拡大（住宅15%、公共産業20%の計10GW）により電力供給逼迫の緩和を図る。
太陽光発電
太陽光発電は天候に左右される電源であり、任意に出力可能な供給電源になり難い。
本来変動する負荷側の一部と考えれば、電気を生み出す負荷であり、供給電源の負担を軽減する。
需要側
発電側
発電＋節電＝大きな節電
Japan Photovoltaic Energy Association
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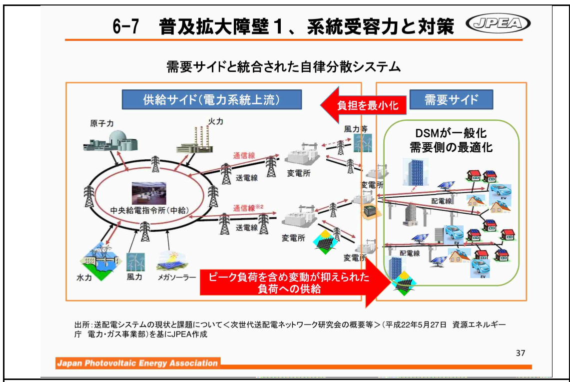
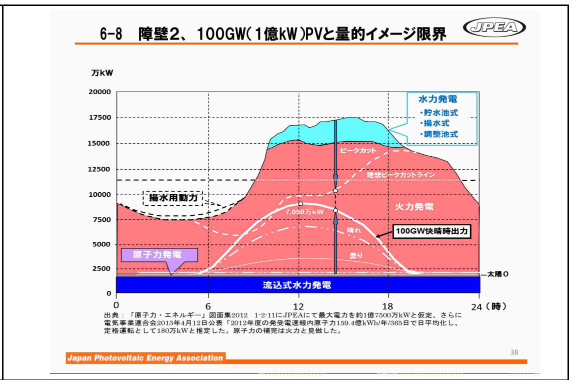

6-7　普及拡大障壁１、系統受容力と対策
需要サイドと統合された自律分散システム
供給サイド（電力系統上流）
負担を最小化
需要サイド
DSMが一般化
需要側の最適化
原子力
火力
中央給電指令所（中給）
水力
風力
メガソーラー
ピーク負荷を含め変動が抑えられた負荷への供給
Japan Photovoltaic Energy Association
37

6-8　障壁2、100GW（1億kW）PVと量的イメージ限界
万kW
水力発電
揚水用動力
火力発電
100GW快晴時出力
原子力発電
流込式水力発電
（時）
Japan Photovoltaic Energy Association
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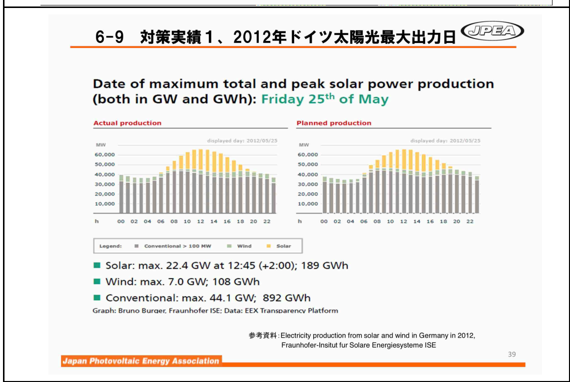
6-9　対策実績１、2012年ドイツ太陽光最大出力日
Date of maximum total and peak solar power production (both in GW and GWh): Friday 25th of May
Actual production
Planned production
Solar: max. 22.4 GW at 12:45 (+2:00); 189 GWh
Wind: max. 7.0 GW; 108 GWh
Conventional: max. 44.1 GW; 892 GWh
Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform
参考資料：Electricity production from solar and wind in Germany in 2012, Fraunhofer-Insitut fur Solare Energiesysteme ISE
Japan Photovoltaic Energy Association
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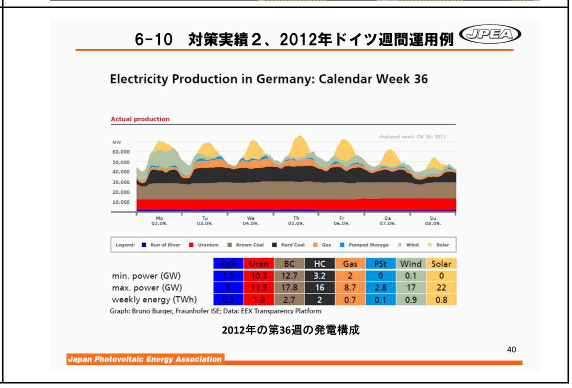
6-10　対策実績2、2012年ドイツ週間運用例
Electricity Production in Germany: Calendar Week 36
Actual production
min. power (GW)
max. power (GW)
weekly energy (TWh)
Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform
2012年の第36週の発電構成
Japan Photovoltaic Energy Association
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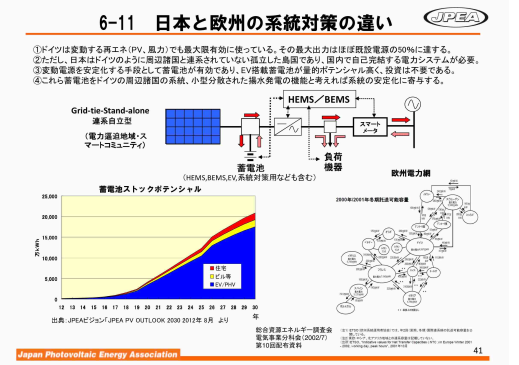
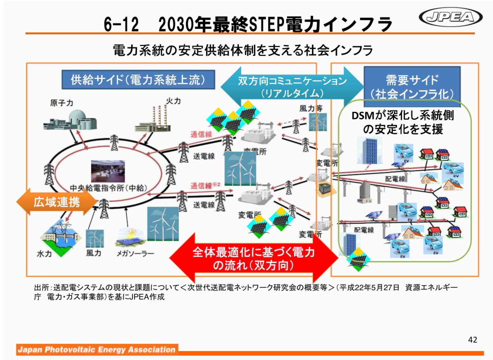
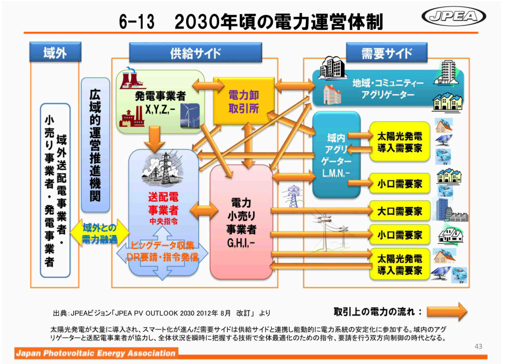
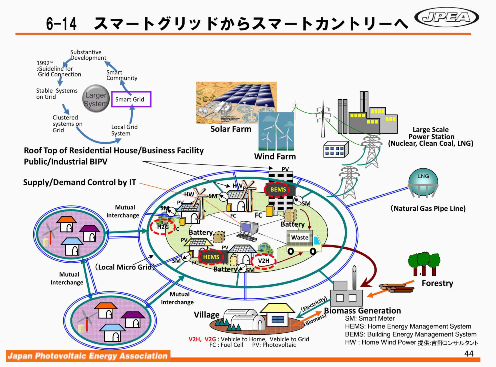
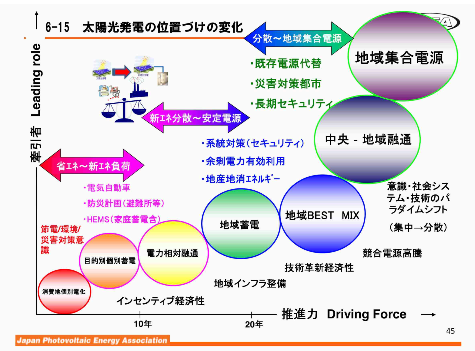










6-16　まとめ

①日本は**欧州と異なり**周辺諸国と電力連系のない**閉じられた島国**のため、変動する再生可能エネルギーの許容限界を知り、さらにそれを超えた安定化技術開発、社会システムづくりにより**国内自家消費的運用（スマートカントリー）を目指す**べきである。

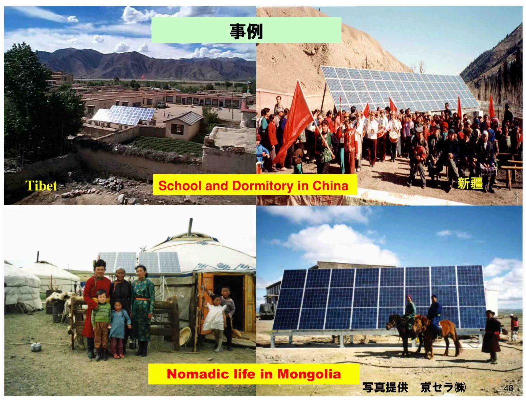
②太陽光発電は、60年前から今日まで独立型システム（蓄電池と併用）として昼夜を問わない安定電源として使われてきた実績がある。日本国内に**分散して普及する蓄電池は**、超小型の**揚水発電が分散設置**される様なもので、これを全体的に制御できれば自家消費的運用も可能性がある。

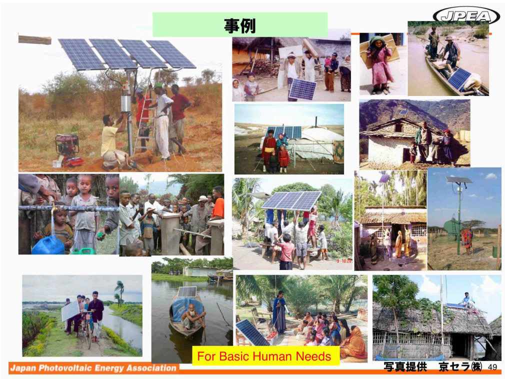
③日本の太陽光発電の発展は、石油代替（Energy Security）→ 経済発展エネルギー確保（Economy）→ クリーンエネルギー（Environment）という3Eの積み重りに支えられてきた。しかし**東日本大震災後は、「S（Safety）＋3E」**として安全性への関心が急激に高まってきた。太陽光発電の将来を描くには、炭酸ガス削減目標、エネルギーミックス、さらには電力システム改革などをベースに置いた上で、**「何のための普及か」**を国民全体でコンセンサスを得る必要がある。ベースとなるのは**エネルギー自給**である。

④太陽光発電市場はFITにより非常に励起されてきた。しかし**FITの功罪と限界**は、これまでの学習と現在の経験から**理解できる**ことである。FITの予後を考慮するにあたり観点を整理すると、政策・経済・資源・市場・技術・国際協力等々広範であり流動している。**太陽光発電は単独の技術としてではなく多面的に**考えなければならないときに来たと言える。

⑤本来、長期にわたる**予測は**その時期までに**達成したい上位の目標**があり、その達成のための事物を整えていくロードマップというべきものである。太陽光発電の場合は、上位目標として地球環境保全・エネルギー保障といった全地球的なものはあるが、**地域や国に落とし込む場合、経済発展、資源開発、災害や事故、時には指導性への野心によって全地球的目標への回帰道筋が大いに揺らぐ。ビジョンや予測は未来への可能性のある選択肢の一つを示している。**

Japan Photovoltaic Energy Association　46




事例
JPEA
For Basic Human Needs
Japan Photovoltaic Energy Association
写真提供　京セラ㈱
49


事例
写真提供　京セラ㈱
50


事例
NEXCO中日本　名二環
（名古屋第二環状自動車道）2MW
㈱ベネッセコーポレーション　720kW
浜中町農業協同組合
計1050kW(105戸計)
イオン伊丹昆陽　960kW(全体1160kW)
写真提供　京セラ㈱
51


事例
MAZDA　Zoom-Zoom
スタジアム広島　100kW
東北電力仙台太陽光発電所
九州電力メガソーラー大牟田発電所3MW
馬路村農業共同組合200KW
写真提供　京セラ㈱
52


事例
JPEA
Italy 2.5MW
Czech 1.2MW
Thailand 6 MW
Italy 1MW
写真提供　京セラ㈱
53
Japan Photovoltaic Energy Association


事例
JPEA
タイ国最大のプロジェクト
250MW+ 計画
6MW×20サイト
120MW　完成式
タイ　メガソーラー
54
Japan Photovoltaic Energy Association
写真提供　京セラ㈱


事例
JPEA
太陽電池　450KW
パワーコンディショナ　500KW
連系盤
京セラ佐倉ソーラーセンター
写真提供　京セラ㈱
56
Japan Photovoltaic Energy Association


事例
JPEA
出力：約70MW
PCS：500KW×144
敷地面積；約127万㎡
年間予想発電量：一般家庭の電力使用量約2万2000世帯分相当
鹿児島　七つ島メガソーラー
写真提供　京セラ㈱
57
Japan Photovoltaic Energy Association


JPEA
Renewable Japan !
What a Wonderful Job!
むすび
太陽光発電は巨大技術開発でも最新のテクノロジーでもない。60年ほど前に発明された小さな光電変換素子が原理的には今も使われている。都度途中成果が実用に生かされ、単純な技術でありながら、いつまでたっても限界の見えない、かつ色褪せない稀有な技術である。資源小国の日本で純国産のエネルギー確保は重要であり、孤立した島国でスマートカントリーを目指せば世界のエネルギー安全保障の範ともなりうる。太陽電池がそのキーテクノロジーになれば。
for The People・for The Earth･from Japan
58
Japan Photovoltaic Energy Association

Biomass power generation using ILC exhaust heat (Mituo Takeda,　Kabuki, Hitachi-cement, Nihon-premium, Mizuing)

1. Introduction

Since International Linear Collider: ILC, become one of the foundation industry for the region, it will be intended to integrate to regional management unification. If the facility is operational once, a number of researchers and their families from abroad will visit and stay, then how the effective use of the waste generated from there is a theme as a national project. Furthermore, it is considered necessary to indicate the way of next generation waste disposal incorporation with the entire region is developed.

