

## Resource Risk Assessment in Geothermal Greenfield Development; An Economic Implications

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### ABSTRACT

This paper reviews the significant uncertainty associated with upstream risk during greenfield development in Indonesia and its impact on downstream development.

### 1. INTRODUCTION

New regulations and the development of a geothermal road map by the government are triggering a geothermal “interest boom” in Indonesia. Plans to resolve critical challenges to moving forward commonly focus on non-resource issues such as project financing and tariff. If resource development risk assessment and management is not included in the plan this can lead to development failure and the slow growth of geothermal development. Based on Supreme Energy’s recent pre-feasibility studies of several fields in Sumatra, high impact resource risks which are sensitive to development cost include: resource temperature, resource size, field permeability and fluid enthalpy. Supreme Energy’s approach to minimizing uncertainties in cost estimation for greenfield geothermal developments has focused on an operational excellence philosophy involving optimization of organizational capabilities and exploration technologies. This involves acquiring the optimal amount and type of data, followed by knowledgeable interpretation of the subsurface process. The strategy to lower resource risk started by selecting geological settings associated with mature volcano-tectonic settings which can create effective permeability, followed by an assessment of surface manifestation type and distribution, through to application of geochemistry sampling tools and 3D MT inversion techniques. Total development cost is sensitive to resource risks and uncertainties directly related to estimation of the number of production, injection and make up wells which affect the cost of the power generation facilities (PGF) and steam field above-ground gathering system (SAGS). The impact on the development cost estimate can range from -x to +y percent. Conservative cost estimation assumptions should be employed if the resource risk is high. Finding the right resource risk-cost balance is critical to supporting the growth in geothermal development planned for Indonesia.

### 2. BACKGROUND

Based on GOI (Government of Indonesia) reviews of the country’s geothermal resource potential, Indonesia has the largest geothermal reserves in the world with most still “untouched”. The formal number used by the GOI is approximately 27,000 MWe consisting of high, medium and low temperature systems. However, the geothermal growth to date has been very slow with only about 1,182 MWe installed capacity (API, 2008). One of the primary reasons for the slow growth is the low electricity price. New regulations and a GOI geothermal road map are triggering the present geothermal “interest boom” in Indonesia. Many reviews and workshops have been conducted to formulate a geothermal electricity price which

is acceptable to all stakeholders, but in many cases resource risk was not identified as a critical parameter. Geothermal resource characteristics which are determined in the upstream phase directly control the downstream development strategy and if there is significant uncertainty in these characteristics, then there will be high risks associated with the chosen downstream development strategy.

In Indonesia under the current geothermal regulations, the upstream-downstream alignment is weak (Figure 1) and this may lead to downstream development failures, or a lack of downstream development activity. If geothermal developments commence downstream activities before the upstream uncertainty is minimized this can lead to a big gap between the predicted and actual reservoir drawdown. This in turn can cause a project ‘train wreck’ (Sanyal, 2000) (Figure 2) because the power plant cannot be operated at its design capacity. High quality exploration programs, effective resource risk management, and strong upstream-downstream linkage is needed to inform an electricity selling price which reflects lower attendant investment risks.

Several papers discuss overall geothermal project risk (e.g. Barnett et al., 2003) and project risk management (e.g. Greene, 1999). The objective of this paper is to review the significant uncertainty associated with upstream risk during greenfield development and its impact on downstream development on the assumption that the bigger the risk the bigger the economic implication. The discussion will focus on key development risk questions such as ‘what are main upstream risks?’, ‘what does it cost to minimize or manage the risks?’ and ‘what is the impact of the risks?’.

