CONCEPTION FOR DEPLOYMENT OF SMALL SCALE BINARY POWER PLANTS IN REMOTE GEOTHERMAL AREAS OF INDONESIA

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INTRODUCTION
The republic of Indonesia is composed of many islands and widely extended. Nowadays, the state with the fourth rich population worldwide has to solve a giant demand on food and energy. Existing resources of oil and gas are limited in Indonesia and the existing infrastructure to reach the customers of the energy is not sufficient as access to many areas in Indonesia is limited. Therefore, de-central, location adapted provision with energy is crucial. One third of the Indonesian population has no access to the electricity grid and about 45000 smaller gasoil fired power plants are operating far of the net (ESDM 2009). These plants have no future due to decreasing access to gas and oil and increasing costs for this energy carrier. Renewable energy can contribute to the provision of energy in remote areas. Geothermal is one of these and has huge resources in Indonesia. Today, geothermal provides ~1.2 GWe electrical capacity which represents only a small part of the identified potential. The Indonesian government plans an extension of the deployment of geothermal electricity until 2025 to 9.5 GWe which represents a significant part of the estimated resources of 27 GWe (Surya Darma et al, 2010). However, there is a gap in reliable technologies for solutions to provide de-central geothermal energy. In addition, human resources respectively engineers are missing to handle the extension of the capacity. Indonesian studies indicate the requirement of 50-70 good educated geothermal engineers for each additional 1000 MWe installed capacity (Saptadji, 2010). Further development of geothermal technology is as important as capacity building. Recently a German-Indonesian cooperation started with the project “Sustainability concepts for exploitation of geothermal reservoirs in Indonesia – capacity building and methodologies for site deployment” in order to find site specific technical solutions and to support the required education in Indonesia. In this context a PHD-program was initiated and installed to support these goals. First reservoir engineering field studies conducted in autumn 2010 shall yield further boundary conditions for plant optimization and adaptation for possible locations in Indonesia. A comprehensive exploration program, planned for 2011, will partly focus on low enthalpy geothermal “green fields” in magmatic and amagmatic settings to further elaborate potential sites for future deployment (Fig. 1).

FACTORS OF DEPLOYMENT
It is difficult to predict future rates of deployment, because of numerous variables involved (Huenges, 2010). With the present engineering solutions, an
increase from the current value to 10 GWe installed capacity in Indonesia should be achievable. The gradual introduction of new technology improvements is expected to boost the growth rate. In addition to large scale power plants other core technologies (for example, small scale binary plant) are entering the field demonstration phases to prove commercial viability. Low temperature power generation with binary plants opened up the possibilities of producing electricity in areas that do not have high temperature resources and thus give an opportunity for many remote areas. If these technologies can be proven economical at commercial scales, the geothermal market potential will be limited only by the size of the grid or the total demand.

**Economic and Political Factors**

Utilization of geothermal resources varies from being nearly site-independent (mostly dry environments) to site-specific (for hydrothermal sources). The distance between electricity markets or centers of heat demand and geothermal resources is a factor in the economics of power generation.

When making development choices, there is sometimes a trade-off between the quality of hydrothermal resources and their remoteness from secure grid connections or demand centers. The renewable, reliable, and cost-competitive nature of geothermal energy has, in the past, attracted some energy-intensive industries (e.g., aluminum smelting, pulp and paper, timber drying) to collocate with geothermal resources to attain a comparative commercial advantage. In the context of mandates for increased use of renewable energy and for reductions of greenhouse gas emissions, this collocation trend is expected to increase.

The deployment of all technologies relies on the availability of skilled installation and service companies. For deep geothermal drilling and reservoir management, such services tend to be concentrated in a few countries only. Larger deployment is generally facilitated by establishing insurances to cover drilling, development, and production risks. Therefore, project risk management is another requirement for financing, installing, and operating large geothermal installations. Prior knowledge and expertise within the local banking and insurance industries generally assist in accelerating local deployment rates.

Geothermal deployment will also be supported, politically, by a CO2-mitigation strategy, through establishing incentives for market penetration of geothermal energy supply technologies. These incentives can include, for example, subsidies, guarantees, and tax write-offs to cover the risks of initial deep drilling. Policies to attract energy-intensive industries (e.g., aluminum smelting) to known geothermal resource areas can also be useful. Feed-in tariffs with confirmed geothermal prices have been very successful in attracting commercial investment in some countries (e.g., Germany). Policy support for research and development is required for all geothermal technologies. Public investment in geothermal research drilling programs should lead to a significant acceleration of geothermal deployment.