By operating the linear accelerator of 30km or more as the main ILC facilities, a large amount of heat is generated. By utilizing the exhaust heat, it is possible to ensure the thermal energy source, which accounts for significant costs in organic waste treatment at low cost. Biomass power generation, although a wide variety of methods have been taken, as simple as possible is good, by using an inexpensive heat, direct combustion power plants which accept any type of organic waste are proven, and can be expected.

2. Biomass direct combustion power generation plant

(1) the value of biomass direct combustion power generation plant

· It is possible to generate electricity by using animal and vegetable waste generated in the region.

- By using the waste heat of the ILC facility, it is possible to dry them with costs cheaper

- Along with the drying → incineration → power generation is simple line, also accepted any kind of organic waste.

And disposal destination of sewage sludge and organic waste will expand.

- Reduction of the incineration plant of each municipality is measurably proceed.

(2) flow of direct combustion power plant

In biomass direct combustion power plant flow as shown in Figure 1, it is to accept all of the biomass from the high moisture content livestock manure to as low as rice straw, is to dry by the ILC exhaust heat and recovered heat. Then burned directly, and then the power generation by the steam, use the full generated power at the ILC facilities.

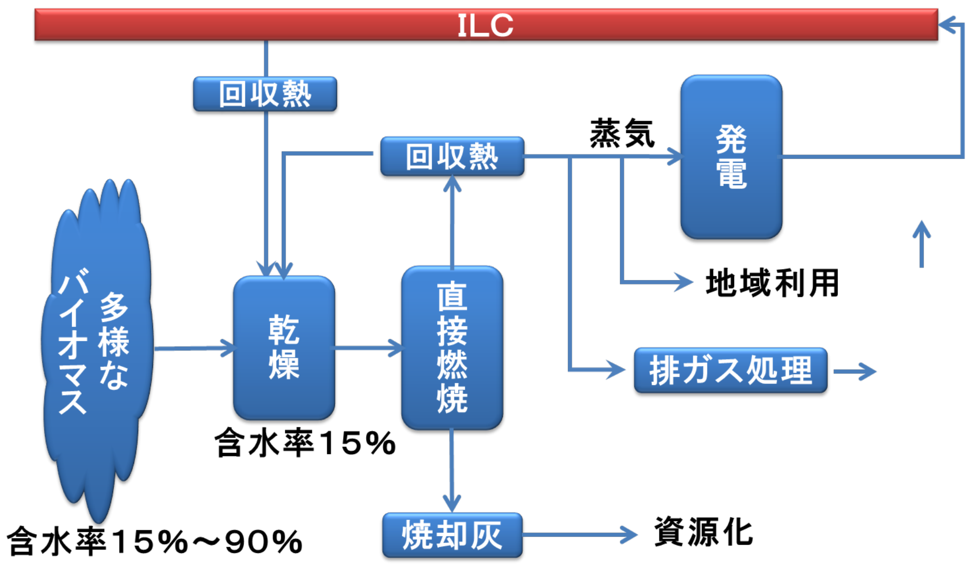


Figure 1 biomass direct combustion power generation plant flow

(3) Considerations of direct combustion power plant

<Notes of dry>

· For drying machine, the rotary dryer type is safe to cope with the wide variety of biomass.

· When the oxygen concentration is high, it is necessary to lower the oxygen concentration replaced with steam (turbine extraction steam) and the exhaust gases, since there is likely to be burned in a dryer.

· In order to keep the dry exhaust as much as possible, it will be exhausting and dehumidified in the wet scrubber, re-heating by the ILC recovered heat, and recycling and re-using some part.

· Surplus exhaust, you can either use as combustion air of incinerator, or on the deodorizing process, then dissipated to the atmosphere.

<Incinerator type>

· By taking into account the nature, input amount, fluctuation range of input, the optimum furnace type should be selected from stoker, fluidized bed, and the other.

· Review of the post-process of the exhaust gas treatment.

3. Power generation amount expected by biomass direct combustion

(1) Biomass endowment amount and effectiveness available amount

In the Tohoku region (Iwate, Miyagi Prefecture) and Kyushu region (Saga, Fukuoka Prefecture), each of the biomass endowment amount and effectiveness available amount can be estimated from NEDO data, as shown in Table 1.

Table 1 Biomass endowment amount and effectiveness available amount

		林地残材		切り捨て間伐材		果樹剪定材		タケ		稲作残渣・稲わら	
		有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年
東北地区	岩手県	4,980	90,142	5,982	127,390	5,214	59,956	1,475	18,432	39,315	534,690
	宮城県	1,316	24,627	2,167	46,155	3,117	35,847	4,644	58,055	51,075	694,617
九州地区	佐賀県	746	13,495	477	10,148	7,733	88,935	17,311	216,383	18,752	255,031
	福岡県	402	7,282	1,757	37,423	12,614	145,056	29,999	374,992	27,493	373,900

		稲作残渣・籾殻		麦わら		その他の農業残渣		ササ		ススキ	
		有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年
東北地区	岩手県	4,790	68,022	1,444	19,638	9,455	102,111	2,417	32,876	135,516	1,843,020
	宮城県	5,416	76,909	971	13,208	9,146	98,779	0	0	28,703	390,362
九州地区	佐賀県	2,309	32,791	8,109	110,288	12,201	131,770	54	738	3,998	54,367
	福岡県	4,504	63,962	7,706	104,805	8,079	87,249	18	239	27,714	376,913

		国産材製材廃材		外材製材廃材		建築廃材		新・増築廃材		公園剪定枝	
		有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年
東北地区	岩手県	12,459	225,502	2,699	48,846	2,742	49,625	2,467	44,659	14,815	87,487
	宮城県	6,154	111,394	4,462	80,109	10,114	183,068	725	13,117	2,652	30,503
九州地区	佐賀県	1,640	29,683	162	2,938	3,896	70,511	291	5,266	611	7,022
	福岡県	1,547	27,996	1,045	18,919	4,007	72,535	2,246	40,650	3,562	40,965

		乳用牛糞尿		肉用牛糞尿		ぶた糞尿		採卵鶏糞尿		ブロイラー糞尿	
		有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年
東北地区	岩手県	6,642	39,690	14,815	87,487	6,642	39,690	2,847	32,739	13,686	223,060
	宮城県	5,578	32,132	13,198	77,927	3,973	23,750	1,262	14,505	1,096	17,866
九州地区	佐賀県	1,133	6,521	8,581	50,669	1,582	9,449	467	5,364	2,489	40,560
	福岡県	4,112	23,683	3,382	19,977	1,077	6,443	3,706	42,624	524	8,523

		下水汚泥（濃縮汚泥）		し尿浄化槽・余剰汚泥		集落汚水汚泥		食品加工廃棄物		家庭系厨芥類	
		有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年	有効利用可能量DW-t/年	有効利用熱量GJ/年
東北地区	岩手県	680	6,046	309	2,992	623	6,297	200	576	18,311	373,577
	宮城県	0	0	241	2,332	463	4,678	4,400	12,672	34,234	698,455
九州地区	佐賀県	0	0	372	3,602	190	1,922	2,561	7,374	11,744	239,609
	福岡県	3,562	31,687	818	7,920	142	1,437	1,800	5,184	69,199	1,411,822

		事業系厨芥類	
		有効利用可能量DW-t/年	有効利用熱量GJ/年
東北地区	岩手県	7,567	154,388
	宮城県	14,740	300,728
九州地区	佐賀県	4,922	100,427
	福岡県	31,011	632,706

＊バイオマス推計方法の定義

(1)賦存量

賦存量は、バイオマスの利用の可否に関わらず理論上1年間に発生、排出される量とした。なお、本定義によらないものは個別に定義してた。

(2)有効利用可能量

有効利用可能量とは、賦存量よりエネルギー利用、堆肥、農地還元利用等、既に利用されている量を除き、さらに収集等にに関する経済性を考慮した量を利用可能量とした。

(3)熱量

賦存量と有効利用可能量について、熱量の推計を行った。熱量はバイオマス種により直接燃焼またはメタン発酵により発生するメタンの熱量として算出を行った。

Summarizing the results, the number are shown in Table 2.

Table 2　Summary table

		有効利用可能量DW-t/年	有効利用熱量GJ/年
東北地区	岩手県	318,092	4,279,248
	宮城県	209,847	3,041,795
計		527,939	7,321,043
九州地区	佐賀県	112,331	1,488,343
	福岡県	252,026	3,964,889
計		364,357	5,453,232

(2) The expected amount of power generation from biomass direct combustion

After calculating the total amount of heat per year from each of the effective use possible amount of both regions,

Tohoku district: 7,321,043GJ/year ≒ 2,033,623,055kwh

Kyushu district: 5,453,232GJ/year ≒ 1,514,786,650kwh

Power generation amount in the case of use all the effective utilization heat quantity by the efficiency 20% of the power generation system,

Tohoku district: 2,033,623,055kwh × 0.2 = 406,724,611kwh

Kyushu district: 1,514,786,650kwh × 0.2 = 302,957,330kwh

Output in the case of the power generation equipment that runs the power generation per year 7,000 hours,

Tohoku district: 406,724,611kwh ÷ 7,000h = 58,104kw

Kyushu district: 302,957,330kwh ÷ 7,000h = 43,280kw

When there is an effective available amount of about 10 to 20%, it can be expected that the following output.

Tohoku district: 58,104kw × 10 ~ 20% = 6,000 ~ 10,000kw

Kyushu district: 43,280kw × 10 ~ 20% = 5,000 ~ 10,000kw

(3) Amount of heat required for biomass fuel drying
Required amount of heat to dry the biomass waste, is calculated as follows.

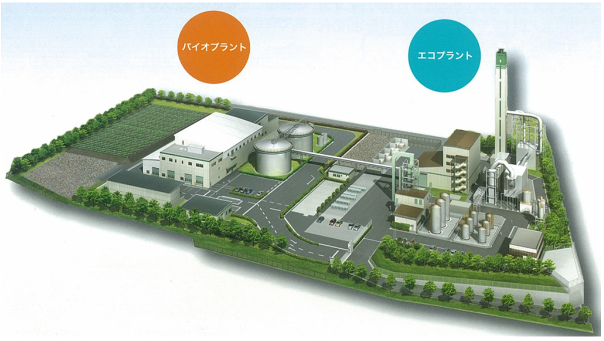
① Effective available capacity
If drying the moisture content from 60% → 15%, water evaporation amount W is,
W = effective use possible amount × (1- solids ratio before drying / solids ratio dried)
Tohoku district W = 527,939t/year × (1-40% / 85%) = 279,497t-H_2O/year
Kyushu W = 364,357t/year × (1-40% / 85%) = 192,895t-H_2O/year
② The necessary amount of heat to dry
Latent heat of vaporization at 70℃ (qj) = 2,332kJ/kg, and the drying efficiency (n) = 60%.

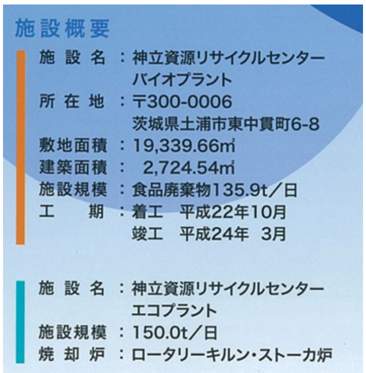
$$q = W \times qj / n$$

Tohoku district q = 237,572 × 2,332 / 0.6 = 924GJ/year
Kyushu district q = 192,895 × 2,332 / 0.6 = 750GJ/year
③ If you have 10 to about 20% of the effective possible amount of use
Tohoku district 924GJ/year × 10 ~ 20% = 100 ~ 200GJ/year
Kyushu district 750GJ/year × 10 ~ 20% = 75 ~ 150GJ/year

4. Challenges for biomass direct combustion power generation
(1) Collection challenges
· How much ensured biomass collection amount is, from location issues?
· It was assumed 10 to about 20% of the effective use possible amount, as a planning.
· Local understanding can be obtained in broad-based way?
(2) Issues of plant installation
· ILC facility adjacent is favor, but challenges such as landscape and smell issue remain.
· Whether it is possible to underground plant including the cost?
· What is extent of temperature, amount, operating time, and period of the tunnel exhaust heat?
· Recycling of incinerator ash? or final disposal method?

