R&D of geothermal resources for power generation and heating

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Origin of geothermal energy in Japan

Oceanic Plate

Volcano

Magma

H₂O

(Tatumi 1995)

Velocity change of S wave

(Pacific Plate)

(Tohoku University)
Development style of geothermal energy in Japan

- **EGS (Treatment Injection)**
  - The Geysers
  - Yanaizu-Nishiyama

- **EGS (Improvement of permeability of tight rock)**
  - Hijiori, Ogachi, Rosemanowes, Soultz, Basel, Cooper Basin

- **EGS (Improvement of permeability of existing fractures)**
  - Desert Peak

- **EGS (Connection to hydrothermal reservoirs)**
  - Desert Peak

- **Basement rock (Crystalline)**
  - 1.5〜2km, 200〜350℃
  - 2.5〜5km

- **HT hydrothermal system**
  - 3〜several km, 350℃

- **Brittle-Ductile Transition (BDT)**
  - 3〜6km, 400〜600℃

- **Subduction-origin magma intrusion (Japanese case)**

**Heatpump**

**Power Plant**
Hydrothermal energy in Japan

Geothermal potential (MWe)

Indonesia
USA
Japan
Mexico
Philippines
Iceland
NZ
Italy

Stefansson (2005)
Geothermal energy in Japan

Installed capacity (MWe)

USA
Philippines
Indonesia
Mexico
Italy
New Zealand
Iceland
Japan
El Salvador
Kenya
Turkey
Costa Rica
Nicaragua
Russia
Iceland
Kenya
Turkey
Costa Rica
Nicaragua
Russia

Stefansson (2005)
Japanese geothermal R&D

(Bertani, 2012)
Japanese geothermal R&D

Geothermal Power Generation in Japan

- Capacity (MW)
- Power Generation (GWh)
- Capacity factor (%)

METI's budget for geothermal development

- R&D (technology)
- R&D (assessments)
- Development subsidies
- Education, Publication
- Loan guarantee

(Yasukawa, 2015)
Geothermal power stations in Japan (1999-2012)

17 geothermal power plants with 20 units

- 12 areas, 14 units 10MW or bigger
- 3 + 1 units 1MW-10MW
- 2 units less than 1MW

**Installed capacity of 540 MW in total**

**On-going projects** (began before 2011)
- Exploration by TOHGEC group in Hachimantai, aiming at 10 MW.
- Environmental assessment by Yuzawa-Chinetsu Co. Ltd. in Wasabizawa, aiming at 42 MW in 2020.
Geothermal power stations in Japan (at present)

24 geothermal power plants with 27 units

- 12 areas, 14 units 10MW or bigger
- 3 + 1 units 1MW-10MW
- 9 units less than 1MW

Installed capacity of 518 MW

On-going projects:
- 19 prospects over 10MW
- 7 prospects 1MW-10MW
- 18 prospects less than 1MW
  (as of July 2014)

Coming soon:
- Additional 2MW for Abo Tunnel
- Additional 0.05MW for Goto-en both in 2015
1. National Parks
   Approximately 80% of high potential geothermal resources exists inside national parks where no exploration/development is allowed.

2. Coexistence with hot springs
   Some owners of hot springs make strong campaign against geothermal development in afraid of degradation of the springs.

3. Uncertainties, lead time, cost
   Uncertainties in resources, high initial cost and long lead time prevent private sectors to invest to geothermal developments.

4. Size of hydrothermal systems
   20-30 MWe/field would be suitable for sustainable production from naturally existing hydrothermal systems in Japan.
Governmental supports for geothermal power developments

Ministry of Economy, Trade and Industry (METI)

Surface issues

New Energy and Industrial Technology Development Organization (NEDO)
- Small scale binary plant (hot spring power generation)
- Scale measure
- Environmentally friendly design methodologies
- Monitoring system of hot springs
- Innovative concept of geothermal development

Sub-surface issues

Japan Oil, Gas and Metals National Corporation (JOGMEC)
- Treatment injection type engineered geothermal systems (EGS)
- Magnetic precise exploration
- Development of high efficient drill-bits
- Loan guarantee and financial supports
1. Treatment injection for production recovery at Yanaizu-Nishiyama

- Installed capacity 65,000kW
- Beginning of the operation May, 1995
- Lot 54 km²
- Reservoir type steam dominant
1. Treatment injection for production recovery at Yanaizu-Nishiyama

Surface survey⇒drill a re-injection well⇒injection⇒increase steam flowrate

Cross section of the field and schematic of re-injection
Geothermal R&D in FREA
1. Treatment injection for production recovery at Yanaizu-Nishiyama
2. Monitoring system of hot spring

