Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

# Geothermal Energy for Green, Sustainable Development and Community Prosperity in the Eastern Indonesia: NZAID-Gadjah Mada University-supported CaRED Program

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**Keywords:** sustainable geothermal resources, Eastern Indonesia, Indonesia-New Zealand collaboration, CaRED Program

## ABSTRACT

As well as being environmentally friendly, renewable, and sustainable, geothermal energy is indigenous meaning that it can ensure energy supply to the surrounding community. Most of the geothermal potential in the eastern part of Indonesia has not been utilized, mainly because the characteristics of the resources have not been well-understood. Geothermal exploration aims to discover a geothermal reservoir that is economically producible. Such a reservoir must have temperature suitable for electricity generation and/or direct utilization, good permeability, and benign fluid, i.e., the fluid that is not corrosive and/or excessively depositing mineral scales that can damage the production facilities and not containing constituents harmful to the environment.

The program mainly focuses on research activities related to geological characteristic of the geothermal systems and mitigation of scaling and corrosion problems. In addition capacity building of geothermal stakeholders and community development will also be part of the work. Our work aims to: 1) Build a catalogue of the Eastern Indonesian geothermal systems that have potential of corrosive fluids. 2) Mitigate the resource risks due to the occurrence of corrosive fluids in the undeveloped systems in Eastern Indonesia, to help minimize the failure in selecting the sites for development. 3) Mitigate the development risks (corrosion and scaling). 4) Provide government institutions and developers with sound guidelines for successful exploration and development of geothermal resources in eastern Indonesia and guidelines in monitoring the environment of the produced geothermal fields. 5) Enhance the capacity of human resources of geothermal stakeholders. 6) Strengthen the community support to geothermal resource development through public education and enhancement of the community's capability to create productive economic activities related to geothermal development.

This work is part of Gadjah Mada University's (UGM) Community Resilience and Economic Development (CaRED) program supported by NZAID. The CaRED program is the first integrated collaboration scheme between Indonesia and New Zealand involving the geothermal stakeholders; government, academia, industries and communities.

## 1. INTRODUCTION

Geothermal is the heat energy from the Earth. In Indonesia and countries in the Pacific Ring of Fire, the location of the high-temperature geothermal resource (reservoir temperature ≥ 225°C) is indicated by geothermal manifestations such as hot springs, fumaroles, and thermal grounds. In a volcano-hosted geothermal system there is heat transfer from a magmatic heat source to the reservoir rocks and the deeply infiltrating meteoric fluids. As parts of the Earth's system, a geothermal resource can only be well located and characterized through an integrated geoscientific studies.

Geothermal fluid is tapped by drilling production wells into a geothermal fluid reservoir (~ 2 km). The heat energy of high-enthalpy fluids is then converted to electricity through an electricity generating system. Alternatively the hot fluids (especially those with medium enthalpy) can also be directly utilized for example for heating in an industrial process. A lot of different engineering expertise is required for both geothermal fluid production and utilization including electricity generation.

Indonesia has approximately 40% of world geothermal energy reserves, with 27,000 MWe potential. Currently, it is ranked as the third in the world for geothermal energy consumption, following the US and the Philippines (Bertani, 2010). With the increasing demand of energy in one hand and the shortage of fossil energy resources in another and the prediction that Indonesia will be the third biggest emitter of greenhouse gases and aims to reduce green house gas emissions by 16% by 2025 (Suwa, 2012), the country is now facing a challenge to the increase utilization of its green and renewable energies. Based on the geographical position, Indonesia has several options for the development of renewable energies, but as one of the top five countries with high geothermal potentials, Indonesia thrives to accelerate the development of its geothermal resource (National Energy Council, 2011). Being renewable, sustainable and indigenous therefore, geothermal energy is reliable, for its supply is independent from season and energy market situation outside the country. High-temperature geothermal systems are being the priority for economic development due to their potential for both electricity and direct utilizations.

High-temperature systems however possess risks of having acid fluids that can cause corrosion in some parts of the system, and scaling/mineral deposition in other parts. Our research therefore will focus on such systems. Based on the geologic setting, the high-temperature geothermal systems in eastern Indonesia are hosted by volcanoes or volcanic complexes. They are located in North Sulawesi, Halmahera, Bali, Nusa Tenggara, and Ambon Islands (Geology Agency, 2012).