5. Reference Case (Hitachi cement)
Biomass methane fermentation plant




施設概要
施 設 名 ：神立資源リサイクルセンター
バイオプラント
所 在 地 ：〒300-0006
茨城県土浦市東中貫町6-8
敷地面積 ：19,339.66㎡
建築面積 ： 2,724.54㎡
施設規模 ：食品廃棄物135.9t／日
工 期 ：着工 平成22年10月
竣工 平成24年 3月

施 設 名 ：神立資源リサイクルセンター
エコプラント
施設規模 ：150.0t／日
焼 却 炉 ：ロータリーキルン・ストーカ炉

This project, has large part at the joint venture with local governments and the private sector, in a sense might also say PPP (Public Private Partnership) civil cooperation. There is a need to local governments to be a prerequisite to gain certification of Biomass Town, confirmation of intention is important (Figure 2).

Figure 2 Tsuchiura Biomass Town Initiative

(1) Overview of biomass utilization business

Framework of the business is as follows, the gas by methane processing mainly from food waste (general waste, industrial waste) is used as a co-combustion gas of the cement burning fuel. Further it features a composting facility, by utilizing a part of, such as digestion solution from the methanation facility, perform the manufacture and sale of compost (Figure 3). In this project, there is also a merit of burden reduction, such as a reduction in the size of the incinerator, in local government.

As for business scale, it becomes 100t/day of methane gas reduction facility, and 30t/day composting facility.

The facility of summary flow is shown in Figure 4. By acceptance of garbage, animal and plant residues in biomass in the building, after removal of the fermentation unsuitable material at fracture separation, it is fed to the methane fermentation tank through the solubilization, anaerobic fermentation process is performed.

Biogas obtained by methane fermentation process, is used as auxiliary fuel substitute of the existing incineration facilities, also makes use of the surplus steam boilers of the existing incineration facility as a heat source of the methane fermentation tank and dryer of the new plan facility.

Digestion solution after methane fermentation is to solid-liquid separation at the dehydrator. Dehydration residue is subjected to aerobic fermentation process in the later stage of fermentation composting facility, to provide compost to the regional farmers and citizens. Filtrate after dehydration processed by water treatment to the sewage discharge standards, then it will be discharged into the sewer.

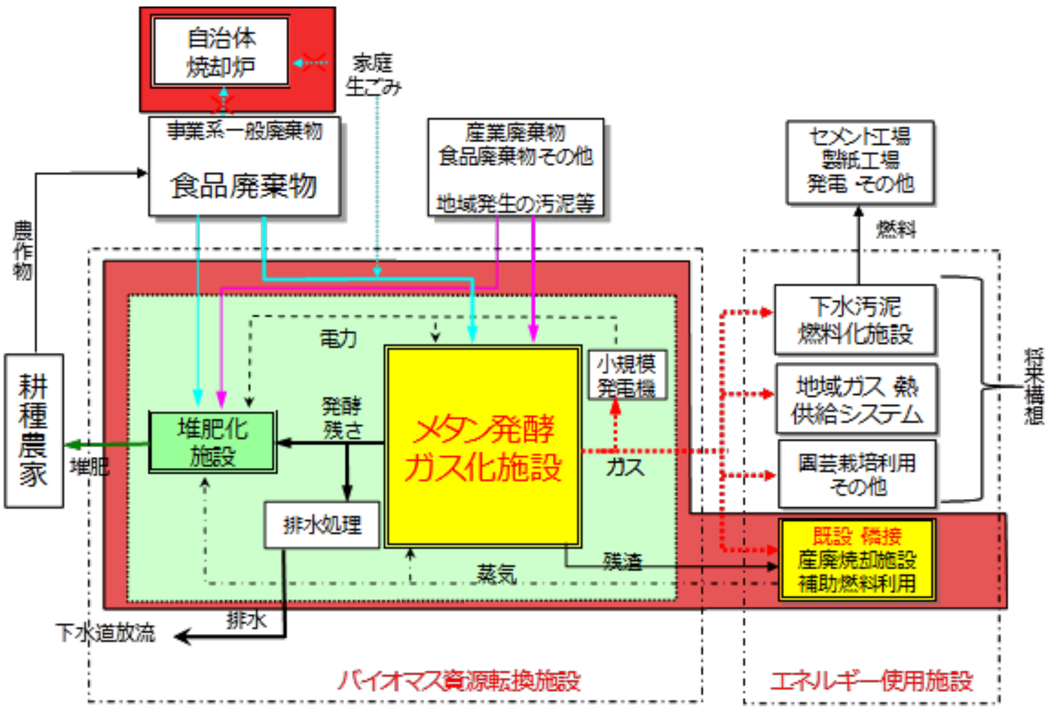


Figure 3 framework of business

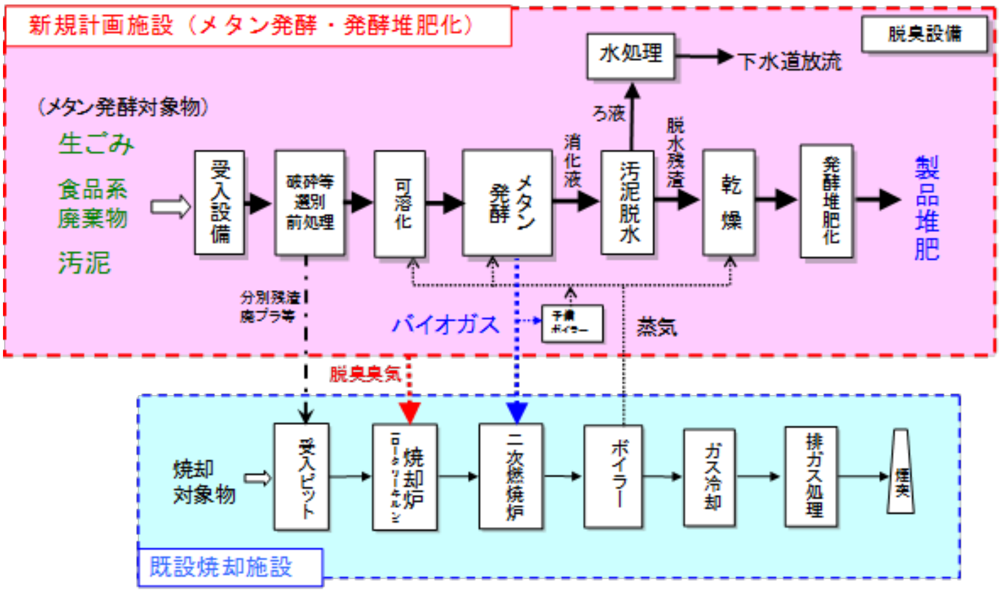
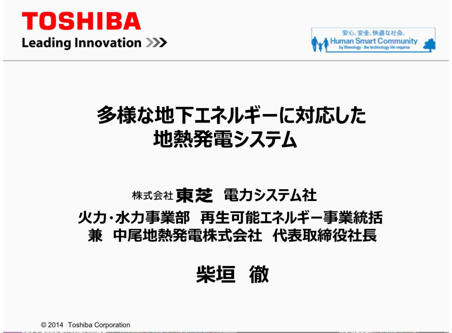
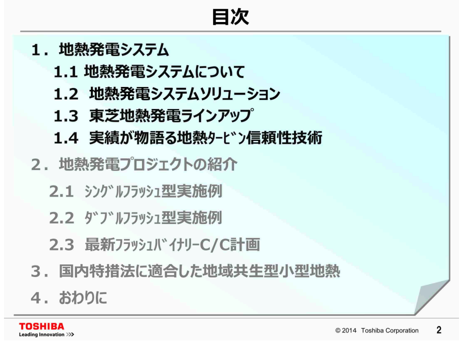
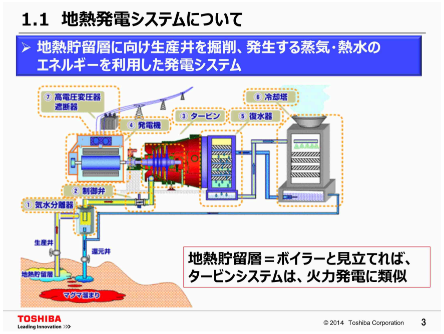


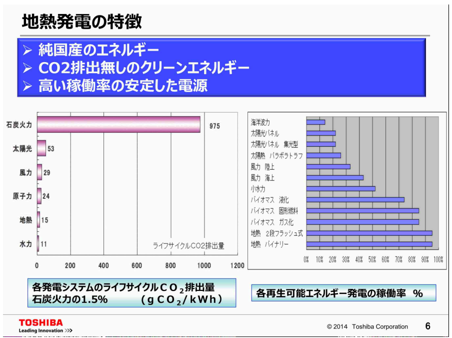
Figure 4 the processing flow of methane gas

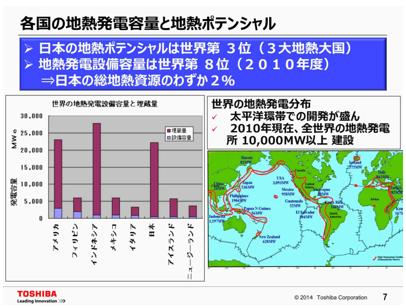
Geo-thermal Power Generation System using variety of under-ground energy (Toru Shibagaki, Toshiba)