Support is also needed for programs to educate and enhance public acceptance of geothermal energy use, and to conduct research toward the avoidance or mitigation of potential induced hazards and adverse effects.

**Capacity building**

One of the limiting factors for the growth of geothermal energy supply in Indonesia is the availability of qualified human resources. To help overcome this limitation the Indonesian-German cooperation project will support initiatives to expand geothermal training in Indonesia. A number of initiatives are planned: Indonesian-German expert exchange program; PhD program with several PhD positions in Exploration, Reservoir Engineering and Geothermal Plant Technology supervised in Germany, GFZ experts will participate in a teaching program at Indonesian partner institutions.

**Controlling Technology Factors**

Geothermal power generation technologies have different degrees of maturity. The deployment conception has to strengthening the weak points of the existing technologies in Indonesia. Reducing subsurface exploration risks will contribute to more efficient and sustainable development in Indonesia. The drilling of high temperature reservoirs requires advance technologies to prevent reservoir damage by drilling mud; an example is the use of balanced drilling procedures. Improved utilization efficiency requires better auxiliary energy use and improved performance of surface installations. Better reservoir management, with improved simulation models, will optimize reinjection strategy, avoid excessive depletion, and plan future make-up well requirements, to achieve sustainable production. The quality of the heat extracted, and its potential diversity of use, increases with heat source temperature. Improvements in energy utilization efficiency from cascaded use of geothermal heat are an important deployment strategy. Evaluating the performance of geothermal plants, including heat and power installations, will consider heat quality of the fluid by differentiating between the energy and the exergy content (that part of the energy that can be converted to power).
TECHNOLOGY APPROACHES

Exploration
Indonesia represents a complex subduction zone setting that is subdivided into a wide variety of extensional, strike slip and compressional sub regimes and hosts abundant magmatic geothermal activity. Understanding alteration patterns and structural controls on geothermal activity in this magmatic region is the most critical issue for defining successful site specific exploration and utilization strategies. A suite of different methods and techniques is required to image and characterize hidden geothermal systems in high enthalpy regions.

Structural Geology
A first critical step in systematic geothermal exploration is the classification of geothermal fields related to tectonic settings at the Great Indonesian Arc. On selected sites, detailed data from former exploration and new geophysical field experiments are used to develop integrated 3D structural geological geomechanical models to image subsurface structures. For Indonesia, one of the most challenging aspects is to develop such a geological system embedded in very thick near surface sedimentation covered by tight vegetation. Outcrop analogues are investigated to characterize the structural inventory to ultimatively combine surface with subsurface data.

Magnetotellurics
Electrical conductivity is a key parameter for the exploration of geothermal reservoirs, especially in volcanic areas where clay alteration minerals surrounding the reservoir present a strong conductivity background. Magnetotellurics (MT) has been widely used in geothermal sites throughout the world. MT can provide electrical conductivity models from the near surface down to depths of several kilometers. Our methods involve field experiments, data processing and 2D/3D modeling of conductivity distribution. MT models can be integrated with other geophysical and geological data to produce conceptual reservoir models.

Seismology
We focus on natural micro- to-local scale seismicity to characterize subsurface active faults and stress state of geothermal fields. The methods involve advanced data analysis and modeling/inversion of P and P-/S-velocity and attenuation using tomography methods. Integrated interpretation of different results from the passive seismology study and further data (structural geology, MT and others) will improve the understanding of geothermal systems, particularly the prediction of fault zones that control heat transfer or fluid flow.

Seismsics
Reflection seismic techniques are a key technology for reconnaissance studies for exploration wells. In areas with high geothermal gradients, high-resolution seismic investigations open a new field of application, which has only recently gathered some experience in correlation with exploration wells. A geological-geotechnical evaluation of selected sites will lead to specific reflection seismic campaigns and multi component acquisition techniques will be developed. Effectively, a site-specific workflow can be developed for high resolution reflection seismics employing 2D/3D techniques to image the structural pattern of geothermal fields.

Reservoir Engineering
Reservoir engineering is essential for an appropriate development of geothermal resources. Optimum economic utilization of geothermal reservoirs requires analysis of the geological system together with adequate planning. These include chemical and petrophysical reservoir characterisation, reservoir stimulation and modelling as well as understanding of the processes and interaction of the borehole-reservoir system.

Stimulation
Stimulation treatments are an option to enhance the productivity of low permeability geothermal reservoirs by inducing artificial fluid pathways. At GFZ specific stimulation treatments have been developed to enhance the existing permeability; i.e. hydraulic fracturing, thermally induced fracturing and chemical/acid stimulation. In hydraulic stimulation experiments, fluids are injected under high pressure into the subsurface rocks to create new fractures or extend existing fractures.