- Multifunctional monitoring by sensors (Temp., Flowrate, Conductivity) and plug-in sensors
- Air temp. sensor
- Wired/wireless data transmission capability
- Flexible interface to various types of pipes
- Flexible power interface (AC/DC)
- Removal data storage
- Battery for stabilization
- PV (optional)
- Plug-in sensors (water level etc.)
2. Monitoring system of hot spring

1. EM flowmeter
2. Conductivity sensor
3. Temperature sensor
4. Short pipe
5. Reducer
6. Short pipe
7. Reducer
Concept of the Japan Beyond-Brittle Project (JBBP)

1.5～2km
200～350℃

1.5～2km
200～350℃

EGS (Treatment Injection)
The Geysers
Yanaizu-Nishiyama

EGS (Connection to hydrothermal reservoirs)
Desert Peak

EGS (Improvement of permeability of existing fractures)
Hijiori, Ogachi, Rosemanowes, Soultz, Basel, Cooper Basin

2.5～5km

2.5～5km

Basement rock
(Crystalline)

3～several km
350℃

3～several km
350℃

HT hydrothermal system

3～several km
350℃

3～several km
350℃

Brittle-Ductile Transition (BDT)

3～6km
400～600℃

3～6km
400～600℃

Subduction-origin magma intrusion (Japanese case)

EGS (Fracture initiation in sedimentary rock)
Groß Schönebeck

EGS (Improvement of permeability of tight rock)
Fenton Hill, Newberry

HT hydrothermal system

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Experiences from Japanese HDR projects in Ogachi and Hijiori

Low water recovery rate
- Ogachi: 25-30% (Kaieda et al., 2005)
- Hijiori: 45-54% (Oikawa et al., 2001, Tenma et al., 2005)

Difficulties in reservoir design
- possible local anormally in stress (Kaieda et al., 2005)
- interference between reservoirs (Tenma et al., 2005)

Recently appeared problems

Possibility of induced/triggered damaging earthquakes
- Higher risk in seismogenic area (Evans et al., 2012)
- Rumor of citizens on subsurface development
Concept of the Japan Beyond-Brittle Project (JBBP)

Power Plant

1.5～2km
200～350℃

2.5～5km程度

Basement rock (Crystalline)

3～several km
350℃

Hotter, deeper and more ductile!

Japan Beyond-Brittle Project (JBBP)

3～6km
400～600℃
Advantages of the JBBP Type-Ⅲ development

Several GW for over 30 years / caldera

Baseload power generation
Planning of national projects to establish innovative energy and environmental technologies in 2030.

Planning of research on “development of subduction-origin SC geothermal resources in Japan” (1 year, 100 Million JPY)

AIST, Fuji Electronics, JFE Eng., Geothermal Eng., Tohoku U., Hokkaido U., U. Tokyo, Kyushu U., TIT
Closed loop
Circulation of antifreeze

Open loop
Usage of groundwater

GSHP
Several open-loop systems were installed in 1960-70s. However in urban areas, it was then strictly restricted by regulations to prevent land subsidence.

Renewed interest appears after WGC2000 held in Japan.

MOE began giving subsidies for installation of GSHP systems for the purpose of reduction of Urban Heat Island Phenomena (UHIP).

METI also began subsidies for energy saving purpose.

Symbolic buildings air-conditioned by GSHP system:
- Building of the highest tower of Japan, Tokyo Sky Tree (2013)
- Extension of International Terminal, Haneda/Tokyo airport (2014)
The Urban Heat Island Phenomenon

Commonly observed in East and South-East Asian countries.

Temperature increase in Tokyo and world average
**Current situation**

- Increase air temperature
- Increase energy demand for cooling
- Increase exhaust heat

**Impacts of the GSHP**

- Reduce urban heat-island phenomenon
- Suppression of energy demand for cooling
- Heat transfer by ground water

Reduction of UHIP by the GSHP
The number of installations in Japan

1981-2011 yr

Annual Installation

Cumulative Number of Installation

Annual Installation for Hybrid
Annual Installation for Open Loop
Annual Installation for Closed Loop
Total Installation for Closed Loop
Total Installation for Open Loop
Total Installation for Hybrid
Total Installation for All

(MOE, 2012)
Installed facilities

- House 434
- Office 114
- School 40
- Public Building 72
- Shop 40
- Kindergarten & Nursery 15
- Hospital 19
- Welfare Facility 12
- Hotel 35
- Spa Facility 16
- Factory 28
- Road (Snow Melting) 59
- Parking Lot (Snow Melting) 2
- Agriculture 33
- District Heating & Cooling 1
- Exper. 44
- Others 26

Total 990

(MOE, 2012)
Capacity of the GHHPs

1981-2011 yr

Annual capacity for Hybrid
Annual capacity for Open Loop
Annual capacity for Closed Loop
Cumulative capacity for Closed Loop
Cumulative capacity for Open Loop
Cumulative capacity for Hybrid
Cumulative capacity for All