### Geothermal Development Scheme

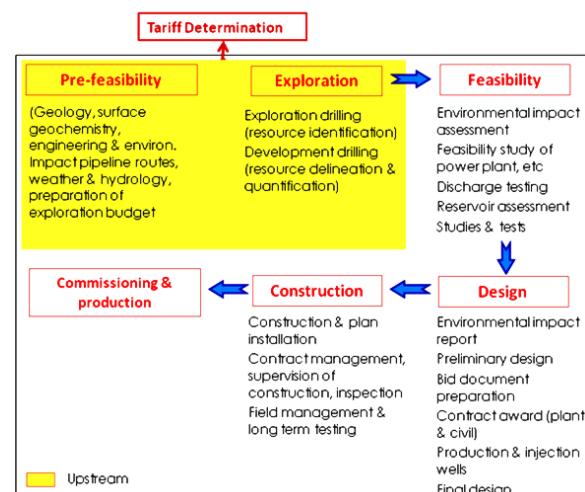
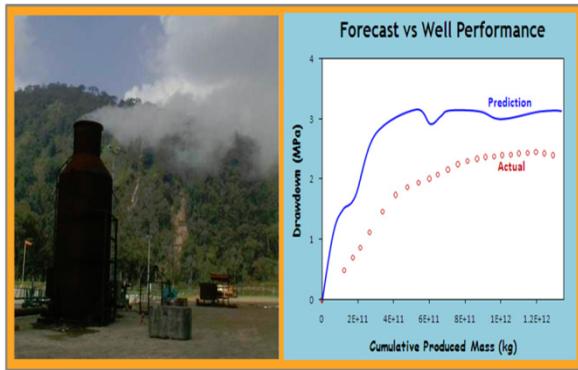


Figure 1: Current point of determining electricity tariff from geothermal developments in Indonesia.

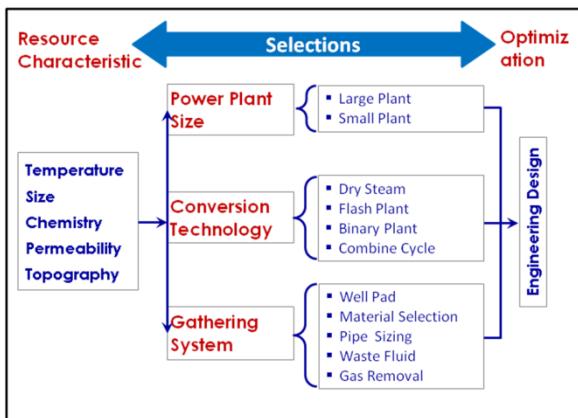


**Figure 2: Unmanaged risk can cause big gap between predicted and actual geothermal reservoir performance.**

### 3. RISK AND UNCERTAINTY

Risk involves a state of uncertainty where some of the possible outcomes are undesirable. Resource risk profiles differ from prospect to prospect. Risk management can be considered as a systematic way of dealing with hazards (Beck, 1986). It is the realization that a situation may induce “harm” that inspires the recognition of risk in association with hazard. In this discussion risk will be discussed as the probability of occurring (uncertainty) and the impact (hazard).

In general, and similar to other energy projects, the biggest uncertainty in geothermal development for power generation is related to the outputs of the resource or upstream development although the biggest cost or budget impact is in the downstream development (Figure 1). Based on a pre-feasibility study of several fields in Sumatra by Supreme Energy, the key resource risks that should be considered during pre-feasibility and before exploration drilling include temperature, size, permeability and fluid enthalpy. In general, the uncertainties in all these parameters have a direct impact on technology selection and the size of downstream development such as surface above ground system (SAGS) and power generation facilities (PGF) (Figure 3).



**Figure 3: Resource characteristics govern the downstream development budget.**

The uncertainty discussed here relates to the risks in developing a greenfield 110 MWe power generating plant. The resource temperature is a parameter that has high impact. Reservoir temperatures above 200 °C are needed for cost-effective electrical generation from a greenfield development of 110 MWe. Reservoir size and reserves reflect potential development size. As this discussion is focused on 110 MWe, the ‘proven’ resource size

uncertainty range is from 0-110 MWe < 110 MWe > 110 MWe. Permeability is discussed as is well output in the range 5<5-8>8 MWe/well using Indonesian drilling experience. One of the most sensitive parameters related to the geothermal fluid produced is enthalpy and an enthalpy uncertainty range of 1000 (liquid) to 2700 (vapor) kJ/kg is considered. A brief discussion follows on options for minimizing resource uncertainty based on Supreme Energy’s surveys.

