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Quick scan
Small scale geothermal plants

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SUMMARY

As a collaborative research and partnership program of Indonesia (ITB and UI) and the Netherlands (IF Technology) a series of workshops were held to address concerns and interests of making geothermal energy more valuable than it is now. The first workshop was held on April 7th, 2016 at Institut Teknologi Bandung and participated by about 60 invited people from industries, universities, research agency, local and central government, representatives of local communities, NGO, as well as small-medium-large enterprises surrounding the geothermal energy potential location. The second workshop held on April 7th, 2017 at UI, ITB presented its findings on small scale power plant case study. The presentation consists of technical, financial, and social aspect using low-medium enthalpy resources. Therefore, the studies in Work Package (WP) 3 low-medium enthalpy geothermal continue to a quick scan for feasibility in small scale power plant using low-medium enthalpy geothermal resources.

Previous study, WP 3.01, found that preferable manifestation for small scale in West Java is Cisolok Hot springs based on its geothermal fluids parameter with temperatures of 95°C and flow rate of 5 kg/s. For waste heat brine, Awibengkok-Salak is preferable due to temperature of brine reach 170 ^{o}C and categorized as two phase geothermal systems so that brine availability is high. This parameter will be the basis for preliminary design of small scale geothermal power plant. The binary cycle is divided into two cycles: the primary cycle which contain the geothermal fluid and the secondary cycle which enclosed system contain an organic working fluid. Based on secondary fluids selection study, preferable working fluid is Pentane. The selection of turbine pressure design that used in this system is 3 bar using the optimization maximum power output. The net cycle power that can be achieved by this system is 23 kWe. The heat exchanger and pump type that used in this case is shell and tube heat exchanger and centrifugal pump. Required investment for small scale geothermal power plant is 1.7 Million USD. Electricity price vs IRR sensitivity shows that 102 USD cent/kWh of price with IRR is 9.79%.

The power generation in Salak is generated by utilizing the brine separation result from the separator. By simulating the binary cycle output, the total power that can be extracted from the total brine output from the separator is approximately 13 MW. However, by referring to the small-scale project that discussed in previous section so the maximum power generation for

this case is adjusted to 5 MW. The selection of the turbine pressure design that is used in this system is 8.5 bar with geothermal mass flow rate is 90 kg/s. The pressure of brine output from the separator is still high around 8 bar. Therefore in this this case is no need to use the feeding pump to transport brine to the plant. The total investment to develop a 5 MW geothermal binary plant that utilizes the manifestation in Salak is USD 16.6 Million and minimum electricity price is USD 23.8 cent/kWh. With this price the IRR on Equity would be 9.70% for 30 years project time.

The optimization of geothermal energy utilization is expected to encourage local economic development by adding value of geothermal heat for local products, generating income as tourist attraction, contributing to electricity supply, as an attempt to put an end to excess wasted thermal energy, and as an opportunity for following geothermal projects to come. Even more, produce their own electricity at a competitive price and also become (less) independent form grid electricity, giving a long-term stability. At least in remote areas, can produce more sustainable electricity at lower price (compared to diesel generated electricity). It is expected that the development of small scale geothermal plants can expand the economy. Stakeholders; public, investors and developers, need to get continuous education, so that they can benefit by gaining in depth knowledge of the advantages and conditions of constructing a geothermal energy installation. Investors and developers should know how to effectively deal with the local community to avoid conflict.

This report concludes that small scale geothermal power plant in Cisolok and Awibengkok-Salak can be implemented depend on technical, financial and social assessment with several notes to be considered.

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1 INTRODUCTION

1.1 GEOTHERMAL RESOURCES: POTENTIALS & UTILIZATION

Primarily low/medium enthalpy geothermal energy is used for direct heating. The best-known forms are bathing, space and district heating, agricultural applications, aquaculture, some industrial uses and geothermal (ground source) heat pumps (see also Figure 1). The value and feasibility of direct use of geothermal resources can be enhanced through use of waste heat and cascaded system of geothermal energy. There are many options for the potential application of geothermal energy. Next to direct heating, low/medium enthalpy geothermal energy can also be used for cooling and electricity production.