62,476kWt

(MOE, 2012)
Number of borehole drillings

- Single U-tube
- Double U-tube
- Coaxial
- Pile

(MOE, 2012)
1. Potential assessment and mapping

- Preparation of potential maps by conducting geological field survey and groundwater survey, and regional scale groundwater flow - heat transport simulation
- Potential assessment for GSHP system in Tohoku region with a focus on Fukushima Prefecture
* Originality: Development of potential map incorporating groundwater flow (no examples in other countries) and contributing to accurate design and low cost system

2. Development of optimization technique of the GSHP system

- Optimization of GSHP system that meets the hydrogeological characteristics of the area and development of integrated technology
  (Collaboration with Fukushima University, Nihon University, Fukushima High-tech Plaza, Local Companies)
* Originality: Comparison of various types of system within same site. By utilizing huge geological data of GSJ, the optimization technology of the model area will be expanded nationwide
Ground heat exchanger (GHE) utilizing groundwater advection effect was installed at Fukushima Chikakaihatsu Pvt. Ltd.

Characteristics of GHE:
① Set to 50m depth adjusting with the depth at which groundwater flows. Conventionally, depth was 80m
② Casing with slits was fixed with groundwater in its surrounding (Grout: groundwater)
③ Installed double U-Tube of outer diameter 40mm thicker than conventional type
④ Above natural groundwater table, casing was grouted with mortar, such that heat exchange with ground is possible

Installation cost increases with depth, however, heat exchange capability increases with depth. Hence, reduction in number of heat exchanger is possible.
Technology seeds of company:
- Increasing efficiency of heat exchange leads to the cost reduction and energy saving.
- In areas with abundant groundwater and its flow, higher heat exchange rate can be expected. However, that performance has not been evaluated enough.
- Main point of this program is to construct a system utilizing artesian well as GHE, evaluate the performance and show its merits. In such a way, this kind of system can be developed in other regions rich in groundwater and artesian wells.

Evaluation of technology seeds by AIST:
- Installation of required system components, carry out experimental operation and evaluate the results and energy saving. Additionally, prepare potential maps for the new type system based on hydrogeological data and groundwater field survey.

Outcomes:
- Energy saving, low cost
- Groundwater of artesian well can be used for drinking and other purposes, particularly during disaster and natural calamities.
Heat exchange system utilizing artesian well (Low cost and high efficiency system)

Well boring
Φ250×100m

Pumping test
Groundwater: GL-0.60m
Pumping rate: 1m³/min
Pumping water level: GL-2.15m

Schematic diagram of the system

Heat-source well
W－U字管×3組

Electric valve

Drainage tank

Heat pumps
Collaborative Research with Fukushima University

Theme: Quaternary geological structure analysis and hydrological analysis in Aizu Basin

Overview: As part of potential assessment for GSHP system in Fukushima Prefecture, hydrogeological analysis including geological structure and subsurface temperature of Aizu Basin will be done. Basic data needed for potential assessment will be collected.

Potential assessment for GSHP system in Fukushima

- Construction of basic data for potential assessment
- Selection of suitable locations for closed and open loop system
- Development of heat exchanger suitable for hydrogeological structure of the area

Outcome

- Dissemination of GSHP system in Fukushima Prefecture by collaborating with local university
- Human resource development incorporating basic to practical researches on GSHP system
R&D on the GSHP in FREA
Results: Near 100m temperature rises sharply

Vertical temperature profile of wells

R&D on the GSHP in FREA

Temperature (°C)

Depth (m)

Vermont temperature profile of wells
Utilization of geothermal resources in Japan
- Green and domestic energy.
- Role as a base-load electricity after March 11, 2011.
- Reduction of Urban Heat Island Phenomena.

R&D in FREA, AIST
- Contribution to rapid increase of geothermal power generation.
- FS for innovative geothermal power generation using magma.
- Potential evaluation of GSHP.
- Optimization design technology of the GSHP.
- Contribution to local industry.
Geothermal projects in FREA

1. Treatment injection for production recovery at Yanaizu-Nishiyama
Expectation of the core team of the JBBP (may be optimistic)

(a) simpler design and control of the reservoir
(b) nearly full recovery of injected water
(c) sustainable production,
(d) lower cost when developed in relatively shallower ductile zones in compression tectonic settings,
(e) large potential quantities of energy extraction from widely distributed ductile zones,
(f) smaller scale precipitation,
(g) establishment of a universal design/development methodologies,
(h) suppression of felt earthquakes from/around the reservoirs

More close to the ideal HDR
Origin of geothermal energy in Japan

(Yano et al., 1999)
Performance evaluation of ground heat exchanger based on space-cooling operation results in summer

- Relationship between Heat exchange rate and Heat-source water temperature is almost straight, and there is no effect of heat storage

- 3 nos. of 5kW Heat Pump used
- Measurement of temperature of heat transfer medium, COP etc. during space-cooling operation
- It was estimated that with 50m × 1no. GHE, 1.5～2 nos. of heat pump can operated with System COP of 3.5
- By improving the insulation of office room, it is possible to operate 3 heat pumps
Space-cooling operation

Well temperature rises with cooling operation, but temperature gets stabilized and returns to steady state.