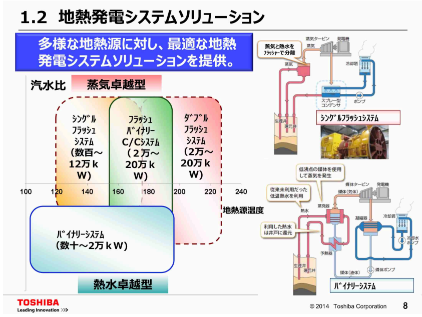


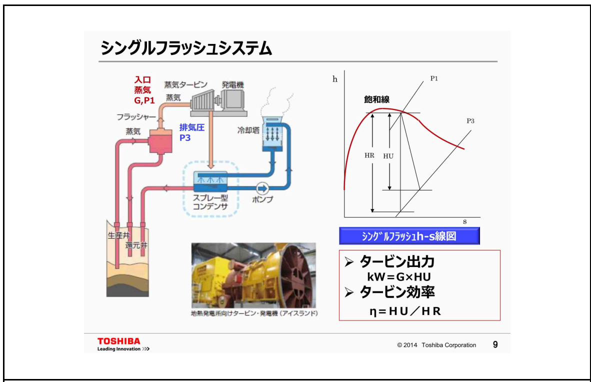











シングルフラッシュシステム
入口蒸気 G,P1
蒸気タービン
発電機
フラッシャー
蒸気
排気圧 P3
冷却塔
スプレー型コンデンサ
ポンプ
生産井
還元井
地熱発電所向けタービン・発電機（アイスランド）
飽和線
シングルフラッシュh-s線図
➢ タービン出力
kW＝G×HU
➢ タービン効率
η＝HU／HR
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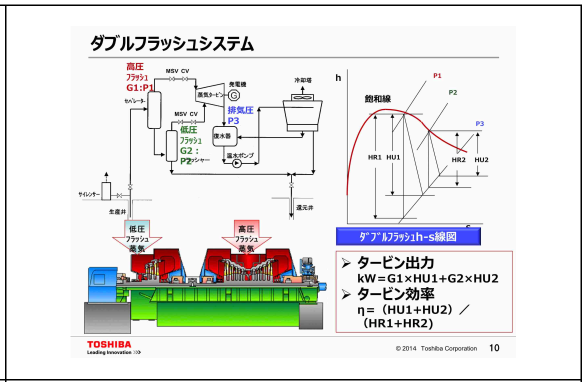
ダブルフラッシュシステム
高圧フラッシュ G1:P1
低圧フラッシュ G2：P2
排気圧 P3
高圧フラッシュ蒸気
低圧フラッシュ蒸気
飽和線
HR1 HU1
HR2 HU2
ダブルフラッシュh-s線図
➢ タービン出力
kW＝G1×HU1＋G2×HU2
➢ タービン効率
η＝（HU1＋HU2）／（HR1＋HR2）
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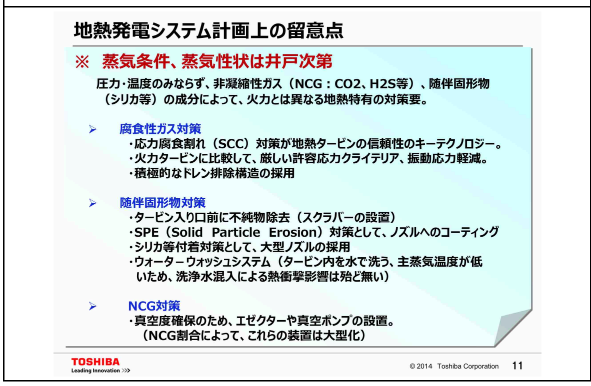
地熱発電システム計画上の留意点
※ 蒸気条件、蒸気性状は井戸次第
圧力・温度のみならず、非凝縮性ガス（NCG：CO2、H2S等）、随伴固形物（シリカ等）の成分によって、火力とは異なる地熱特有の対策要。
➢ 腐食性ガス対策
・応力腐食割れ（SCC）対策が地熱タービンの信頼性のキーテクノロジー。
・火力タービンに比較して、厳しい許容応力クライテリア、振動応力軽減。
・積極的なドレン排除構造の採用
➢ 随伴固形物対策
・タービン入り口前に不純物除去（スクラバーの設置）
・SPE（Solid Particle Erosion）対策として、ノズルへのコーティング
・シリカ等付着対策として、大型ノズルの採用
・ウォーターウォッシュシステム（タービン内を水で洗う、主蒸気温度が低いため、洗浄水混入による熱衝撃影響は殆ど無い）
➢ NCG対策
・真空度確保のため、エゼクターや真空ポンプの設置。
（NCG割合によって、これらの装置は大型化）
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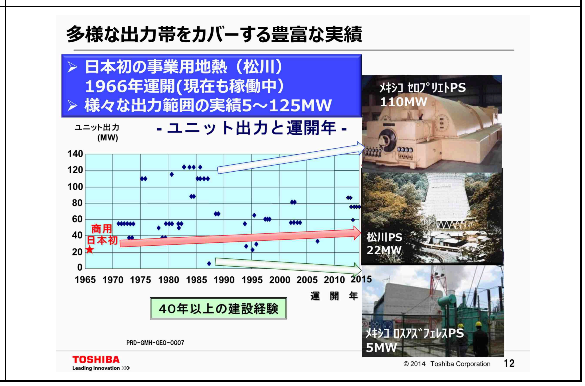
多様な出力帯をカバーする豊富な実績
➢ 日本初の事業用地熱（松川）
1966年運開(現在も稼働中)
➢ 様々な出力範囲の実績5～125MW
- ユニット出力と運開年 -
ユニット出力 (MW)
商用日本初
40年以上の建設経験
運開年
メキシコ セロプリエトPS 110MW
松川PS 22MW
メキシコ ロスアズフレスPS 5MW
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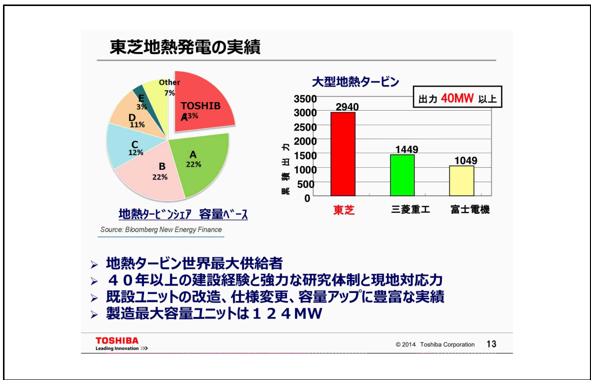
東芝地熱発電の実績
TOSHIBA 43%
A 22%
B 22%
C 12%
D 11%
E 3%
Other 7%
地熱タービンシェア 容量ベース
Source: Bloomberg New Energy Finance
大型地熱タービン
出力 40MW 以上
実績出力
2940
1449
1049
東芝
三菱重工
富士電機
➢ 地熱タービン世界最大供給者
➢ ４０年以上の建設経験と強力な研究体制と現地対応力
➢ 既設ユニットの改造、仕様変更、容量アップに豊富な実績
➢ 製造最大容量ユニットは１２４MW
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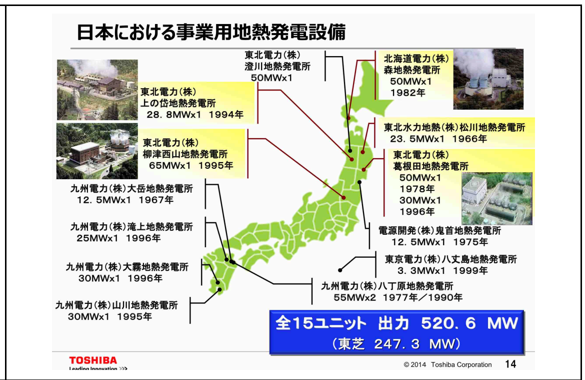
日本における事業用地熱発電設備
東北電力(株) 澄川地熱発電所 50MWx1
北海道電力(株) 森地熱発電所 50MWx1 1982年
東北電力(株) 上の岱地熱発電所 28．8MWx1 1994年
東北水力地熱(株)松川地熱発電所 23．5MWx1 1966年
東北電力(株) 柳津西山地熱発電所 65MWx1 1995年
東北電力(株) 葛根田地熱発電所 50MWx1 1978年 30MWx1 1996年
九州電力(株)大岳地熱発電所 12．5MWx1 1967年
九州電力(株)滝上地熱発電所 25MWx1 1996年
電源開発(株)鬼首地熱発電所 12．5MWx1 1975年
九州電力(株)大霧地熱発電所 30MWx1 1996年
東京電力(株)八丈島地熱発電所 3．3MWx1 1999年
九州電力(株)八丁原地熱発電所 55MWx2 1977年／1990年
九州電力(株)山川地熱発電所 30MWx1 1995年
全15ユニット 出力 520．6 MW
（東芝 247．3 MW）
TOSHIBA
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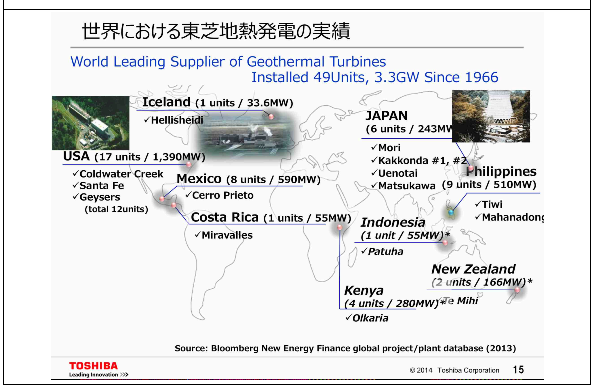
世界における東芝地熱発電の実績
World Leading Supplier of Geothermal Turbines
Installed 49Units, 3.3GW Since 1966
Iceland (1 units / 33.6MW)
✓Hellisheidi
USA (17 units / 1,390MW)
✓Coldwater Creek
✓Santa Fe
✓Geysers
(total 12units)
Mexico (8 units / 590MW)
✓Cerro Prieto
Costa Rica (1 units / 55MW)
✓Miravalles
JAPAN
(6 units / 243MW)
✓Mori
✓Kakkonda #1, #2
✓Uenotai
✓Matsukawa
Philippines
(9 units / 510MW)
✓Tiwi
✓Mahanadong
Indonesia
(1 unit / 55MW)*
✓Patuha
New Zealand
(2 units / 166MW)*
✓Te Mihi
Kenya
(4 units / 280MW)*
✓Olkaria
Source: Bloomberg New Energy Finance global project/plant database (2013)
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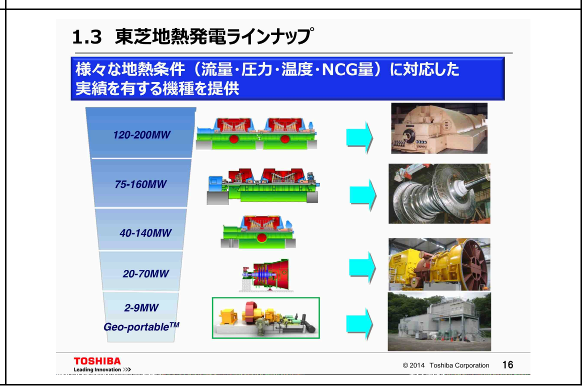
1.3 東芝地熱発電ラインナップ
様々な地熱条件（流量・圧力・温度・NCG量）に対応した実績を有する機種を提供
120-200MW
75-160MW
40-140MW
20-70MW
2-9MW
Geo-portable™
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1.4 実績が物語る地熱ﾀｰﾋﾞﾝ信頼性技術

東芝最新地熱タービン技術の信頼性を実証

Calpine 11号機,14号機(ｶﾞｲｻﾞｰｽ・ｶﾘﾌｫﾙﾆｱ) ｽｰﾊﾟｰﾛｰﾀｰ化

- 地熱タービンに耐腐食最新技術を適用（2002年ﾘﾌﾟﾚｰｽ）

結果 ：１１号８年間、１４号10年間連続運用、開放点検 良好

効果 ：CO2削減：年間約60万ton/台（対石炭）
稼働率向上による収入増、ﾒﾝﾃﾅﾝｽ費最小化：約３０億円改善／10年

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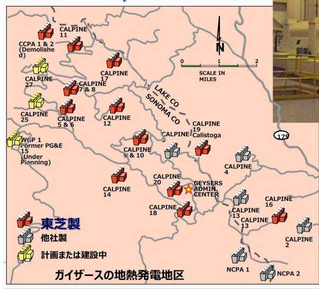
ガイザース, 米国カリフォルニア

１９７１年以来
１７ユニット建設
合計出力 １，３９０MW



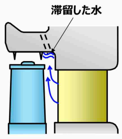
Calpine 19 : Calistoga Unit 18

- SCDF-26”
- 定格出力 48.5MW
- 最大出力 88.0MW
- １ケーシング当り最大出力ユニット

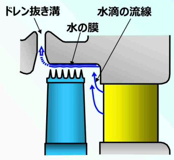
ｶﾞｲｻﾞｰｽﾘﾊﾋﾞﾘ工事 信頼性向上技術

ドレン排出 性向上（腐食対策）

- 従来設計
  - 大粒の水滴は、外壁のフィンにより堰き止められる
  - 滞留した水は、高速蒸気流によってポケット内で回転し、フィンを損傷させることがある



- 最新技術
  - ノズル後縁から剥がれた大粒の水滴は、遠心力によって、ノズル－羽根間のスペースを外壁へと流出
  - これら水滴はダイヤフラム外壁のひさしに沿って膜状に流れ、段落出口のドレン抜き溝からスムーズに排出。



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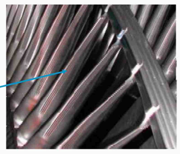
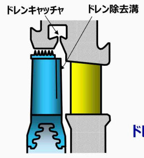
ｶﾞｲｻﾞｰｽﾘﾊﾋﾞﾘ工事 信頼性向上技術

湿分除去羽根（腐食対策）

・ﾄﾞﾚﾝを積極的に排除し、耐エロージョン性を向上





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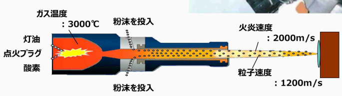
ｶﾞｲｻﾞｰｽﾘﾊﾋﾞﾘ工事 信頼性向上技術

ロータへのコーティング（腐食対策）

- 処理ﾌﾟﾛｾｽ：HP-HVOF
- 特徴：強力な接着力を有する精細なコーティング層を形成



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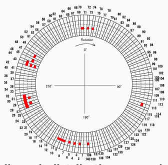
ｶﾞｲｻﾞｰｽﾘﾊﾋﾞﾘ工事 信頼性向上技術

耐SCC設計クライテリア（腐食対策）

オリジナル設計

ガイザース20号およびカリストガ1、2号機の15年間の実運用データから、ホイール部のSCC発生データを蓄積
これらのデータから、“ Crack Occurrence Rate”, を確立し、SCC発生防止のクライテリアを確立

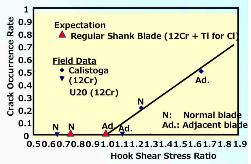


Dovetail crack distribution on a wheel

スーパーロータ設計

実機データをもとに、下図のクライテリアにて強度設計を実施。

10年連続運用において、耐SCC性を実証



COR of 1st stage dovetail for First Generation SuperRotor

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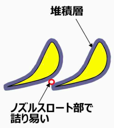
ｶﾞｲｻﾞｰｽﾘﾊﾋﾞﾘ工事 信頼性向上技術

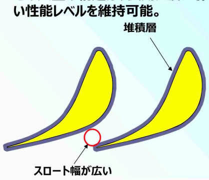
シリカ堆積物による閉塞に対する耐性向上

- 従来設計
  - 動翼振動応力低減のため、動翼固有振動数離調を優先に設計。
  - 段落によって、ノズル枚数を増加要シリカによる閉塞のため、性能低下などにより、蒸気通路の清掃のためにしばしば開放要。



詰ってしまった静翼

- ﾗｰｼﾞｺｰﾄﾞ（大型）ﾉｽﾞﾙの採用
  - ｽﾅｯﾊﾞ翼による振動応力低減により、大型ﾉｽﾞﾙの採用が可能。ｽﾛｰﾄ幅増加により、ｼﾘｶ堆積層の影響を受けにくい。
  - この大型の構造は、長期に渡って高い性能レベルを維持可能。