Geothermal energy resource development is challenging, because it is a high-risk business that requires high technology and high investment. Consequently, research and development, capacity building of human resources (those involved in technical sectors and those in the government/regulatory sectors), as well as community education to build a positive attitude towards geothermal energy development becomes vital prerequisites.

From the scientific and technological points of view, to proceed with a high degree of confidence in developing a geothermal prospect, knowledge on resource size, reservoir temperature, permeability, and the chemistry of the reservoir fluid is critical. The biggest development risk is drilling into an acidic zone in the subsurface, particularly the magmatic-derived acid fluids, as demonstrated by the research on Karaha-Telaga Bodas, West Java (Moore et al., 2004), and Alto Peak, Philippines (Reyes et al., 1993). This type of fluid is highly corrosive and can damage the production wells. The other negative impact of the acidic magmatic fluids is the removal of constituents from a deeper part of the geothermal system that in turn will be deposited as scale in other parts of the system, lowering the reservoir permeability, and blocking the production facilities. The eastern Indonesian region has more complex geologic settings compared to those in the western part of the country (e.g., Hamillton, 1979, 1988). Consequently, geology and related studies described in the following sections of this proposal become important bases to geothermal resource development steps in the region.

The government of Indonesia has a responsibility to make the inventory of all geothermal prospects in the country, set the priority of resource development, offer the geothermal working areas to the potential developers, and to monitor the development processes. However, during inventory process by the government and the exploration stages by the developers the possibility of the presence of corrosive fluids is often overlooked because there has been a lack of research about it in the green fields, especially those in eastern Indonesia. This resource uncertainty is one of the many reasons for the slow progress of geothermal development in the country. Along with R&D, capacity building of the Indonesian human resources has to be accelerated to help overcome this particular problem (Azimudin, 2012).

Based on the data from the Indonesian Statistic Bureau (2010), eastern Indonesia possesses a gross domestic product (GDP) about 50% lower in comparison to that of western Indonesia. The development of indigenous energy to power the economic activities will certainly help alleviate poverty in this part of the country. Since community prosperity is the main aim of geothermal development, community awareness about the importance of this clean and renewable energy as well as community support toward a development program are success keys to attain the aim. Lack of knowledge about geothermal energy and a wrong understanding about its development process will result in resistance and other counterproductive reactions from the community. The community's positive perspective and supportive attitude must be built through community empowerment, including public education, as well as involvement of community elements in the relevant steps of geothermal resource development.

## 2. PROGRAM SCENARIO

Our program entitled Geothermal Energy for Green Sustainable Development and Community Prosperity in eastern Indonesia will provide important technical solutions of the geothermal power plant in eastern Indonesia. The steps of the program are described in Figure 1.