#### 3.1 Reservoir Temperature

In greenfield developments where no wells are present, geochemistry plays an important role in determining the existence of high temperature systems. Assessment of surface manifestation type and distribution is critical. Geothermometry from fumaroles and boiling chloride springs can give an accurate estimate of reservoir temperature, whereas other type of manifestations may not represent the target reservoir if the fluid is sourced from heated surficial water. Fumaroles and chloride springs often have a direct connection to the target reservoir and information from these can help to define the conceptual model of the geothermal system.

Results from both fumaroles and chloride springs are often uncertain and thus not able to lower temperature risk. Moreover, high to medium topography minimizes the occurrence of manifestations. In typical Indonesia volcanic arc systems, the “rule of thumb” is that fumaroles are usually found both in high elevation associated with “up flow” or low elevation related to “out flow”. However, there are many exceptions to the “rule of thumb”. Many times it has been very difficult to sample fumaroles due to weak steam flow or they are located within an unexploitable resource area such as a national park (Hadi, 2008).

Chloride springs associated with Indonesian volcanic arc systems often represent deep outflows more than 5 km away from the main resource (Figure 4). The fluids from these types of chloride spring are usually diluted with other type of geothermal or surficial water. Again, many exceptions from this “rule of thumb” occurred in Supreme’s surveys (Hadi, 2008). If core well data is available, alteration assemblage as well as temperature projection may predict a high temperature system or reservoir top. However, very shallow temperature wells may give a misleading indication of the reservoir temperature.



**Figure 4: Chloride spring found in Indonesia, boiling but no silica sinter, outflow?**

### 3.2 Reservoir Size (Volume)

Reservoir size (volume) is one of the most sensitive parameters in determining reserves and it is usually estimated based on the available “container” (area and depth) and the “filler” or pore volume. Resource area is normally constructed by combining earth science data, with particular emphasis on geophysical information. Numerous geophysical techniques are available to delineate reservoir boundary with varying uncertainties. Presently there is no proven tool to accurately interpret a resource boundary. Deep penetrating techniques such as MT can delineate geothermal resource area with high confidence by interpreting alteration caused by geothermal fluid-rock interaction sealing the reservoir, as well as a resistive core associated with the reservoir. However, MT interpretation can be uncertain and mislead the resource area estimation (Cumming, 2008; Ussher, 2005; Arnason, 2000) (Figure 5). Geothermal prospects may evolve from many events which cause relict alteration and mislead MT interpretation of the cap or conductive layer (Melaku, 2005). In Indonesia where volcanic arc systems associated with major fault zones frequently create major graben formations, MT interpretation can be complex due to sediment masking, bad quality data or distant station spacing (Hadi, 2008). Resource size can only be proven by drilling - relict geothermal systems often mislead the MT interpretation and exploration strategy.

Reservoir depth is very hard to assess and while it can be indicated from MT, usually can only be proven by drilling. The reservoir thickness is uncertain and is usually estimated based only on comparable exploited geothermal resources. Micro earthquake data is often used to estimate the bottom of the reservoir or the minimum depth of the earth brittle layer that reservoir fluids may penetrate. But that microearthquake data is typically extending much deeper than wells are drilled, and so can over-estimate thickness.

Pore volume is directly controlled by rock type in the reservoir. Constructing a geological model has high uncertainty because most geothermal reservoirs do not

follow a layer-cake sedimentary model. Instead they are formed from an unpredictable volcanic rock distribution based on an eruptive center. Volcanic facies modeling is often implemented, however, with no well data this exercise is also uncertain. Pore volume uncertainty is also related to the porosity of the rock since alteration can either reduce or increase porosity.

