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Japanese Supercritical Geothermal Project for Drastic Increase of Geothermal Power Generation in 2050

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ABSTRACT

It has been estimated by the authors that nationwide potential of Supercritical Geothermal Resources (SCGR), which has an origin in subduction of oceanic plates, reaches hundreds GWs in Japan. Power generation using SCGR in Japan can significantly contribute to energy security and reduction of emission of CO_2. Temperature range of the supercritical rock body to be developed is around 400-500 deg-C and depth of the top of the rock body is expected to be less than several kilometers. The depth of the supercritical rock body is shallower than most of the other area in the world, and it brings advantages in accessibility, economy, and safety. However, there are a lot of scientific unknowns about the nature, especially rock-mechanical and geo-chemical behavior under supercritical conditions. We also need technological breakthroughs, because temperature and pressure conditions in the supercritical geothermal systems are far beyond the current technological limitations and experiences in the foregoing ultra-high temperature geothermal drillings suggests presence of acidic/corrosive geothermal fluid.

In 2017, Cabinet Office of Japanese government has identified power generation using SCGR as one of the key technologies in their strategy which aims to drastically reduce emission of CO_2 in/after 2050 (NESTI2050) following agreement of COP-21. Studies to identify the best location for proof-of-concept borehole, engineering investigation to extract thermal energy, simulation of fracture creation in supercritical rock body etc., have been underway as national projects mainly funded by New Energy and Industrial Technology Development Organization (NEDO) since FY2018.

1. INTRODUCTION

Stefansson (2005) has inferred that Japan has the world third largest potential of hydrothermal resources using “volumetric potential evaluation”. The Japanese government has drastically changed its energy policy from being highly nuclear-oriented to “more renewable policy” after the incident of Fukushima-dai-ichi Nuclear Power Plant in 2011. However, the installed capacity of geothermal power generation system in Japan has remained around 0.5 gigawatts, because of many obstruct factors in the development of hydrothermal systems in Japan, including uncertainties about geothermal reservoirs, the relatively small sizes of reservoirs, difficulties in the establishment of a social consensus, and costs.

Geothermal researchers in Japan had investigated the suitable and industry-acceptable ways of developing geothermal resources to solve negative factors and drastically increase amount of geothermal power generation. They have concluded that this can be achieved by development in and beyond the zone of brittle-ductile transition (BDT) in volcanic basement. It has been expected that rock bodies with high temperature and geologically/rock-mechanically homogeneous nature are widely distributed depth of several km in Japan, and natural reservoirs which are hydraulically isolated from shallow systems can exist beyond the BDT (Saishu et al., 2014). The nature of the rock bodies in the BDT can be used to solve many of the factors hindering the development of hydrothermal systems, and a project named "Japan Beyond-Brittle Project (JBBP)" has been initiated in 2010 and feasibility studies has started (Muraoka et al., 2014).

From conductivity image by MT surveys and analyses of natural earthquakes, Ogawa et al. (2014) have discovered a rock body beneath a volcano, with high temperatures (possibly >400 deg-C) and several percent of brine having an origin in ancient sea water.

We interpreted that such rock bodies have origin in melt/magma created at subduction zone of an oceanic plate. We also inferred that this rock body in the BDT should contain liquid in supercritical conditions from estimation of temperature and pressure. Such supercritical geothermal resources (SCGR) should contain a huge amount of thermal energy, capable of generating more than several tens of gigawatts of electricity for 30 years from each supercritical geothermal systems (SCGS). Geological investigations from various aspects have also revealed that the emplacement depth of SCGS in Northeast Japan (Tohoku) is less than several kilometers, which is shallower than those in the other subduction zones (Reinsch et al., 2017, Okamoto et al., 2019). These SCGS are therefore accessible by current drilling technologies even we need efficient cooling technology and pressure management. The Japanese government has identified power generation using SCGR as one of the eight key technologies in their strategy to drastically reduce emission of CO_2 around 2050 (NESTI2050, CAO, Japan, 2107). Studies to deepen understanding of nature of SCGS and engineering investigations to safely/economically extract thermal energy from the SCGSs are underway as a national project (Supercritical Geothermal Project (SCG-PJ)) funded by Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO), Japan (Asanuma et al., 2018).

Based on the experiences from previous drilling of the well WD-1a in Kakkonda, Japan (Muraoka et al., 1998) and two wells of the Icelandic Deep Drilling Project (IDDP) in Krafla and Reykjanes, Iceland (Mortensen et al., 2014; Friðleifsson, et al., 2017), we expect that conditions in supercritical geothermal systems are extremely harsh because of presence of corrosive gas/fluid, high formation temperature and pressure. Moreover, insufficient scientific understanding of the supercritical geothermal systems brings uncertainties to plans for drilling/completion and energy extraction. Researchers in the SCG-PJ have concluded that well-examined interdisciplinary studies and development is critical to achieve power generation using SCGR, and drill of a borehole to one of the typical SCGS is in Japan is significantly important to proof our scientific understanding on the SCGS and to evaluate applicability of existing technologies and materials for supercritical geothermal development.