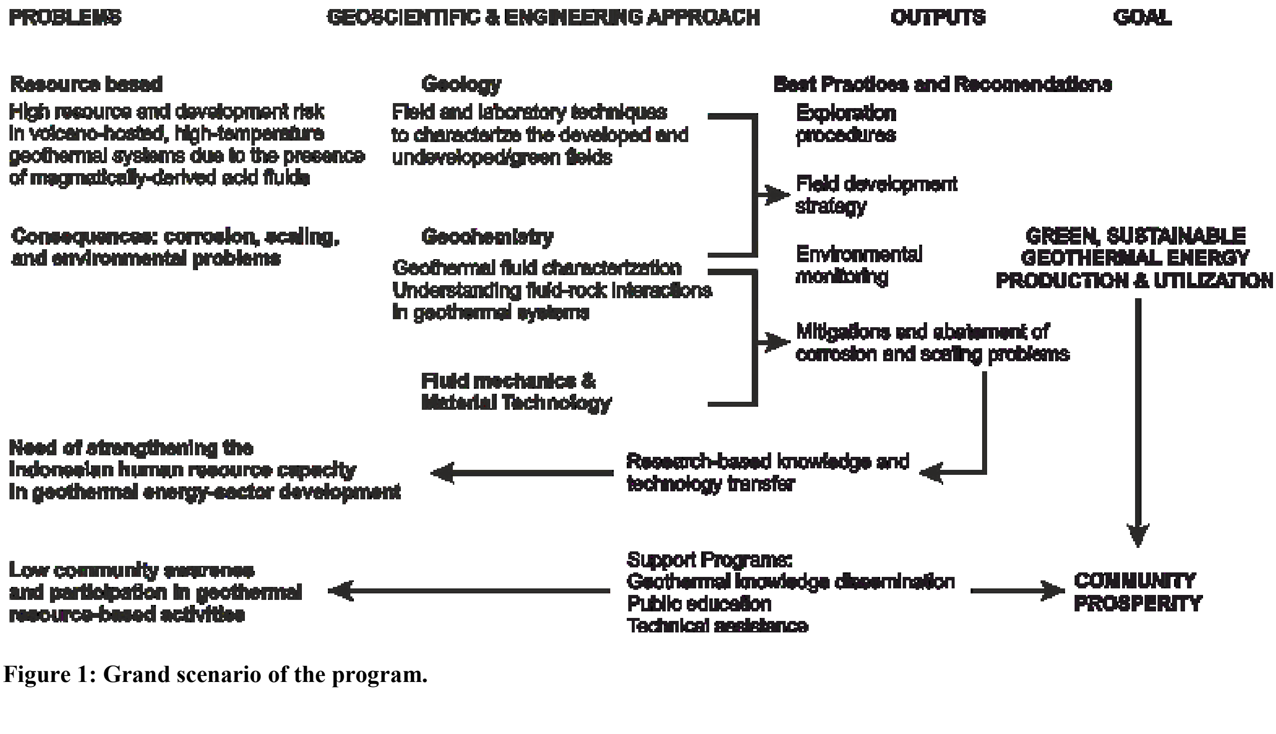


**Figure 1: Grand scenario of the program.**

In line with the goals of UGM CaRED Program our work will be an integration of research, training/knowledge transfer, and community development activities, each under the following themes:

a) Research: Characterization of Geothermal Systems in Eastern Indonesia with Potential of Acid Fluids and Mitigation of their Problems in the Development Stages. This research aims to reduce the resource uncertainty and development risk that in turn will help accelerate the geothermal potential utilization. Characterization of geothermal systems will help understand the temperature and permeability distribution within the field, and the quality of the reservoir fluids, and hence increase the confidence in decision making for field development. Systems that contain a significant amount of acid fluids can have corrosion problem in some parts and deposition of scale minerals in other parts. These can hamper the energy production and to some extent, reducing the quality of the environment. The research work will involve desk studies, field verifications, laboratory analyses and experimentations. The research will be focused in volcano-hosted geothermal prospects in the Eastern Indonesian Archipelago where the three geothermal systems in the North Sulawesi Province (Lahendong, Tompaso, and Kotamobagu) that have been identified by deep drilling will be used as references (Utami et al, 2007; Utami et al, 2010; Utami, 2011; Utami, 2013). The subsurface geology and fluid geochemistry data from the deep drilling become essential parts of this research since they are needed to verify the study. The results will be used to guide the exploration and development of the green fields in eastern Indonesia.

b) Capacity Building and Workshop: Geothermal Exploration and Development. This activity aims to strengthen the capacity of human resources involved in geothermal development sectors in eastern Indonesia including government staff, geothermal company personnel, and academicians. This will consist of a series of training or transfer of hands on knowledge gained through the research and workshop to disseminate the results of the research. We expect that the involvement of the Eastern Indonesian academic society in this activity will increase along the course of the program, such that in the future they can be one of the motors of the geothermal research and education in their areas.

c) Community Development: Dedicating Geothermal Energy for Community Prosperity. This is an important support program that aims to bring geothermal closer into the people's heart and in turn, increase community prosperity through productive economic activities related to geothermal development. The program will be implemented in collaboration with local government and other stakeholders. Our role in this program will be in the form of disseminating knowledge and information about geothermal, providing technical advisory to the government & other stakeholders for example in developing geothermal public education facilities for eastern Indonesia and in conducting geothermal resource-based activities that help open the livelihood opportunities such as geothermal tourism and geothermal-powered agricultural industries (Utami et al, 2011).