1.2 DIRECT USE: CATEGORIES, APPLICATIONS, AND ELECTRICAL POWER GENERATION

The development of lower temperature binary technology has made electric power production from low temperature geothermal resources feasible. Small scale geothermal power plants can encourage geothermal electricity production. Excess or industrial waste heat and low-medium geothermal resources can be used to build small scale geothermal power plants. Geothermal resources located in rural or remote areas that are off the grid or that currently depend on diesel generators can benefit from the development of small scale power plants. Like most renewable energies, geothermal development carries high initial costs, but costs are lower once the plant is in operation. With small scale power plants revenue faster, they can be cost competitive with diesel generating power enjoyed by neighboring communities enabling market demand growth in the long run.

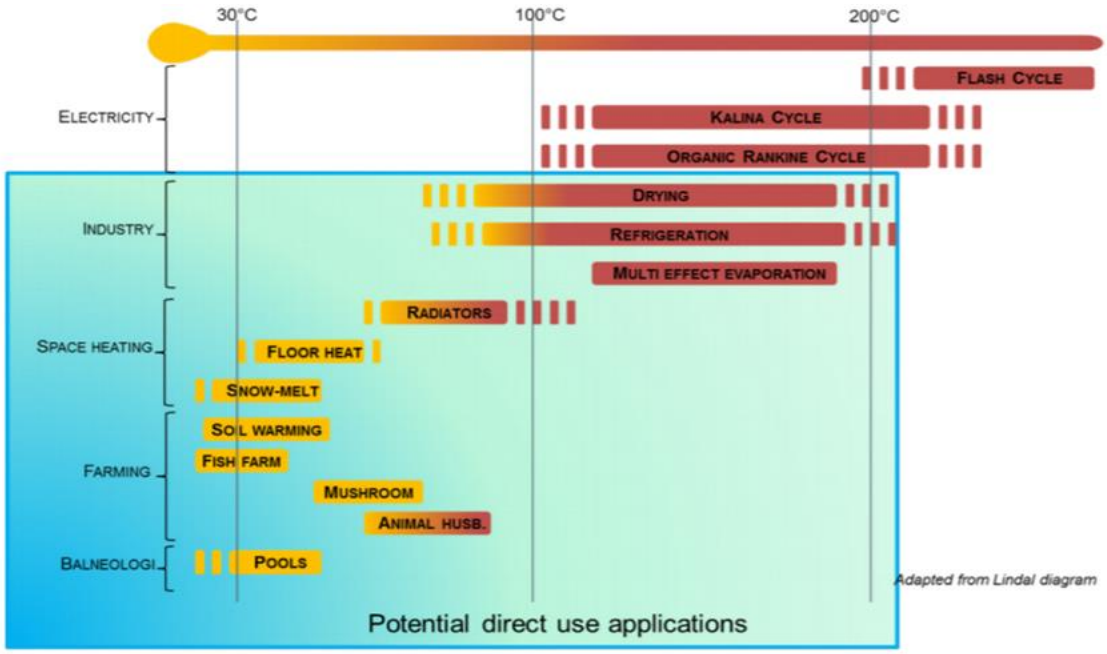


Figure 1: Temperature range for potential direct use application

1.3 SMALL SCALE GEOTHERMAL POWER PLANT

1.3.1 Definition

According to Vimmerstedt (1998), the definition of a small scale geothermal power plant are small geothermal projects less than 5 MWe while others (Entingh, et al., 1994 and Pritchett 1998) refer to a range of 100 to 1000 kWe as “small”. However, in this report, small scale defines as power plant less than 5 MWe.

1.3.2 Source

The source for small scale geothermal power plants can come from:

- hot spring with adequate flow rate;
- well head generating unit of a high enthalpy well;
- waste brine from a high enthalpy power plant;
- low-medium enthalpy wellbore in a volcanic hydrothermal system;
- low-medium enthalpy wellbore in a sedimentary basin system.