2. OUTLINE OF THE SUPERCRITICAL GEOTHERMAL PROJECTS IN JAPAN

History of Japanese SCG-PJ is shown in Figure-1. The SCG-PJ initiated as a scientific project in the beginning of 2010's aiming to discuss/understand nature of deep geothermal systems as a future energy system under umbrella of international continental drilling project (ICDP) (Muraoka et al., 2014). After change of Japanese energy policy following incident of Fukushima-dai-ichi Nuclear Power Plant, the SCG-PJ has been mainly funded by METI and NEDO, one of the funding agencies of METI, to make feasibility studies of power generation. R&D of supercritical power generation have been fully funded after FY2017. Main partners of the SCG-PJ are AIST, Tohoku University, Akita University, Tokyo Institute of Technology, Kyoto University, Kyushu University, Geothermal Engineering Co., Ltd. (Geo-E), Geothermal Research and Development Co., Ltd. (GERD), West Japan Engineering Consultants Co., Ltd. (WEST JEC), Teiseki Drilling Co., Ltd. (TDC), Telnite Co., Ltd., Fuji Electric Co., Ltd., and Renergies Co., Ltd..

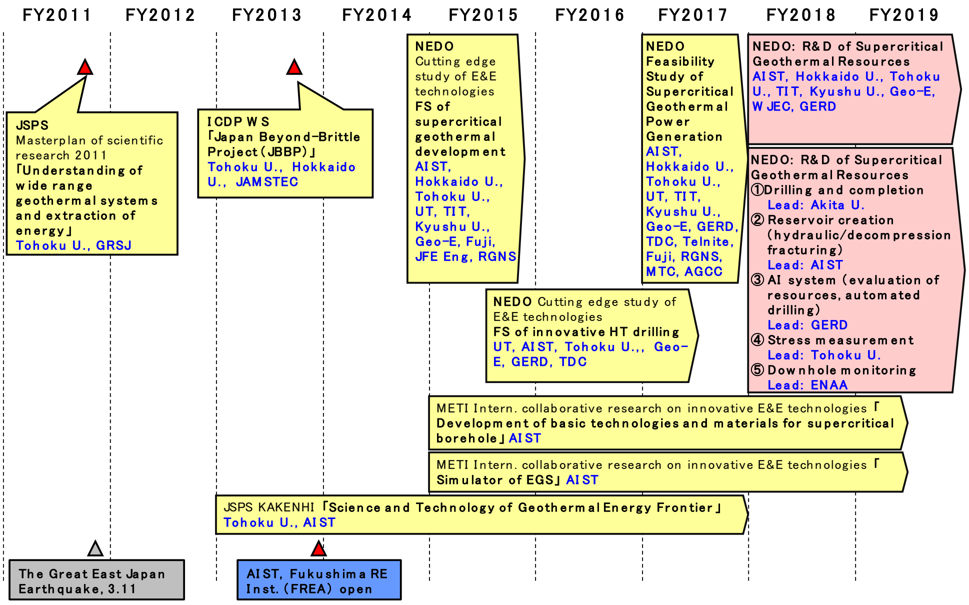

Figure 1: History of Japanese SCG-PJ

We have compiled existing geological, geophysical and geochemical data as a part of the SCG-PJ in FY2017-2018 and have established a conceptual model of typical supercritical geothermal system in Northeast Japan as seen in Figure-1. The depth of emplacement of the SCGS is around 3-5km and less permeable zone is created at the top of the SCGS by silica precipitation (Saishu et al, 2015). The permeability in the SCGS would smaller than that in shallow hydrothermal systems because of elastic-plastic transition of the rock body. However, Prof. N. Watanabe, one of the members of the SCG-PJ in Tohoku University, has inferred that permeability remains in the order of 10^{-15}-$10^{-14}m^2$ around at the top of the SCGS (Watanabe et al., 2017). We have estimated production from boreholes using flow simulators in reservoir and borehole using simplified 1D model of the SCRG and have found that production of around 40MWe can be expected for cases of naturally existing supercritical reservoir and reservoirs with enhanced permeability by fracturing (Watanabe et al., 2017). We have also concluded that "borehole heat exchanger system" can extract thermal energy less than 5MWe even permeability around the borehole is impractically enhanced by human operation. Results from cost estimation demonstrated that unit cost of the power generation using the SCGR is less or comparable to the hydrothermal power generation in some cases, even there are remaining uncertainties in the cost of new material and development technologies.

Following roadmap of SCG-PJ created by CAO, METI and NEDO are funding to 8 projects for research and development of the SCGR in FY2019 as summarized in Table 1.