## 3. ROADMAP OF THE PROGRAM

This program will be an integrated works including research, capacity building, and community development held for three consecutive years and divided into five stages of progresses including technical/social approach, engagement and cooperation, capacity improvement, development, and sustainability. By including the prior and on-going activities, Table 1 illustrates the roadmap of the program.

**Table 1. Project Road Map showing the stages of activities and their level of progress**

| CaRED Program Stage / Activity | Technical/ Social Approach | Engagement and cooperation | Capacity improvement | Development | Sustainability |
|---|---|---|---|---|---|
| | (Stage 1) | (Stage 2) | (Stage 3) | (Stage 4) | (Stage 5) |
| Research | | | | | |
| Capacity Building | | | | | |
| Community Development | | | | | |

The stages in Table 1 indicate the progress of each activity, not the running year of the program. Each activity in the program has reached a different level of progress (blue bars represent the prior and on-going activities while the green bars represent future activities to achieve stage of progress that has been formulated). The ongoing activities might not always be directly related to development in eastern Indonesia but they certainly enrich our experience to ensure the success of the program.

## 4. SCOPE OF THE PROGRAM

### 4.1. Research

<u>4.1.1. High-temperature geothermal systems and identification of the occurrence of acid fluids</u>

A study by Bogie et al. (2010) looked at the relationship between volcanic landform and the possibilities of the occurrence of productive geothermal systems. It demonstrated that the successfully developed geothermal fields of Java are associated with very mature andesitic eruptive centres that have undergone caldera collapse followed by resurgent volcanism, sector collapses and in one case; maars. It is possible that at least some of these landforms may be common to geothermal fields in island arcs. Thus, volcano-hosted potential geothermal prospects in eastern Indonesia can be similarly identified. The most likely heat source to many of volcano-hosted geothermal systems is magma intruded into their roots (Hochstein and Browne, 2000). It may be a single major magma body that is replenished at intervals by new magma from deeper crustal levels or the mantle (e.g., Arehart et al., 2002; Rae et al., 2004; Utami, 2013).

A geothermal system above cooling magma essentially opens to the escaping magmatic gases or acts as a trap due to gas-gas and gas-mineral reactions that consume these gases. An understanding of these reactions is important for evaluating the utilized as well as undeveloped geothermal systems in the long-term transfer of magma gases into the atmosphere (Arnórsson et al., 2010).

Every volcanic geothermal system has its birth, evolution and extinction. The evolution of the systems and the tentative models of the development of their thermal structures and magmatically-derived acid fluid are illustrated in Figure 2. During the early lifetime of a volcanic geothermal system convecting hydrothermal fluid will transport heat from the cooling magma to higher levels in the crust. When the heat source becomes extinct, either due to a shift in the position of the conduit of the rising magma, or by drifting of the geothermal system from this source, we are left with a body of rock and fluid whose energy is no longer replenished. Gradually, this hot body that constitutes the geothermal system will cool down. While young, degassing of the magma heat source likely adds gases to the circulating hydrothermal fluid. These gases include $H_2O$, $CO_2$, $H_2S$, SO2, $H_2$, CO, HCl, HF and likely many more volatile species. Some of these gases act like acids when dissolved in liquid water, such as $SO_2$ and in particular HCl. Upon mixing they will turn the fluid acidic. On converging plate boundaries (such as geologic settings in many parts of Indonesia) the situation may be more complex (e.g., Corbett and Leach, 1998, Utami et al., 2007).