Rock physics
Effective energy production from geothermal reservoirs requires that the physical properties of the host rock have to be characterized as precisely as possible. Additionally, rock physical experiments provide a valuable complementary method to investigate particular processes associated with mechanical and thermodynamic changes induced during operation. The results of such investigations improve the outcome of hydro-thermo-mechanical-chemical (HTMC) simulation codes in order to derive statements on reservoir productivity, sustainability, and best-practice operation.

Modelling
An appropriate numerical model is important for planning the well path and fracture design,
interpreting hydraulic tests and stimulations, and predicting reservoir behaviour during geothermal power production. Such models should include: (i) the reservoir geology and structure, (ii) the geometry of wells and fractures and (iii) the hydraulic, thermal, mechanical and chemical (HTMC) conditions of the reservoir and fractures generated due to changes in reservoir conditions.

**Geochemistry**

Chemical reactions between the geothermal fluid and either plant materials or reservoir rocks can damage the reservoir (by clogging the pores) as well as the plant components (by corrosion). Therefore, geochemical processes are investigated in field and lab scale. Lab experiments focus on mineral formation processes induced by changes in p-T-conditions in synthetic brines. In the field, in situ parameters are measured online and fluid samples are collected and analyzed (Fig. 2). Additional well tests (e.g. tracer tests) help to understand the controls on sustainability and efficiency.

![Fig. 2: Sampling a hot spring at Tiris, East Java.](image)

**Corrosion and scaling**

Many components in geothermal fluids are highly reactive and can cause serious damage to the plant materials. Exact knowledge on the behaviour of applied plant materials depending on fluid chemistry, as well as of the temperature, pressure and flow conditions is essential in order to prevent corrosion, reduce material costs and increase reliability of components. At the GFZ we investigate in cooperation with the Federal Institute for Materials Research and Testing (BAM) the effect of these parameters on suitable materials in laboratory and in-situ field experiments.

**Energy supply**

Deep geothermal heat can be used for heat, electricity and chill supply. Besides extracting heat, the underground can also serve as thermal energy storage. The engineering of geothermal systems is based on conventional engineering approaches that need to be adapted and enhanced according to the specific geological, infrastructure and ambient preconditions at a site (Saadat et al. 2010b). Our work at GFZ focuses on the adjustment of existing, proven components for an integration in new configurations. In collaboration with different partners experienced in standard technology engineering, our goal is to increase safety, reliability and the efficiency of the overall system.

**DEPLOYMENT OF SMALL SCALE BINARY POWER PLANTS**

Geothermal small scale energy provision in remote areas requires a holistic approach by commonly addressing challenges in geothermal exploration, reservoir engineering, and power plant development. At many locations in Indonesia medium enthalpy / medium temperature resources can be found in shallow depth of about 300-500 meters at Blok Langkoan, Lahendong geothermal field, North Sulawesi (Azimudin, 2001) or about 600-800 meters at Atadei, East Nusa-Tenggara (Nanlohy, 2003), that could be accessed easily. The power plant has to be based on modular components in order to be able to adapt the system to site requirements, such as temperature, flow rate, and cooling possibilities, data which is generated during geothermal exploration and reservoir engineering. The smallest binary cycle unit, which was developed and set up in this context,
is designed for 60 kWe electrical capacity (Fig. 3). It has been presented at the WGC 2010 in Bali and performance test of this system at the in situ geothermal laboratory Groß Schönebeck (Germany) is under preparation. The goal is to be flexible with locations in different geological environments, scalable by the modular set up, and ensuring a reliable and efficient operation.

![Fig. 3: Small scale power plant (60 kWe) for decentral solutions. Geothermal fluid inlet temperature: 145°C; Working fluid: n-Butane; Weight: 3 t, Dimensions (excl. cooling): 2.8x2.3x2.2 m](image)

In addition, a demonstration of operation of such kind of modular power plant is under preparation in collaboration with Indonesian partners at an existing already developed Indonesian geothermal field. Parallel to this activity several green field exploration campaigns are started to realize later the demonstration of the whole chain from exploration, reservoir development to provision of electrical power. The next step will be the determination of target areas types under consideration of the geothermal potential, the knowledge of technology to access the reservoir, and the customer demand structure. This should be the base for a large scale deployment for small scale power plants, hopefully with support of interested financing agencies and the Indonesian government.

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