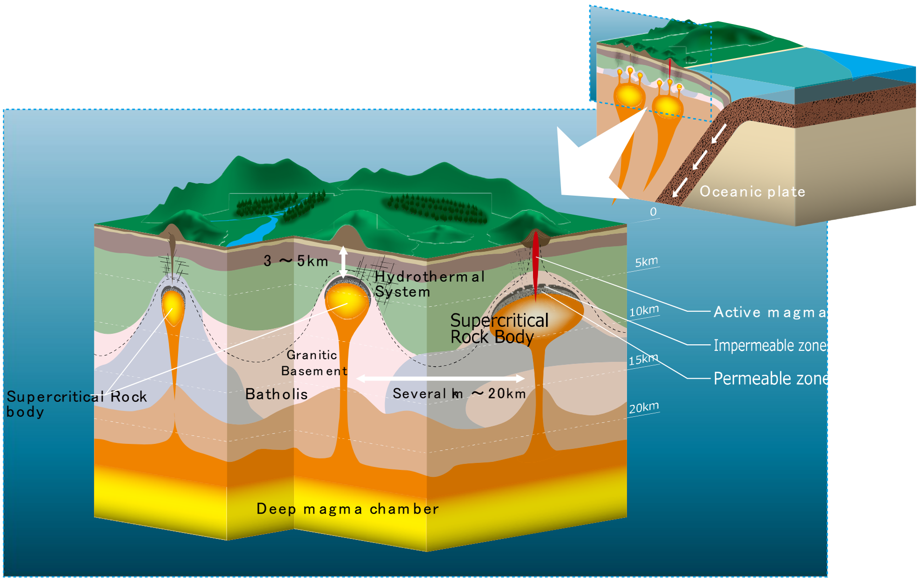

Figure 2: Conceptual model of the SCGS in Northeast Japan

Following roadmap of SCG-PJ created by CAO, METI and NEDO are funding to 8 projects for research and development of the SCGR in FY2019 as summarized in Table 1.

Table 1: On-going SCG-PJs in Japan (as of August 2019)

Title of PJ	Funding Agency	PI	Contractors (only direct contractors)	Outline of PJ
Evaluation of supercritical geothermal resources	NEDO	H. Asanuma (AIST)	AIST, Hokkaido U., Tohoku U., TIT, Kyoto U., Kyushu U., HRO, Geo-E, GERD, WJEC	*Collection of existing and new geological, geophysical (MT and natural seismicity), and hydrogeological data at three promising area in Hokkaido, Tohoku, and Kyushu. *Joint interpretation of the data set and modeling of supercritical geotherm systems in each site. *Estimation of extract-able thermal energy and development style by simulation. *Comparison/evaluation of worldwide supercritical geothermal systems.
Study on ell design and surface facilities specification required for supercritical geothermal power generation	NEDO	S. Naganawa (Akita U.)	Akita U., NKKTubes, Geo-E, Fuji Electronics	*Investigation of specifications of wells and surface system for exploration and commercial power generation. *Feasibility study of cement for supercritical boreholes. *Cost estimation. *Demonstration of feasibility of supercritical geothermal power generation from engineering and economical points of view. *Survey of fracturing, stimulation and induced seismicity in oil/gas and geothermal development.
Study on creation of artificial supercritical geothermal reservoirs	NEDO	H. Asanuma (AIST)	AIST, Tohoku U., JAPEX, TDC, Renergies	*Modeling of hydraulic and decompression fracturing under high temperature/pressure conditions. *Simulation of creation and management of artificial supercritical geothermal systems. *Development of 1st prototype of "downhole decompression fracturing tool".

Development of AI system for supercritical geothermal development	NEDO	K. Osato (GERD)	GERD, AIST, Muroran IT, Tohoku U., Akita U., Kyoto U., Kyushu U., Geo-E, TDC, GSC	*Development of core of AI system for evaluation of deep geothermal resources. *Development of AI system for sei-automated drilling system.
Development of stress measurement system in supercritical geothermal well	NEDO	T. Ito (Tohoku U.)	Tohoku U., OYO, GSC	*Design/manufacturing and evaluation of a prototype of in-situ stress measurement tool for supercritical boreholes.
Development of innovative monitoring system of supercritical geothermal system	NEDO	J. Kasahara (ENAA)	ENAA, Kyoto U., JFCC	*Development of acoustic monitoring system of supercritical geothermal system.
Development of basic technologies and materials for supercritical geothermal wells	METI	H. Asanuma (AIST)	FREA, AIST	*Development of an ultra HT DVS and pressure vessel with new non-metallic material including SiC/SiC composite (Kohyama, 2012) for supercritical boreholes.
Development of simulator of EGS	METI	H. Asanuma (AIST)	FREA, AIST	*Laboratory studies of behavior of fracture system in geothermal conditions. *Investigation of permeability evolution by stimulation of existing fractures under HT/HP conditions. *Development of simulators for EGS and supercritical geothermal system.

SUMMARY

SCGR in Japan has a potential to produce huge amount of stable and safe electricity and drastically reduce emission of CO_2, although lack of scientific understanding of various phenomena in the SCGS and extremely harsh environment in the SCGS makes it difficult to easily use the SCGR for commercial power generation. Authors in this paper consider that interdisciplinary studies and development is critically of importance and that the drill of the 1st proof-of-concept borehole penetrating into SCGS is the biggest opportunity to validate our scientific understandings and to evaluate development technologies and materials. We are proposing Japanese government and funding agencies for their support at least until the end of drill/tests of/in the 1st proof-of-concept borehole.

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