### 3.3 Permeability

Reservoir permeability can be described as a continuous pathway in the reservoir where fluids move, and if penetrated by a borehole directly it will control well output. Fault or structure permeability is often a desire drilling target in exploration. Quantitatively estimating productive permeability for well targeting purposes is difficult and such estimates can only be made qualitatively. Open structure permeability is assessed by surface structure information, alteration mapping and linkage to surface manifestations (Ramos, 2005; Hole, 2002). Surface and subsurface structure results are frequently different in trend. MT methods have been used in the past to identify major subsurface faults, however, more lately MEQ data has been shown effective during exploration and can provide more detailed information.

The integration of surface and subsurface data can be used to qualitatively estimate the probability of encountering permeability. Exploration has frequently focused around up flow zones where high permeability is usually expected. Finding up flows is always a challenge because even the usual MT “doming and thinning” approach used to target up flows is not always a guarantee of success. Although the conductive layer as mapped by MT can provide a very good guide to top of reservoir as defined by the 200 C isotherm, it cannot directly differentiate parts of the resource that may be considerably hotter than this or areas that have particularly high permeability. (SKM, 2004) (Figure 6).

The biggest uncertainty related to permeability is estimating the size of the permeable zones. Quantifying permeability is best done by correlation with drilling results from similar fields.

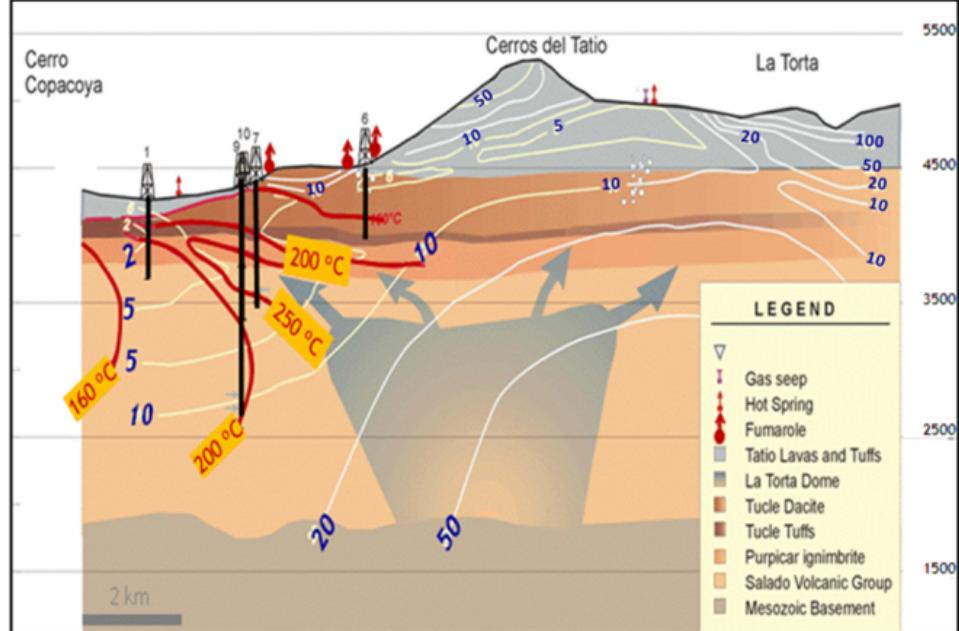
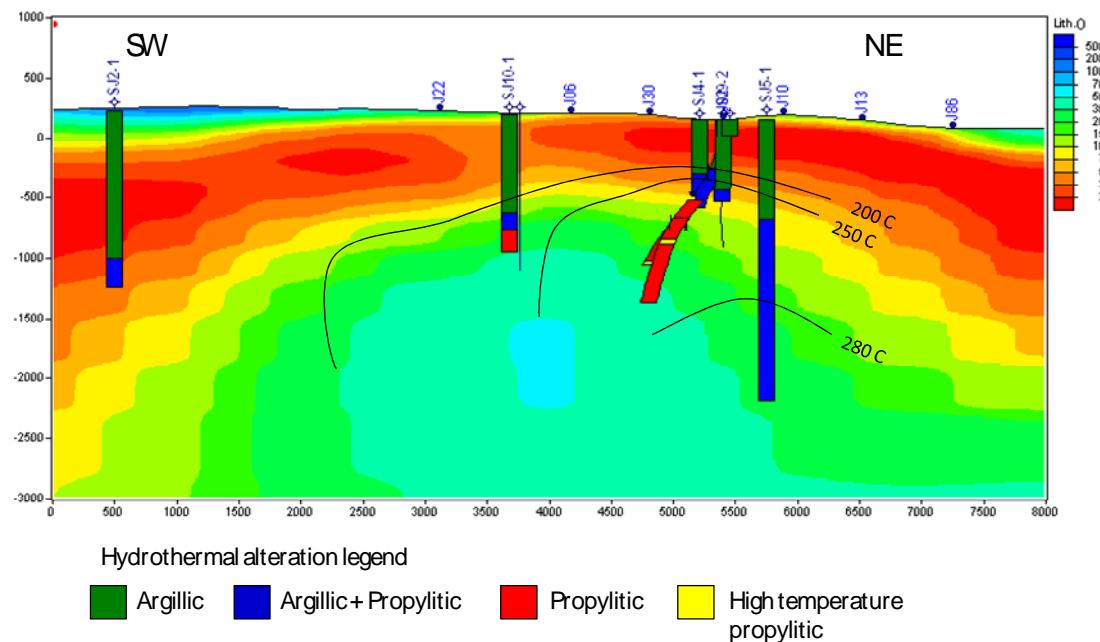