1.3.3 Technology

Small scale geothermal power plants use flash steam and binary technology. Whether a flash steam or binary system is used is site specific. Resource temperature, chemical composition of the geothermal fluid and maintenance preferences are considered factors. Flash steam plants in small scale applications are low cost, relatively simple, and require no working fluid. However, compared to binary plants, flash steam plants operate at higher temperatures. Binary plants operate at lower temperatures and use a second working fluid.

The “Onsen” Binary plants in Japan, adopt the concept of Binary geothermal power plants, which use chemical fluids known as a second liquid (e.g., Isobutene and n-Pentane) that boils at a lower temperature than water. Hot spring water passes through a heat exchanger and heats up the second liquid in a closed loop. Heat from the geothermal water causes the secondary fluid to flash to vapour, which then drives the turbines, and subsequently the generators. The vapour is condensed back to liquid and begins the cycle again. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere.

1.3.4 Examples

Numerous papers describing the applications of flash steam and binary system in small scale geothermal developments have been published. They detail the technology under various circumstances. The following text cites several examples of small scale geothermal power plant from hot springs and a wellhead generating unit.

Onsen Hot Springs of Japan

In Japan, hot springs alone can attract millions of tourists each year. Particularly near volcanic areas, in several areas the temperatures of some these hot springs are about 90-100°C. They are too high in temperature for bathing but below temperatures for power generation with flash plants.

Typically, hot springs bathing uses temperatures around 42°C. By incorporating a binary power plant upstream of the hot spring system, the excess thermal energy can be used for small scale power generation while cooling the water temperature for bathing. The advantage of applying this technology is at least two-fold, water temperatures from the hot springs are adjusted for bathing without changing the water quality and electricity can be obtained from existing hot springs without drilling new wells.

An example of application of hot spring power generation concept is the Obama Onsen Energy Plant. The plant uses excess heat from natural hot springs to generate electricity. It is run and funded entirely through collaborating with local people and a company, Koyo Denki Co.