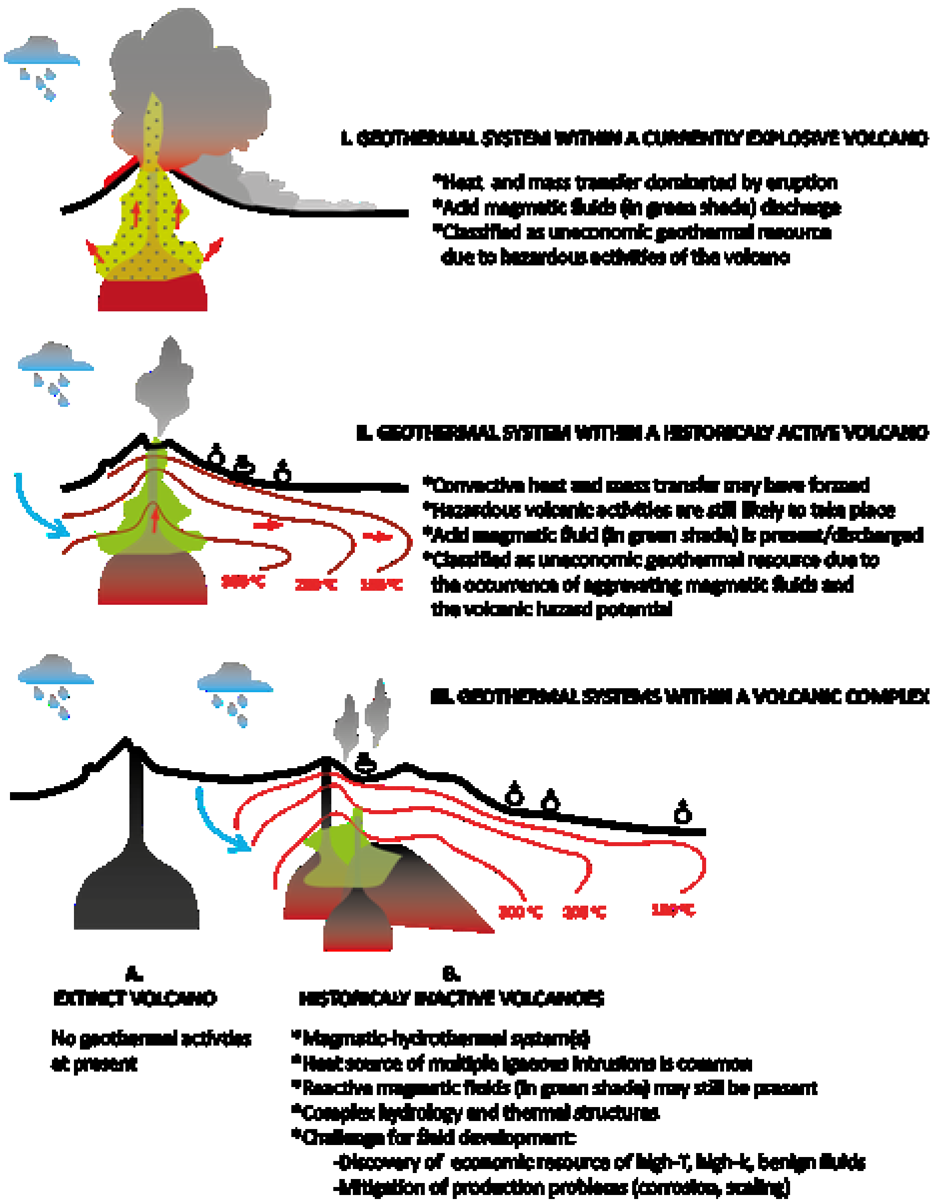


**Figure 2: Illustration of the evolution of volcano-hosted geothermal systems, showing the conceptual model of the development of thermal structures, and distribution of magmatic-derived acid fluids (Utami, 2013).**

Primary minerals of common types of igneous rocks are unstable in contact with the high-temperature fluids of volcanic geothermal systems. These minerals therefore tend to dissolve in these fluids. Their under-saturation is maintained upon progressive fluid-rock interaction by precipitation of hydrothermal minerals (Browne, 1976). Progressive reaction of the acidified fluid with primary minerals of common types of volcanic rocks will, however, neutralize the acidity because many of these minerals act as bases. The volcanic gases may participate in the fluid-mineral reactions and may be consumed by incorporation of some of their components into the hydrothermal mineral phases (Arnórsson et al., 2010).

At Alto Peak in the Philippines, a core of vapor in the central part of the field is enveloped by a liquid dominated reservoir (Reyes et al., 1993). The close vicinity of magma and hydrothermal fluid favors easy mixing of magma gases with that fluid. Based on the geologic setting, the high-temperature geothermal systems (reservoir temperature $\geq 225^{o}C$) in eastern Indonesia can be classified into volcano-hosted systems (Geology Agency, 2012). Utami et al. (2007) and Utami (2011) mentioned that the productive geothermal systems in Indonesia and Western Pacific are located at volcanic complexes that are historically inactive. The systems are relatively mature, meaning that interactions between the magmatic heat source with the surrounding rocks and the infiltrating meteoric fluids have resulted in convective thermal structures and hydrothermal fluids are generally benign (of near neutral-pH alkali chloride compositions), although in parts of the field corrosive and scale-developing fluids may exist. The maturity of the systems can be accessed from the volcanic landform (e.g., Bogie and Lawless, 1986; Bogie et al., 2010) and other geologic signatures, types of surface manifestations and surface fluid compositions (e.g., Hochstein and Browne, 2000) and in systems which have been explored with deep drilling, the subsurface hydrothermal mineralogy and fluid geochemistry (e.g., Moore et al., 2004; Reyes et al., 2003). These will be applied in our research.