Figure 5: Different prediction between MT Interpretation and actual drilling result (Cumming, 2002).



**Figure 6: Interpretation MT “doming and thinning”?? No drilling success for 2 wells on the left of the cross section (SKM, 2004).**

### 3.4 Enthalpy

Fluid enthalpy describes the amount of energy per unit mass contained in the reservoir fluid and is governed by temperature, pressure and fluid chemistry. Enthalpy has a major impact on technology selection, engineering design cost and the number of injector wells. Since a well discharge is needed to determine enthalpy, the estimation of enthalpy is very uncertain before any well is drilled.

Before a deep borehole is available to sample the deep reservoir, the only tool that can be used to predict enthalpy is geochemistry of the fluids from surface manifestation. However, this leads to high uncertainty as fluid geochemistry can only be used to describe the enthalpy qualitatively. Enthalpy can vary across a field, so even with a few exploration wells drilled, there often remains uncertainty about total steamfield production enthalpy until all wells are drilled.

## 4. RISK MANAGEMENT

Risk Management includes plans to minimize and mitigate resource risk (uncertainties). One way to reduce “harm” or minimize uncertainties is to estimate cost by applying an operational excellence philosophy. This focuses on acquiring types and amounts of data which are then used in conjunction with proven sub-surface analysis and interpretation processes. The process also involves identifying interpretation strengths and weaknesses, it employs knowledgeable and experienced practitioners, and it applies technologies that can potentially lower risk.

A strategy to reduce resource risk starts with selecting the correct geological setting, accurately assessing surface manifestation type and distribution, using geochemistry tools and applying 3D MT inversion techniques. However, resource uncertainty is still very significant if there is no deep well penetrating the reservoir. Lower resource risk uncertainty is not directly related to large amounts of data availability, but is related to the type and quality of “hard data”. Data acquisition should be terminated when the value of additional information v-a-v its cost is minimal or where

additional cost cannot add significant value to reducing risk.