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2.1 最近のシングルフラッシュ地熱トピック
ケニア OLKARIA地熱発電所
第四発電所
型式 単車室２流式
出力 4 x 75MW(発電端)
主蒸気圧力 第一発電所4.8bara(2台) 第四発電所5.8bara(2台)
主蒸気温度 150℃/158℃
2014年9月 第四発電所運転開始 第一発電所試運転中
Save the Date
KenGen
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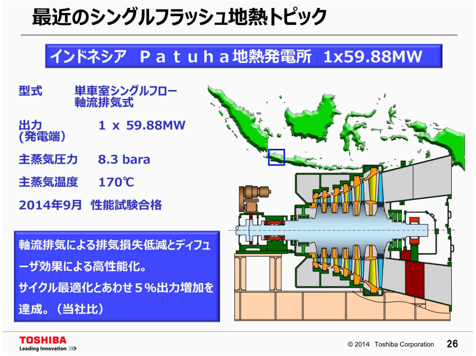
最近のシングルフラッシュ地熱トピック
インドネシア Ｐａｔｕｈａ地熱発電所 1x59.88MW
型式 単車室シングルフロー 軸流排気式
出力 (発電端) 1 x 59.88MW
主蒸気圧力 8.3 bara
主蒸気温度 170℃
2014年9月 性能試験合格
軸流排気による排気損失低減とディフューザ効果による高性能化。
サイクル最適化とあわせ５％出力増加を達成。（当社比）
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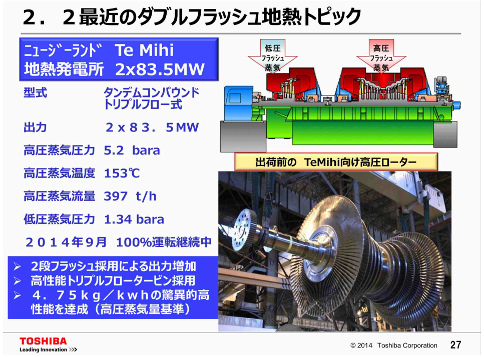
２． ２最近のダブルフラッシュ地熱トピック
ﾆｭｰｼﾞｰﾗﾝﾄﾞ Te Mihi 地熱発電所 2x83.5MW
低圧フラッシュ蒸気
高圧フラッシュ蒸気
型式 タンデムコンパウンド トリプルフロー式
出力 ２ｘ８３．５MW
高圧蒸気圧力 5.2 bara
高圧蒸気温度 153℃
高圧蒸気流量 397 t/h
低圧蒸気圧力 1.34 bara
２０１４年９月 100%運転継続中
出荷前の TeMihi向け高圧ローター
2段フラッシュ採用による出力増加
高性能トリプルフロータービン採用
４．７５ｋｇ／ｋｗｈの驚異的高性能を達成（高圧蒸気量基準）
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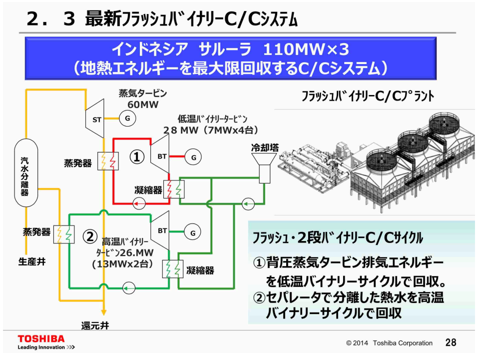
２． ３ 最新ﾌﾗｯｼｭﾊﾞｲﾅﾘｰC/Cｼｽﾃﾑ
インドネシア サルーラ 110MW×3
（地熱エネルギーを最大限回収するC/Cシステム）
蒸気タービン 60MW
低温ﾊﾞｲﾅﾘｰﾀｰﾋﾞﾝ 28 MW（7MWx4台）
ﾌﾗｯｼｭﾊﾞｲﾅﾘｰC/Cﾌﾟﾗﾝﾄ
冷却塔
汽水分離器
蒸発器
凝縮器
高温ﾊﾞｲﾅﾘｰﾀｰﾋﾞﾝ26.MW (13MWx2台)
生産井
還元井
ﾌﾗｯｼｭ・2段ﾊﾞｲﾅﾘｰC/Cｻｲｸﾙ
①背圧蒸気タービン排気エネルギーを低温バイナリーサイクルで回収。
②セパレータで分離した熱水を高温バイナリーサイクルで回収
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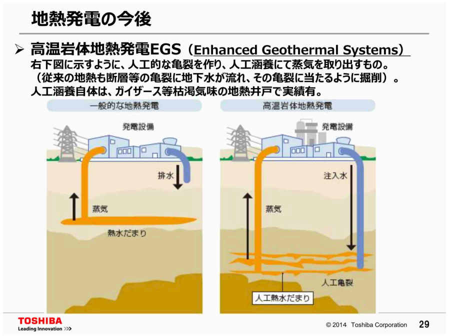
地熱発電の今後
高温岩体地熱発電EGS（Enhanced Geothermal Systems）
右下図に示すように、人工的な亀裂を作り、人工涵養にて蒸気を取り出すもの。
（従来の地熱も断層等の亀裂に地下水が流れ、その亀裂に当たるように掘削）。
人工涵養自体は、ガイザース等枯渇気味の地熱井戸で実績有。
一般的な地熱発電
高温岩体地熱発電
発電設備
排水
蒸気
熱水だまり
注入水
人工亀裂
人工熱水だまり
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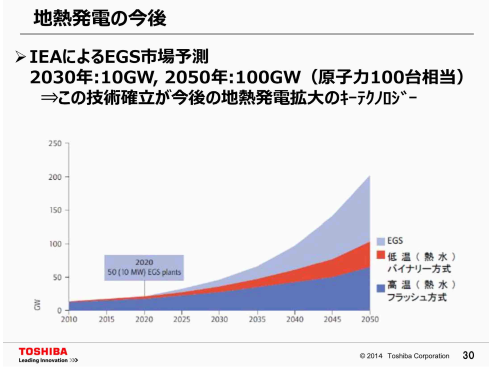
地熱発電の今後
IEAによるEGS市場予測
2030年:10GW, 2050年:100GW（原子力100台相当）
⇒この技術確立が今後の地熱発電拡大のｷｰﾃｸﾉﾛｼﾞｰ
2020
50 (10 MW) EGS plants
EGS
低温（熱水）バイナリー方式
高温（熱水）フラッシュ方式
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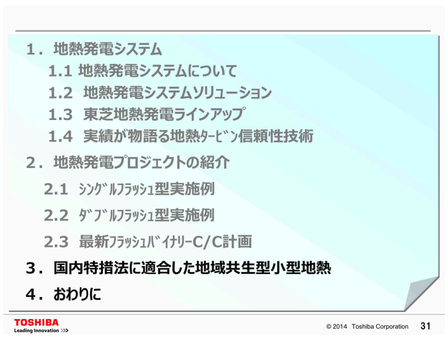
１．地熱発電システム
1.1 地熱発電システムについて
1.2 地熱発電システムソリューション
1.3 東芝地熱発電ラインアップ
1.4 実績が物語る地熱ﾀｰﾋﾞﾝ信頼性技術
２．地熱発電プロジェクトの紹介
2.1 ｼﾝｸﾞﾙﾌﾗｯｼｭ型実施例
2.2 ﾀﾞﾌﾞﾙﾌﾗｯｼｭ型実施例
2.3 最新ﾌﾗｯｼｭﾊﾞｲﾅﾘｰC/C計画
３．国内特措法に適合した地域共生型小型地熱
４．おわりに
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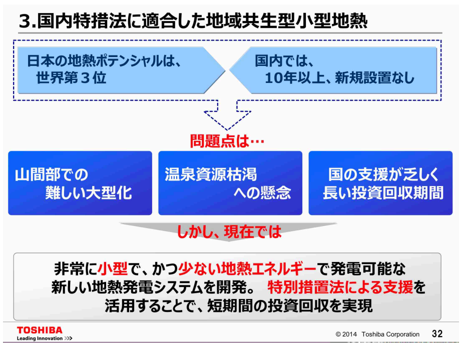
3.国内特措法に適合した地域共生型小型地熱
日本の地熱ポテンシャルは、世界第３位
国内では、10年以上、新規設置なし
問題点は…
山間部での難しい大型化
温泉資源枯渇への懸念
国の支援が乏しく長い投資回収期間
しかし、現在では
非常に小型で、かつ少ない地熱エネルギーで発電可能な新しい地熱発電システムを開発。 特別措置法による支援を活用することで、短期間の投資回収を実現
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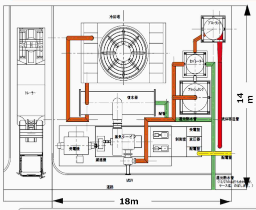
地熱発電事業　事業性検討

- **建設コスト**：開発地点により下記要因で大きく初期コストが変化
  ①井戸掘削コスト（深さ、蒸気噴出量、掘削期間）
  ②送電線コスト（山間地のため、系統連系点までの距離、容量）
  ③補機コスト（蒸気条件、性状により、補機容量が変化）
- **地元理解**：候補地は温泉地に隣接、温泉枯渇危惧の払拭要
  ①地熱開発における周辺温泉へのモニタリング
  ②地域との共同事業化：休止又は老朽温泉井戸の代替掘削による湯煙発電、余剰熱水を温泉へ供給
- **耐久性**：地熱蒸気の枯渇や、腐食、固形物堆積による出力減
  ⇒適正メンテナンス費の計上、代替生産井の計画
- **発電単価**：燃料不要であるが、大容量化が難しく高い発電単価
  ⇒日本においては、固定買取制度により、数MWでも事業採算性向上（地熱開発千歳一遇のチャンス到来）

地域共生型　小型地熱発電所計画

2000kW級　標準レイアウト（発電所敷地300m²以下）



小型地熱発電所

- 蒸気量24～30ton/hで2000kWの発電が可能（生産井戸1～2本相当）
- 発電に使用しない熱水は、温泉向けとして供給
- 発電所は300m²の敷地（百坪発電所）
- 特別措置法を活用、40円/kWhで売電することで、投資回収は、5年未満

奥飛騨中尾地区小型地熱開発事例

奥飛騨温泉郷

- 奥飛騨温泉は５ヵ所（平湯温泉、新平湯温泉、福地温泉、新穂高温泉、中尾温泉）の総称であり、130軒の温泉旅館で構成されています。
- 一方、バブル以降、年間の集客数はピーク時から減少傾向であり、地域活性化が求められています。

環境省再エネ事業業務委託

奥飛騨地熱井掘削

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Leading Innovation >>>

Summary of Geo-thermal power generation of Tohoku Electric Power
(Kentaro Otuki, Tohoku Electric Power)

1. Mechanism and characteristics of geothermal power

○ Mechanism of geothermal power generation

The steam of low temperature that has finished work in a steam turbine becomes condensed water in the condenser, is back from the reinjection wells in the basement. (Figure 1)

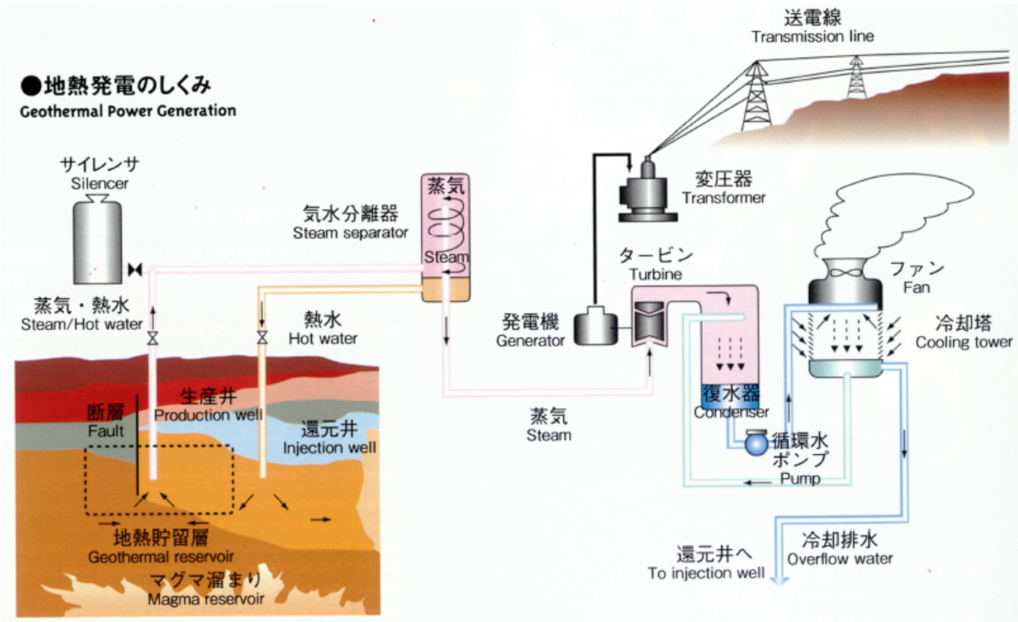


Figure 1 mechanism of geothermal power generation

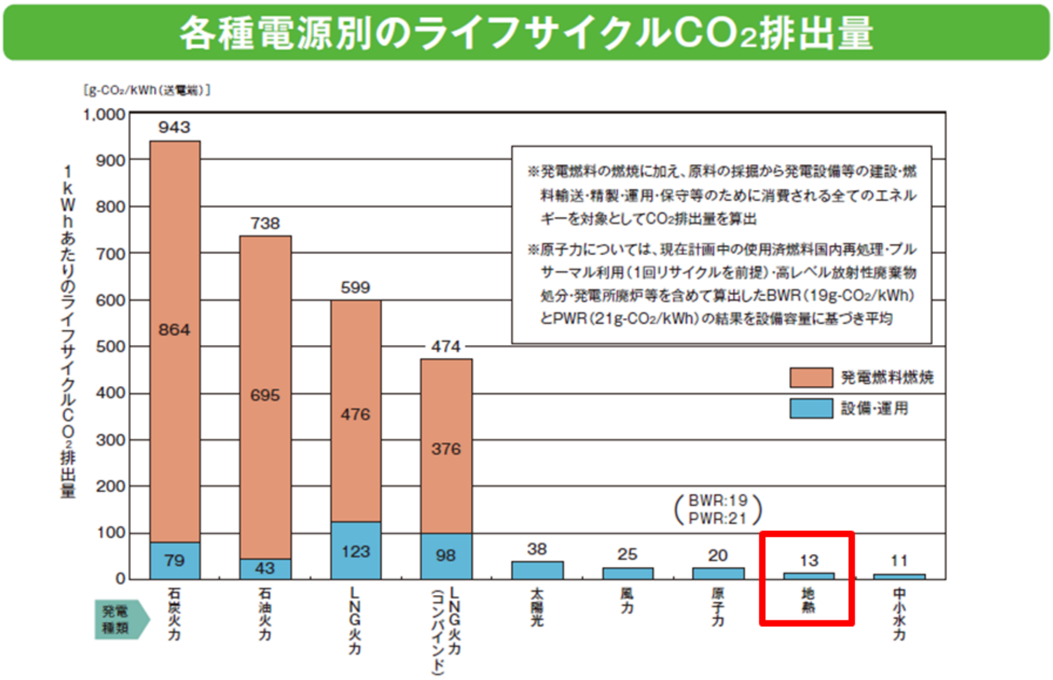
○ Features of geothermal power generation

Features of geothermal power generation is as follows.