An on-going project by the Geothermal Research Centre Faculty of Engineering UGM in collaboration with PT. Pertamina (Persero) aims the possibility of magmatic fluid input into parts of the Lahendong geothermal system (North Sulawesi) by advanced subsurface geology studies. A past project in Ulumbu geothermal field (Flores, East Nusa Tenggara) in collaboration with the Indonesian State Electricity Enterprise (PLN) revealed the natural characteristics of the systems (Kasbani et al., 1997). The results of the project therefore can be incorporated to the work to guide the characterization of other volcano-hosted systems in the eastern Indonesia.

4.1.2. Mitigation of development risks due to the occurrence of acid fluids

As the geothermal fields have their own characteristics, especially the composition of the fluids, based on the experiences from the above samples, it is important to investigate the corrosion and scaling potential for the green fields and evaluate those problems for exploited fields. The works/experiments can be carried out either in the field or in the laboratory. Numerous samples of the geothermal fields that have been experiencing problems caused by acid fluids have been reported from all over the world. The common problems found to be corrosion and scale deposition either in the subsurface, i.e. in the reservoir and the wellbore and/or the surface facilities such as piping systems and turbine blades. The difference of the problems is up on the degree of the damage on the facilities.

Bracaloni et al., (1995) reported that the corrosion problems on turbine blades in Italy are generally associated with the presence of chlorides in the steam. The presence of corrosion products (iron sulphides, etc.) in the steam pipelines may cause some plugging in the turbine blades. The increase in the salinity of some of the fluids recovered has given rise to corrosion as well. A series of breaks connected with stress corrosion cracking phenomena was also detected in the binding wire. External casing corrosion (ECC) in geothermal systems has been reported by Zarrouk (2004). He reported that ECC are found in geothermal fields of andesitic geothermal systems from other countries such as Karaha-Telaga (Indonesia) caused by acid sulphate rich waters form from the oxidation of H2S to form sulphuric acid, Bacman and Palinpinon fields (Philippines), and Cerro Prieto (Mexico). Several methods have been considered to prevent and mitigate the damage from ECC including the use of corrosion resistant cement, multiple lining within the corrosive zone, corrosion resistant casing material and catodic protection.

Brondial (2005) demonstrated that applying pH buffering in geothermal systems has been proven successfully to solve corrosion and silica-scaling problems encountered. it is recommended that the most advisable strategy is to introduce ß - chloropropionic acid- sodium – ß chloropropionate (BCPH- NaBCP) buffer solution at high concentration to the reservoir and then to shut-in the well for a day or two to allow the well to heat up and to build up pressure, after which BCPH-NaBCP solution is introduced using an acid string set at the production well. The acid string is inserted through the hole at the top of the geothermal well assembly to reach a certain level where acidic waters enter the geothermal well.

Fridriksson et al. (2006) investigated some corrosion problems in Reykjanes geothermal field in Iceland. They reported that common corrosion problems were found in several equipments such as in slotted liners and well casings, well head, superheated steam pipelines, cooling towers and cold condensate pipelines, heat exchanger, and electronic equipment in power plants. To overcome the corrosion problems, the appropriate material selection and the injection of a caustic solution (e.g. NaOH) were recommended. The calcite scale deposition in the well at Miravalles geothermal field, Costa Rica, was indicated by the problems found in the wells such as rapid decline both in flow rate and wellhead pressure and the boreholes diameter was reduced sharply after few months of production (Sanyal et al., 1985). The likelihood that the scale being formed in this field was carbonate as indicated by several observations. The calcium carbonate particles were found in the wellhead separator, and the principal non-condensible gas (NCG) was $CO_2$.