Survey technology selections are based on, or depend on the goals of the survey. Pre-feasibility surveys should minimize exploration or drilling risk, but no proven techniques are available, so risks in subsequent activities remain high. However, if the information is needed to support a decision to acquire a geothermal concession area then a higher cost survey is justified and may require a more expensive and detailed MT survey rather than a cheaper but more reconnaissance-type g. In this case the risk mitigation plan is usually based on an understanding of the field conceptual model and drilling risk profile. Based on Supreme Energy experiences on conducting three (3) recent prefeasibility studies collecting 1km MT spacing, detail geology and geochemistry surveys, the cost to acquire information for a 110 MWe green field development is around US\$ 1-1.5 million (Hadi, 2008).

## 5. RESOURCE RISK IMPACT (HAZARD)

Resource characteristics such as temperature, volume, permeability and enthalpy directly control downstream development (which is approximately 70% of a greenfield project budget). Resource risks or uncertainties are sensitive to total development cost because they directly affect estimation of the number of production, injection and make up wells, SAGS and PGF.

The availability of fumaroles and boiling chloride springs significantly reduce the risk of selecting an intermediate-low temperature reservoir. In this context the range of project outcomes from penetrating 200<200-240>240 °C temperature fluids is “higher chance of project failure<higher US\$/kWe>higher chance of project success”.

As a rule of thumb, MT interpretation usually predicts a larger resource area by comparison with what is actually proven. The range of impact from proving 0-50-110 MWe is “project failure” to “higher US\$/kWe” to “project success”.

The impact of lower enthalpy is significantly higher development cost. The difference in SAGS cost outcomes over an enthalpy range of 1500-1000 kJ/kg are approximately US\$ 100/kWe. Over the same range the number of successful reinjection wells ranges from 5 (1500 kJ/kg) to 12 (1000 kJ/kg).

Historical production well drilling average capacities in Indonesia are in the range 5-8 MWe/well (PB Power, 2008). However, the tariff range which is expected to allow geothermal developments to move forward in Indonesia will most probably require a drilling average of 8 MWe/well or above. The range of drilling average outcomes is probably <5 to 5-8 to >8 MWe/well. Based on API (2008) to develop 110 MWe with an assumption of drilling average 10 MWe/well and enthalpy of 1500 kJ/kg, the required drilling budget including injection well and site preparation is approximately US\$ 90 – 100 million. The impact of drilling uncertainty are; (1) Less than US\$ 95 million if drilling average is biggest than 10 MWe/well. (2) Approximately US\$ 95 million if drilling average is 8-10 MWe/well. (3) Bigger than US\$ 95 million if drilling average is less than 8-10 MWe/well.

## 6. IMPACT OF ECONOMIC CONSIDERATIONS ON RISK

Resource uncertainties have the greatest impact on whether any geothermal development will be successful or unsuccessful.

Under the current geothermal regulations in Indonesia, the pre-feasibility study phase must be sufficiently “detailed” for tender purposes.

“Real and up-to-date” information must be used to estimate project cost (site specific). The higher the uncertainty the more conservative must be the estimate. The more conservative the estimate the higher must be the cost (higher tariff). Also, the higher the risk the higher the return expectancy (higher tariff). Resource uncertainties will be carried solely by the developer, so will require higher returns to compensate for the risk. The requirement to accept resource uncertainty and development risk by the developer will lead to higher priced geothermal energy. In the worst case, unrealistically low bids, if accepted, will lead to the undesirable consequence of a failed development and a need to re-bid or adjust the tariff in the future in order for development to proceed. This situation can already be seen in the marketplace.

## 7. CONCLUSIONS

In a government-regulated market environment the geothermal power tariff and its accompanying power purchase agreement must reflect the resource development risk if a government expects a developer to carry this alone. For governments to encourage capital development of this unique domestic (non-exportable) energy resource there must be a mechanism that allows the power tariff to be based on high-quality resource “real and up-to-date” data, which will not be available until exploration wells have been drilled into and located and characterized the geothermal resource.

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