- Net domestic energy that does not rely on imports
- Renewable energy
- Stable power supply in the natural energy
- Environmental load is small, CO_2 emissions is small
- Multi-purpose use is possible (agriculture, forestry and fisheries, tourism, etc.)
- Share is not very large in the world

Life cycle CO_2 emissions of geothermal power generation has become a low level compared to other power sources.

Also, compared to other renewable energies, as high as about 80% facility usable rate, there are many power generation can be characterized by the same output. (Figure 2)



<Source> Federation of Electric Power Companies of Japan, "Nuclear energy drawings collection 2014"

□電源別の設備利用率

地熱	約80%
風力	約20%
太陽光	約12%

<出典>コスト等検証委員会報告書
(内閣府：平成23年12月19日)

Figure 2 life cycle CO_2 emissions, each power supply facility usable ratio

2. World and Japan's geothermal power generation

○ History of geothermal power generation

1904 Driving a generator using natural steam by Jiriko Conti Duke in Italy Larderello (output 0.75 hp)

1913 The world's first geothermal power plant in Italy Larderello (output 250kW)

1918 Vice Admiral Toshiharu Yamauchi started excavation at Oita Prefecture Hayami District Asahi village Tsurumi 950-1. The success of excavation in 1919. (Pore size 4 suns, depth 80 shaku)

1925 Mr. Osamu Tachikawa of Tokyo electric light Ltd. Institute, took over the business

of Yamauchi et al, named "Tsurumi fumaroles", after number of test results, the first successful geothermal power generation in Japan by the turbine. (Output 1.12kW)
1947 Geological survey was started for research on the selection of geothermal development area.
1948 Tone bowling Ltd. succeeded in power generation by steam turbine in Shizuoka Prefecture Joto village Yunosawa laboratory. (3kW)
1951 The geothermal power generation succeeded in Industry and Technology Agency Beppu test site. (Output 30kW)
1958 The world's first start of operation of geothermal power plants in hot water separation type in New Zealand Wairakei. (Output 6,500kW)
1960 Start of operation of private geothermal power generation at Fujita Kanko Inc. Hakone Kowakien. (Output 30kW, 1965 obsolete)
1966 Start a geothermal power generation by Japan Metals & Chemicals Co., Ltd. At Matsukawa geothermal power plant at the first time in Japan. (Output 9,500kW)
1967 Start a geothermal power generation by Kyushu Electric Power Co., Ltd. At Otake power plant. (Hot water separation type, output 11,000kW)
1996 Geothermal power output 500 000 kW achieved.
2006 Japan's first binary power plant (Hatchobaru, 2,000kW) was in operation.
2012 feed-in tariff (FIT) was started.

○ Geothermal power generation facilities in the world

Japan is located in the volcanic zone of the Pacific Rim, abundance of geothermal is said to be third largest after the United States, and Indonesia, however, the introduction amount is not as many than other countries. (Figure 3, Figure 4)

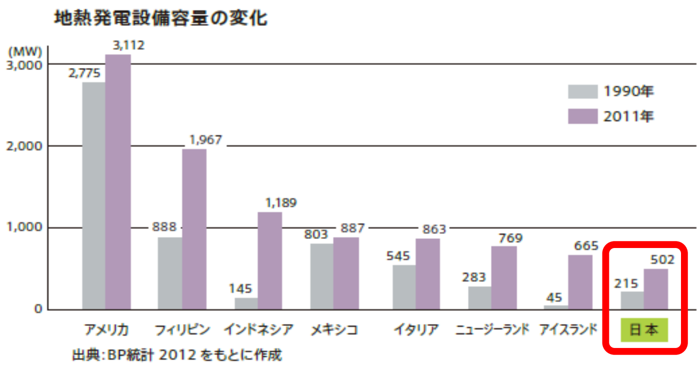
<Source> National Institute of Oil, Gas and metal mineral resources mechanism "geothermal pamphlet"

Figure 3 The world geothermal power generation capacity

世界各国の主な地熱資源量

順位	国名	資源量 (万kW)
1	アメリカ	3,900
2	インドネシア	2,700
3	日本	2,300
4	フィリピン	600
5	メキシコ	600
6	アイスランド	580
7	ニュージーランド	370
8	イタリア	150

※ 1万kW = 10MW
出典:村岡洋文、OHM、2011.7をもとに作成



<Source> National Institute of Oil, Gas and metal mineral resources mechanism "geothermal pamphlet"

Figure 4 World major geothermal resource amount of each country, and the change in the geothermal power generation capacity

○ situation of geothermal development in the world

Geothermal development in countries around the world is accelerating aggressively. (Figure 5)

単位:万kW

米国	2005年	2010年	2015年(見込み)
	256.4	309.3	540

(注)主な地熱発電所:ガイザーズ(カリフォルニア州、14基、出力127.3万kW)等

インドネシア	2005年	2010年	2015年(見込み)
	79.7	119.7	350

(注)主な地熱発電所:サラク(西ジャワ州、6基、出力37.5万kW)等

ニュージーランド	2005年	2010年	2015年(見込み)
	43.5	62.8	124

(注)主な地熱発電所:タウポ(ニュージーランド北島、11基、出力17.5万kW)等

アイスランド	2005年	2010年	2015年(見込み)
	20.2	57.5	80

(注)主な地熱発電所:ヘリシェイディ(アイスランド南西部、5基、出力30.3万kw)等

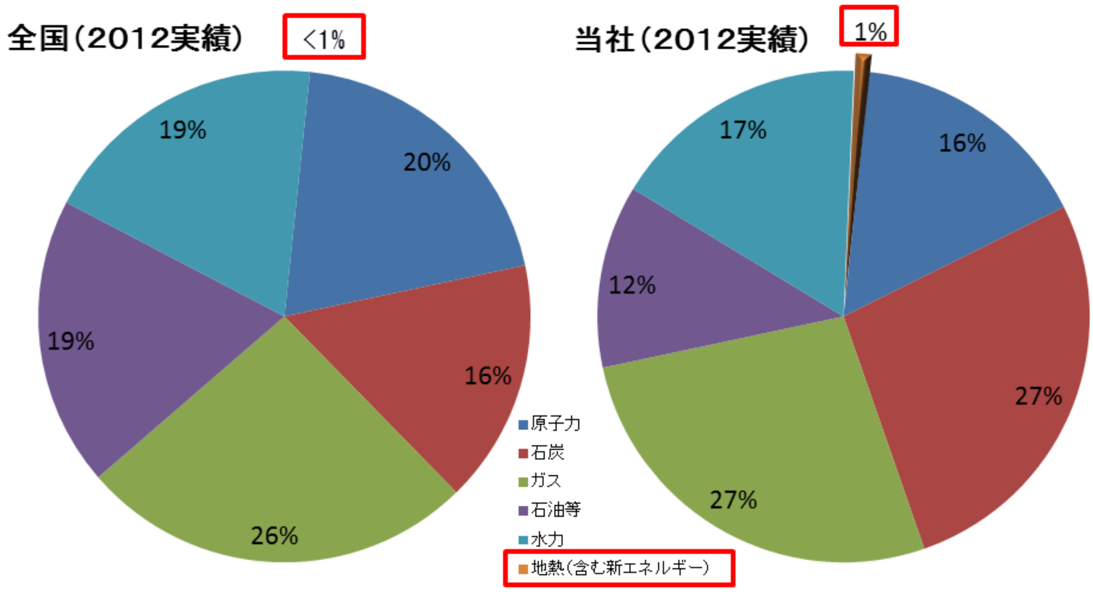
<出典> Ruggero Bertani : Geothermal power generation in the world 2005-2010 update report

Figure 5 status of the world's geothermal development

3. The proportion of power generation scale of nationwide and our company

○ Power configuration ratio based on power generation capacity

As for our company's geothermal power generation, it is about 1% of power generation installed capacity in our company inside, and it is a minority and less than 1% in Japan. (Figure 6)

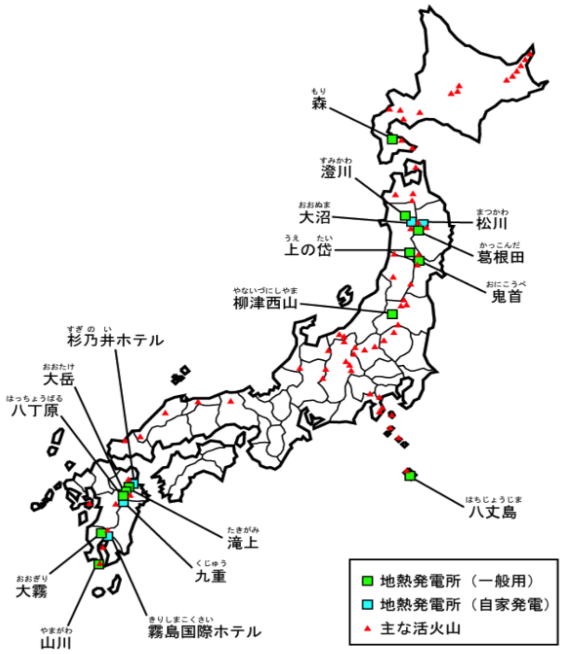


<Source> Federation of Electric Power Companies of Japan, "Nuclear energy drawings Collection 2014" (national data only)

Figure 6 Power supply configuration ratio in accordance with power generation installed capacity (nationwide, our company)

○ Power generation scale of geothermal power

Currently, geothermal power generation in Japan has been developed in the17 points, most of which have been installed in the Tohoku and Kyushu. (Figure 7)



	全国	東北電力
地点数	17地点	5地点
認可出力（万kW）	51．509	24．730（48%）
発電電力量（億kWh）	26．2	10．3（39%）

<Source> geothermal power generation of the current status and trends 2013

<Source> "Japan's geothermal power plant" Industrial Scienc and Technology Institute HP

Figure 7 Japan's geothermal power plant and the power generation amount

4. Features and efforts of our geothermal power

○ Overview of the geothermal power plant of our company

Our Company has 5 power plant 6 generators including a cooperating group, total authorized output accounts for about 48% of the geothermal power plant of Japan. (Figure 8)

Our company’s (including a group of companies) geothermal power plants are, relatively, located in the vicinity of the ILC candidate site. (Figure 9)

発電所名	所在地	号機	設備容量（kW）	運転開始	蒸気供給会社
葛根田	岩手県雫石町	1号	50,000	S53.5.26	東北水力地熱㈱ （旧）日本重化学工業
		2号	30,000	H8.3.1	
上の岱	秋田県湯沢市	ー	28,800	H6.3.4	東北水力地熱㈱ （旧）秋田地熱エネルギー
澄　川	秋田県鹿角市	ー	50,000	H7.3.2	三菱マテリアル㈱
柳津西山	福島県柳津町	ー	65,000	H7.5.25	奥会津地熱㈱
小　計			223,800		
松　川	岩手県八幡平市	ー	23,500	S41.10.8	東北水力地熱㈱
合　計			247,300		

Figure 8 Overview of the Company's geothermal power generation

Figure 9 position of the geothermal power plant of the Company (including a group of companies)

○ Our geothermal power generation organization

The steam production and reduction are conducted by steam supply company. We adopted a joint development system for generating electric power by purchasing the steam (about Matsukawa, consistently operated by Tohoku Hydropower Geothermal Co., Ltd. [group of companies]). (Figure 10)

※ Matsukawa geothermal power plant, consistently operated by Tohoku Hydropower Geothermal Co., Ltd. (group of companies)

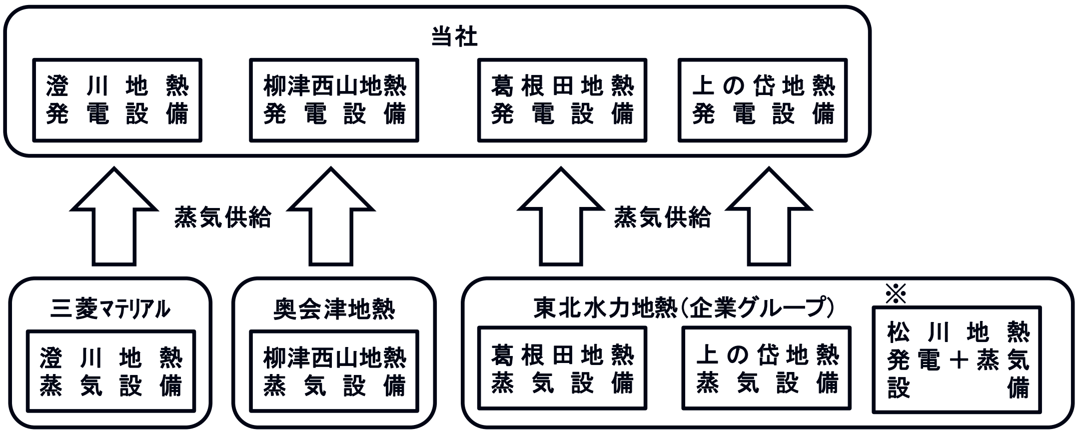


Figure 10 Our company's geothermal power generation organization

○ Features of our geothermal power plant

Geothermal power plants have a simple structure without such a boiler compared to thermal power plants.