- 20m = 16°C
- 50m = 15.5°C
- 80m = 15°C

Average COP = 7.01
Company: Sunpot Pvt. Ltd. (Iwate Prefecture)

Technology seeds of company:
- Development and commercialization of heat pump in Japan, Verification of closed-loop system
- No other small-scale heat pumps (10kW) for Open-loop system are available in Japan. (Even in overseas, big ones used for District heating and cooling, and Cogeneration)
- Development of heat exchanger that can exchange heat with well water and primary side circulation water
- Can be used not only for Space heating and cooling, but also for Hot water supply, Snow melting purposes
- Generally, COP is 4 during space cooling. With this technology, COP more than 8 achieved

Evaluation of technology seeds by AIST:
- Groundwater quality analysis to countermeasure scaling problem (clogging)
- Installation of heat pump system in experiment field
- Purchase, installation and connection of the measurement system
- Analysis of experimental test data
- Preparation of potential maps based on hydrogeological survey (groundwater discharge, water quality)

Outcomes:
- Development of the system not only in disaster hit areas but also in other regions with abundant groundwater availability
- Possibility of using existing well, in that case, excavation cost can be avoided
- Groundwater can be used for drinking and other purposes, particularly during disaster and natural calamities
- Development of heat pump directly using groundwater

Evaluation seed:
- Can be used anywhere
- Heat exchange rate varies with place
- Boring is necessary

Open-Loop
- High efficiency
- Using existing wells
  → Excavation cost unnecessary
- Groundwater use during disaster
- Cannot be used in areas with pumping regulation

Upgrading of heat pump already tested and commercialized
↓ ↓ ↓
Can be used for Open-loop (groundwater)

Effective utilization of groundwater resources
Compilation of potential maps for GSHP system

- **POTENTIAL ASSESSMENT**
  - Preparation of potential maps by conducting geological and groundwater survey, and regional scale groundwater flow - heat transport simulation
  - Potential maps for main regions in each prefecture of Tohoku
  - Contribution to design accuracy and low cost with the incorporation of groundwater flow

- **Improvisation of potential map by TRT**
  - For accuracy check of TRT using existing wells, comparison of thermal conductivities from TRT with filled and unfilled well
  - Validation method as per requirement
  - Upgrading of potential maps by conducting TRT at some

Research area

- [Potential map (example)](image)

- [Map of Japan showing potential areas](image)
Forth-term research plan of SGH Team

- **Potential mapping:**
  By constructing groundwater flow – heat transport model based on hydrogeological information, suitable locations for GSHP system and estimated heat exchange rates will be shown in potential maps.

- **System optimization technology:**
  Development of tool/technology to specify the system that fits good with the geology and groundwater of the region.

![Diagram showing potential map and system optimization technology](image-url)
EGS (Treatment Injection)
The Geysers
Yanaizu-Nishiyama

EGS (Improvement of permeability of existing fractures)
Hijiori, Ogachi, Rosemanowes, Soultz, Basel, Cooper Basin

EGS (Improvement of permeability of tight rock)
Fenton Hill, Newberry

EGS (Connection to hydrothermal reservoirs)
Desert Peak

1.5~2km 200~350°C

2.5~5km程度

Basement rock (Crystalline)

HT hydrothermal system

3~several km 350°C

Brittle-Ductile Transition (BDT)

3~6km 400~600°C

Subduction-origin magma intrusion (Japanese case)
Concept of the Japan Beyond-Brittle Project (JBBP)

- **EGS (JBBP-Type II)**
  - Basement rock (Crystalline)
  - 1.5~2 km
  - 200~350°C

- **2.5~5 km**
  - 3~several km
  - 350°C

- **3~6 km**
  - 400~600°C

- **Power Plant**
  - Brittle-Ductile Transition (BDT)

- **Connection of fractures in BDT to HT hydrothermal systems**

- **EGS (JBBP-Type I)**
  - Isolated fracture system in ductile zone

- **Extraction of slab-origin SC fluids**

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**Brittle-Ductile Transition (BDT)**

- Isolated fracture system in ductile zone

**Extraction of slab-origin SC fluids**

Geothermal projects in FREA

1. Treatment injection for production recovery at Yanaizu-Nishiyama