Ocampo et al., (2003) described that the main problem that occured in Cerro Prieto wells (Mexico) was silica scale both in pipes and reservoir zones close to the bottom of the wells. The scale caused lost production and it was necessary to make around 12 work overs each year to recover the steam lost. Calcite scale and metallic sulfides were also found in some wells.

The silica scaling problem in the reinjection wells in the Berlin geothermal field (El Salvador) was modeled by Castro (2006). The modeling showed that the silica scaling decreased the capacity of the wells to absorb water. The silica-supersaturated reinjection water precipitated its silica within the reservoir, incrusting and plugging the pores and decreasing the water absorption capacity of the reinjection wells. The techniques for mitigating the development risks due to the presence of corrosive and scale-depositing fluids includes recovering silica as well as valuable minerals in the geothermal water, with the objectives to minimize the possible occurrence of the scale and to increase economical value of the geothermal power plant.

In geothermal power plants in the Salton Sea area, a solid waste separated as filter cake from the clarifier contains a mixture of iron-bearing silica, salts, and heavy metals. An acid leaching method using hydrochloric acid has been employed to obtain the iron and other metals. Thus, the remaining silica becomes pure enough for uses as pozzolanic additive for cements (Bourcier et al, 2001; Nurdianto et al, 2011). Similar work on silica recovery has also been done in New Zealand (Brown and Bacon, 2000), Japan (Sugita et al., 1998), Russia (Kashpura and Potapov, 2000), and Indonesia (Riyanto et al., 2010; Reningtyas et al., 2012). The methods include magnesium chloride addition in regards to its ability to increase the polymerization rates and facilitate agglomeration of silica. Synthetic polymer electrolytes can also be used, but are more costly. Moreover, the effect of temperature and pH can also be alternatives to recovering silica from the geothermal water (Harper et al., 1995; Riyanto et al., 2010; Reningtyas et al., 2012).

In fact that the scaling process is controlled by temperature, pH, and cation species and concentrations, the mitigation approaches could be done either by inhibiting the scale formation or by accelerating the process to further recover the scaling components. Recovered components might posses high economic value; thus, further research needs to be conducted and developed so that the final objective to achieve a sustainable geothermal energy utilization could be realized.

### 4.2. CAPACITY BUILDING

Capacity building of geothermal human resources has been conducted by the Faculty of Engineering UGM in collaboration with (in different scheme): (1) New Zealand partners and (2) The Centre for Geologic Resource, Ministry of Energy and Mineral Resources of Republic Indonesia. The content of the Capacity Building program in this program therefore will not duplicate those of the existing program (e.g., Utami et al., 2010) instead it will be tailored to the need of the geothermal stakeholders in eastern Indonesia, and will include the results and lessons learnt from the research. The capacity building will be done through several activities, such as a series of courses on geoscience and engineering, and technical assistances and workshops.

### 4.3. COMMUNITY DEVELOPMENT

Being a source of energy and a natural laboratory, a geothermal site has economic, scientific and technological significance, as well as recreational and cultural values (Utami et al., 2011). However, community awareness about that is generally low. Thus, the community participation or involvement in utilizing the geothermal resource in their area is also low, and that the geothermal resource-based economic activity has not been well developed. In accordance with UGM's mission to nurture the culture of learning, our Community Development program will be firstly directed to disseminate knowledge about geothermal, and secondly to provide technical assistance to the local government and other stakeholders in eastern Indonesia to develop geothermal public learning facilities such as a geothermal education park (Figure 3). Consecutively, technical advisory to conduct geothermal resource-based activities that help open the livelihood opportunities and promote environmental stewardship e.g., Roy, Jr. (2010) and Anave and Cala (2005) for the community in the Philippines, and Hikuroa, (2012) for the Maori geothermal society in New Zealand will be delivered. Lahendong field is located in Tomohon City, North Sulawesi can the candidate of the model for Community Development in the eastern Indonesian region (Utami et al., 2011).