From this reason, we have adopted the remote operating system to monitor and control in the monitoring room of 10-30 km away from each geothermal power plant.

Our company has proceeded further rationalization from 2000 fiscal year, to employ a centralized monitoring and controlling of 5 geothermal power generators of four power plants locations from Akita thermal power plants.

(Figure 11, Figure 12)

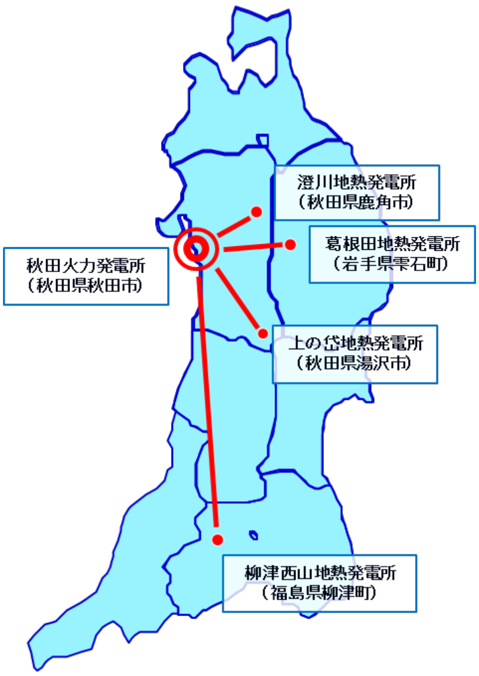


Figure 11 centralized remote monitor control system

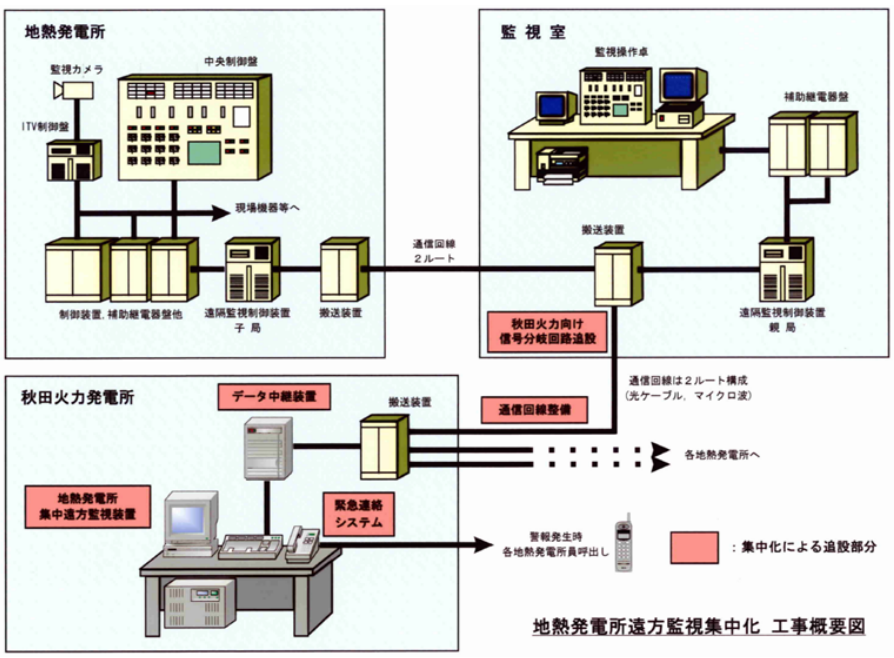


Figure 12 Overview of centralized remote monitor control system

○ Changes in year average output

Our geothermal power plants, there is a high performance experience, after the operation of Kakkonda Unit 1 (1978). In 1990 or later, we have sequentially started the operation of Uenotai, Sumikawa, Yanaizu-Nishiyama, and Kakkonda No.2. Initially, although the output power was the order of 70-80 percent in about 5-10 years, and significant vapor reduction was happened in 10 years passed, and the output power became about 50 percent in about 15 years and now. After that, it is almost stable at this level.

As annual average output (red line) is close to approval output (blue line), it shows a high investment performance. (Figure 13)

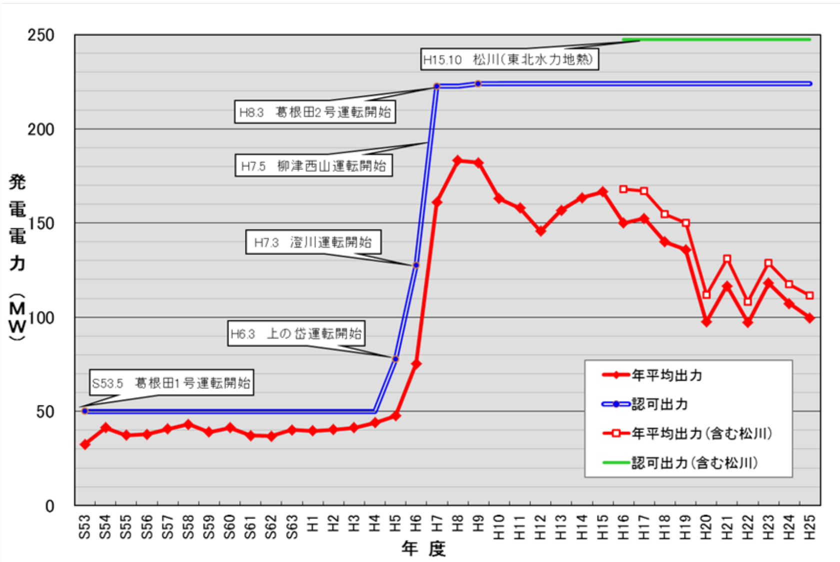


Figure 13 Trends in year average output

○ Transition of power generation time utilization

Transition of power generation time utilization ratio of each power plant can be divided to two groups; Uenotai and Sumikawa of high utilization (70-90 percent) group even 15 years after the start of operation, and Kakkonda, Yanaizu-Nishiyama and Matsukawa of low utilization (50% or less) group. You can see the difference in investment performance point by point. (Figure 14)

The power generation time utilization ratio is the percentage ratio of the amount of power generated during the fiscal year, with the amount of power that can be obtained within the actual power generation time at the rated output.

$$\text{発電時間利用率(\%)} = \frac{\text{年度の発電電力量(kWh)}}{\text{定格出力(kW)} \times \text{年度の発電時間(h)}} \times 100$$

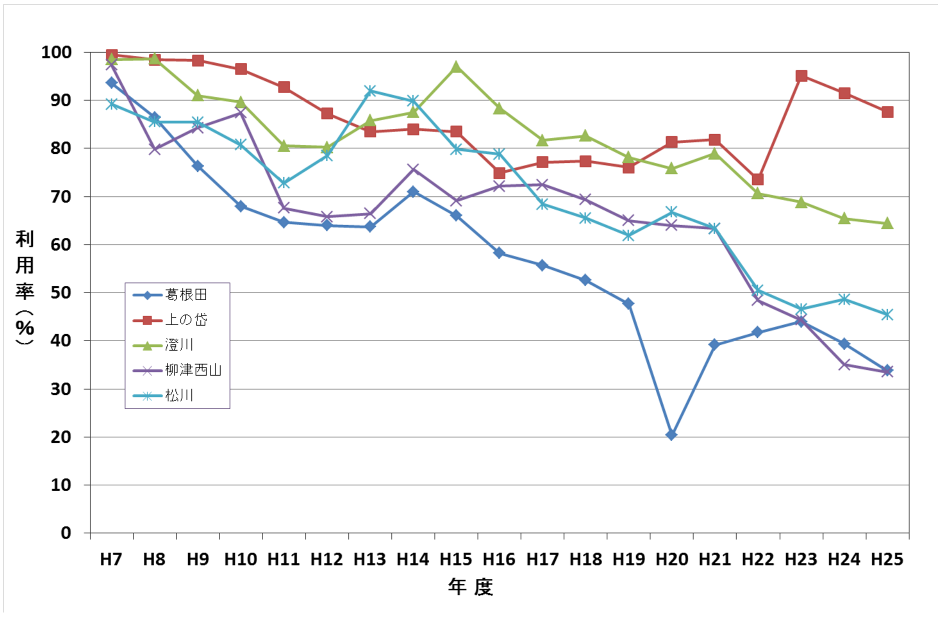


Figure 14 Transition of power generation time utilization ratio

○ Challenge of geothermal power plant operation

"Steam well attenuation", "scale", and "hydrogen sulfide" are the issues as big factors that reduce the output (operating ratio) in geothermal power plant operations.
Our company has implemented for the operating rate improvement efforts.

○ Operating ratio improvement efforts

In Uenotai and Sumikawa geothermal power plant of our company, it has gained a certain degree of success by drilled the replenishment well into the natural park, by receiving benefits of a deregulation of Japan. (Figure 15, Figure 16)

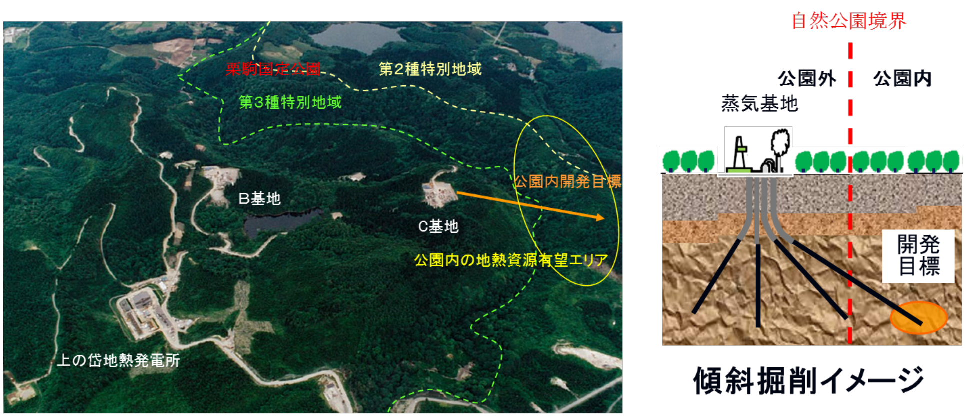


Figure 15 the example of Uenotai thermal power plant replenishment well T-56

Figure 16 The situation of fumaroles of inclination well in the National Monument Park (replenishment production well T-56)

○ Geothermal reservoir recharge project

There is a case that the power generation output is fluctuating in a geothermal power plant by being unable to collect the required amount of steam and hot water stably.

By performing the supply of water to the heat source of the underground more appropriately, JOGMEC (National Institute of Oil, Gas and metal mineral resources) is developing a technology to achieve optimization and stabilization of the collected amount of steam and hot water at Yanaizu-Nishiyama geothermal power plant. (Figure 17)

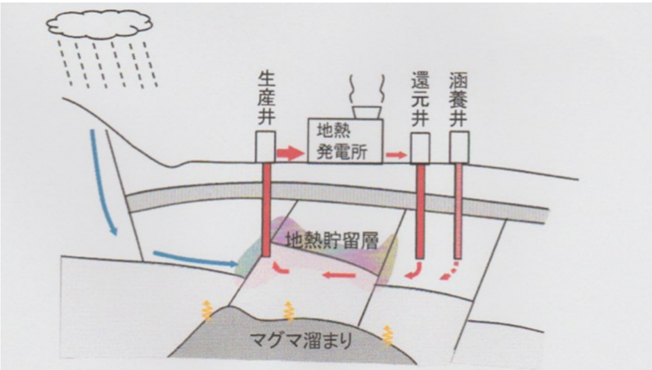


Figure 17 Schematic of geothermal reservoir recharge project

5. Challenges and the Japan's support system for geothermal power generation

○ Challenges geothermal power generation

· Single machine capacity is small.

In business power generation facilities in Japan, 3,300kW ~ 65,000kW

In Japan of private power generation 100kW ~ 23,500kW

· Research ~ development ~ commercial operation take time.

National-wide survey ~ wide area survey ~ rough survey ~ fine survey ~ development survey ~ power plant construction.
(Example: on Uenotai took 23 years)

· Number of new power plant construction is limited.
Since promising areas are unevenly distributed in the Tohoku and Kyushu, and since about half of the possible development area are located in a special area on the Natural Parks Law, new development is difficult.

○ For support measures in geothermal development process
Auxiliary support of Japan related to geothermal development (JOGMEC) has been provided in stages. (Figure 18)

<Source> Agency for Natural Resources and Energy, "the current state of geothermal resources development (September 2014)."

Figure 18 Support measures in geothermal development process

○ Geothermal development point of nationwide
Figure 19, is a situation of geothermal development sites nationwide.
We in the corporate group are being carried out the early stages of the investigation "Kijiyama - Shimonotai (Akita Prefecture Yuzawa City) area".

<Source> Agency for Natural Resources and Energy, "the current state of geothermal resources development (September 2014)."

Figure 19 status of geothermal development sites nationwide

○ Geothermal power plant that was operating since FIT

The operational geothermal power generation facilities after FIT (feed-in tariffs) were five plants and total output of about 250kW. At the moment it is mostly small-scale plant. (Figure 20)

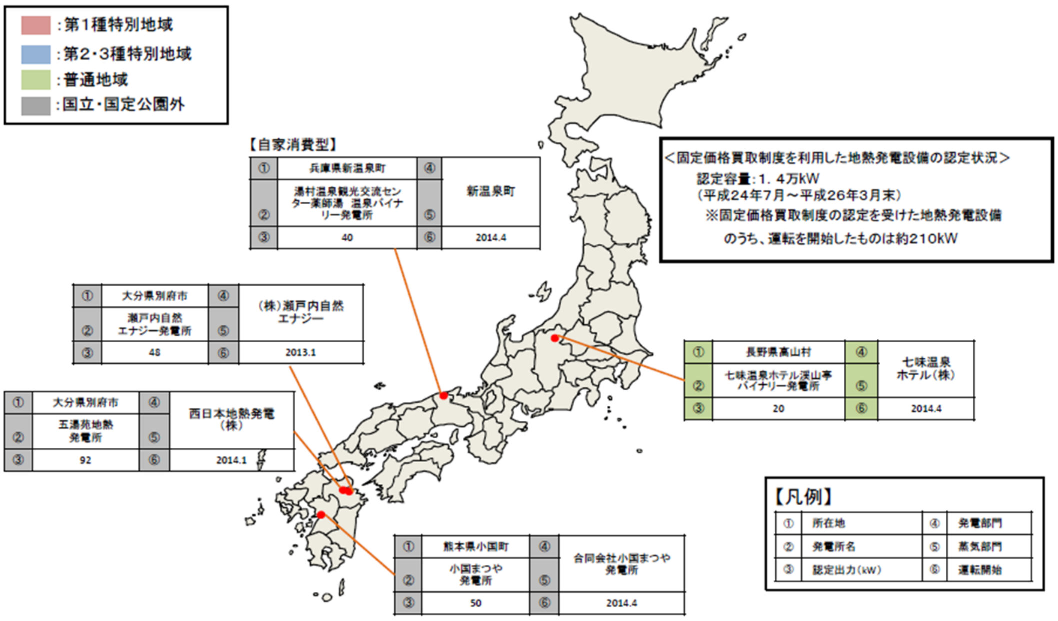


Figure 20 geothermal power plant that has operated since FIT

6. Efforts to geothermal development of our company's corporate group

○ Kijiyama, Shimonotai regional geothermal resource development research projects

Our group of companies "Tohoku Hydropower Geothermal" is making the geothermal resource survey of the early stages, in the adjacent land of Uenotai thermal power plant "Kijiyama, Shimonotai".

In the area of Kijiyama and Shimonotai, up to now, we conducted the ground survey, exploration well two, and monitoring well single drilling, then make ongoing the overall analysis. (Figure 21, Figure 22)

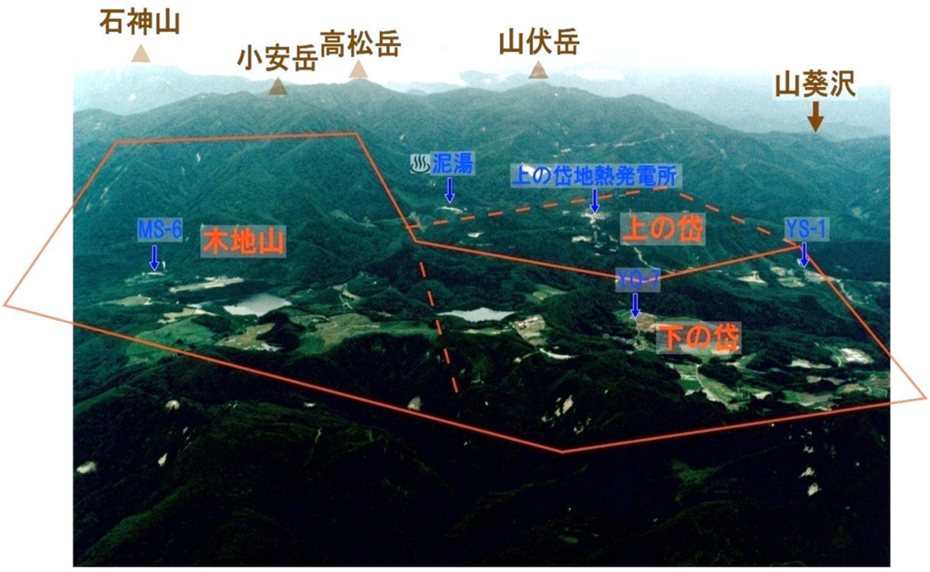


Figure 21 bird's-eye view of Kijiyama, Shimonotai area

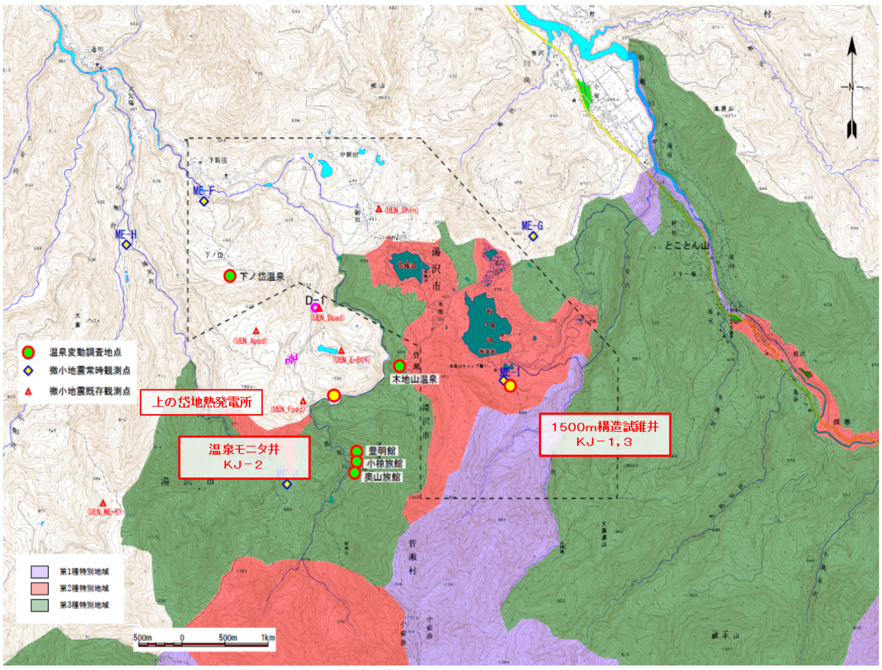


Figure 22 Kijiyama-Shimonotai regional position

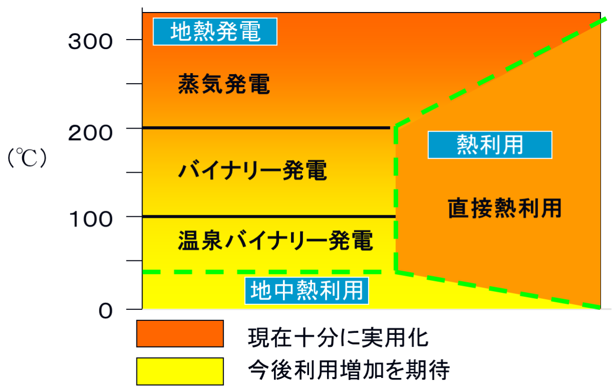
○ Kijiyama, Shimonotai region geothermal development research results and planning
Kijiyama - Shimonotai survey schedule is below.
Continues a similar survey to 2015 fiscal year, and to review and evaluate the commercialization potential on it, is expected to plan an investigation after the 2016 fiscal year. (Figure 23)

年度	H22	H23	H24	H25	H26	H27
調査位置づけ	地熱構造調査	地熱構造モデル作成	地熱構造モデル見直し	地質構造調査・モニタリングデータ収集		
地表調査坑井掘削他	・地質調査 ・地化学調査 ・電磁探査 ・重力探査 ・坑井圧力ﾓﾆﾀﾘﾝｸﾞ ・温泉変動ﾓﾆﾀﾘﾝｸﾞ ・微小地震観測	・電磁探査 ・自然電位探査 ・フラクチャ解析 ・坑井圧力ﾓﾆﾀﾘﾝｸﾞ ・温泉変動ﾓﾆﾀﾘﾝｸﾞ ・微小地震観測	・電磁探査 ・坑井圧力ﾓﾆﾀﾘﾝｸﾞ ・温泉変動ﾓﾆﾀﾘﾝｸﾞ ・微小地震観測	・坑井圧力ﾓﾆﾀﾘﾝｸﾞ ・構造試錐井掘削 ・温泉ﾓﾆﾀﾘﾝｸﾞ井掘削 ・温泉変動ﾓﾆﾀﾘﾝｸﾞ 他	・坑井圧力ﾓﾆﾀﾘﾝｸﾞ ・構造試錐井掘削 ・ﾄﾚｰｻｰ試験	・坑井圧力ﾓﾆﾀﾘﾝｸﾞ ・隣接貯留層との関係評価他 ・事業化可能性の検討

Figure 23 Kijiyama, Shimonotai investigation schedule

7. Utilization of geothermal energy

○ Effective utilization of geothermal energy due to the difference in the temperature
We are utilizing the area of the steam power generation, but in recent years has spread the movement to take advantage of geothermal resources in the binary power generation. (Figure 24)

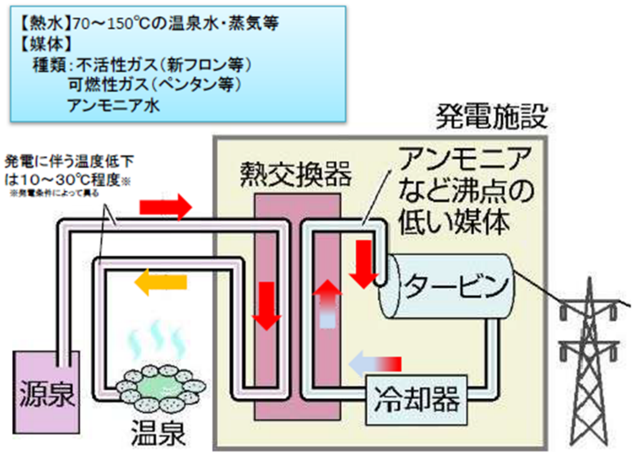


<Source> New Energy Foundation brochure
Figure 24 Geothermal energy area and the availability

○ Mechanism of geothermal binary power generation (hot spring power generation)

Binary power generation is a system for generating electricity by turning a turbine generator, using a medium having a lower boiling point than water boiled in hot spring of heat (70℃ ~ 150℃). (Figure 25)

If the order of several hundred kW is required, it is possible to develop in a short period of about 2-3 years.



<Source> Agency for Natural Resources and Energy, "the current state of geothermal resources development (September 2014)."

Figure 25 mechanism of geothermal binary power generation

○ Case Study of geothermal resources

Matsukawa geothermal power plant (Tohoku Hydropower Geothermal Co., Ltd., Iwate Prefecture Hachimantai) warmed condensed water after power generation by the addition of steam, and sold to Hachimantai Industrial Promotion of the third sector. It has been used in Hotels and cottage villa, and in greenhouses with a hot water supply contract. (Figure 26)

(In the 2010 fiscal year, 70 ℃, up to 260t/h)

供給先

・ホテル等	３８軒	・保養所	２５軒	・別荘	６１３軒
・商店	１５軒	・貸別荘施設	１軒	・病院	１軒
・老人ホーム	１軒	・日帰り温泉施設	１軒		
・農業用ハウス	９５棟（冬期のみ）				

Figure 26 Matsukawa condensed water supply destination after geothermal power plant power generation

End.

7 Editor words

High efficiency energy conversion in International Linear Collider (ILC) is an inevitable issue among advanced accelerator project. ILC should be the model for use of high-efficiency equipment, and the use of sustainable and renewable energy sources. The Technology Group of the Association of Adavanced Accelerator Science and Technology Promotion began a study of this issue. This report is a summary about the technology being studied which has been proposed at green ILC Working Group in February 2014 to March 2015. Technical study is intended to make continued even after April 2015, but the present report is the first stage of the study results, which will be a help document at the time of ILC detailed design stage in the near future. We would like to keep both the Japanese and English version of this report in the ILC-related web-page.

Individual presentations at the working group can be found at;

https://aaa-sentan.org

See the member pages of the inside.

Editor
May 27, 2015