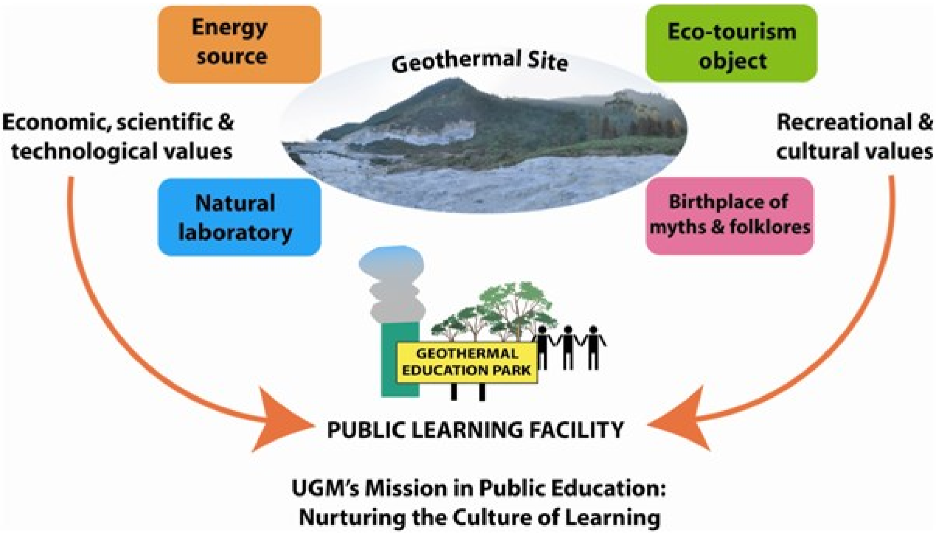


**Figure 3: The values of a geothermal site that can be learnt in a public learning facility (Utami et al., 2011).**

### 5. EXPECTED OUTCOMES OF THE PROGRAM

The outcomes of the program are designed as short term, medium term, and long term outcomes, as follow;

#### 5.1 Short term outcomes (Year-1)

a) Catalog of characteristics of volcano-hosted eastern Indonesian geothermal fields explored by deep drilling (Lahendong, Tompaso, Kotamobagu and Ulumbu).
b) Guideline for field mapping and geothermal environment monitoring.
c) Design of laboratory work for mitigating the effect of acid fluids in geothermal systems
d) Dissemination of the results of the research, and formulation of the research continuation. This will be done through a workshop involving government and company staff, and local academic society.

e) Community awareness about geothermal energy and its role in clean and sustainable development, and in increasing prosperity. This will be achieved through knowledge dissemination for the eastern Indonesian geothermal community

### 5.2 Medium term outcomes (Year 2 -3)

a) Complete catalog of characteristics of the volcano-hosted Eastern Indonesian geothermal fields.
b) Improvement of procedure to reduce the resource risk.
c) Better understanding on corrosion and scaling problems in geothermal process plant and know-how to solve the problems
d) Positive perspective and attitude of the community toward geothermal energy development
e) Improved community capability in utilizing economic potentials through geothermal resource development

### 5.3 Long term outcomes (over 3 years)

a) Establishment of methods for geothermal resource exploration, development, monitoring and problem mitigation suitable for the eastern Indonesian geothermal systems. The impact of this outcome is the reduction of both resource and development risks that will lead to the successful geothermal energy production and utilization in eastern Indonesia
b) Strengthened capacity of the geothermal company personnel and government staff in developing and managing the geothermal resource in the country
c) Increased research and education activities focusing on geothermal development and related issues at UGM
d) Increased community prosperity through productive economic activities related to geothermal development

## 6. CONCLUSIONS

In the world where fossil fuel supply depletion is an issue, geothermal energy is an eminent alternative especially for countries along the Ring of Rire such as Indonesia. However, the utilization of geothermal as source of energy has not yet been optimum in Indonesia due to technical problems, social resistence in the geothermal fields and goverment policy. The program which is a collaborative program between Gadjah Mada University and New Zealand goverment comes up with an integrated work to solve the technical problems related to the characteristic of geothermal source in eastern Indonesia possessing magmatic fluid in a program entitled Geothermal Energy for Green, Sustainable Development and Community Prosperity in Eastern Indonesia: NZAID-Gadjah Mada University-supported CaRED Program. Emphasizing not only in the research, but also in capacity building as well as community development, the program offers solutions for all stakeholders; thus, the establishment of sustainable geothermal power plant as one of the key elements in supporting productive society in regard to the energy supply can be realized.

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