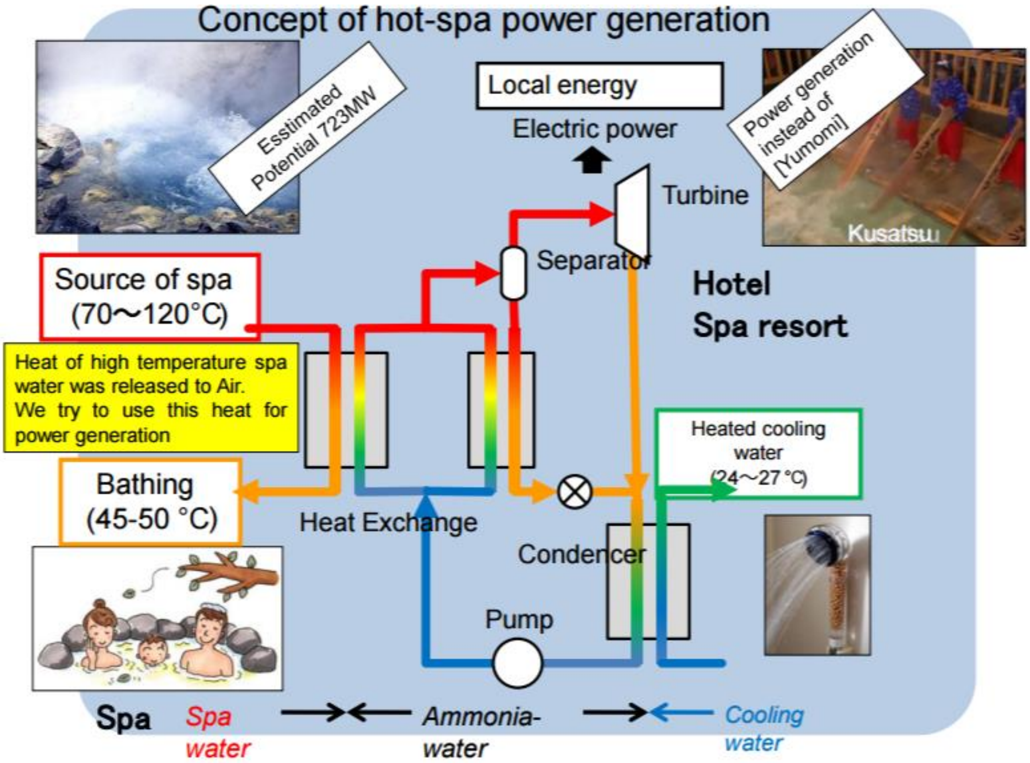
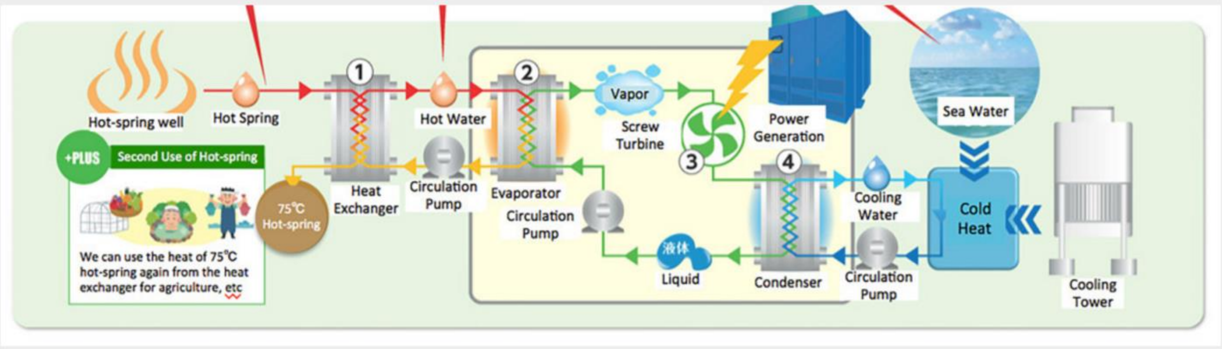


Figure 2: Hot Spring –Hot Spa Power Generation



① Naturally heated 100℃ water flows into heat exchanger. ②The hot water evaporates fluorine. ③Electricity is generated by turning a turbine in the power of the steam.④The vapor is cooled back into liquid fluorine with sea water. Graphic courtesy of Obama Onsen Energy .

Figure 3: Obama Onsen Energy Plant

The first binary power plant installed in Japan is located in the town of Shinoshen, home to the Yumura Onsen where two 20kW binary plants are installed. Even a 400 kW Onsen Binary Geothermal Power plant is in operation Tsuchiya, Fukushima. Water from the hot springs is used to heat the binary plant working fluid and cold water from the nearby lake is used to cool the thermal water before re-injection into the ground.

Chena Hot Springs

In July 2006, two 200kWe ORC power plant modules were installed for the first time using chiller equipment manufactured by United Technology Corp. The power unit at Chena utilizes geothermal fluids at 74°C to produce the 400 kWe of power for the Resort. Because of the low temperature, the ORC module requires larger equipment size which increased the investment cost. The objective of the project at Chena is to reduce the investment cost of the ORC module. By using the chiller, costs were reduced up to $1300 per kW (ORMAT $1800-2000 per kW). The advantage of the ORC chiller module is that it is easily relocated, it has no specific need for location. The binary geothermal plant at Chena is used to for power generation, space heating and cooling, and greenhouse operations.

Figure 4: left: Onsen" Binary Geothermal Systems (2 x 20 kW), Credit: The Town of Shinonsen; right: 400-kW Onsen Binary Geothermal Power Plant at Tsuchiyu, Fukushima Prefecture, Credit: Genki Up Tsuchiyu Company

Figure 5: Modular unit at Chena

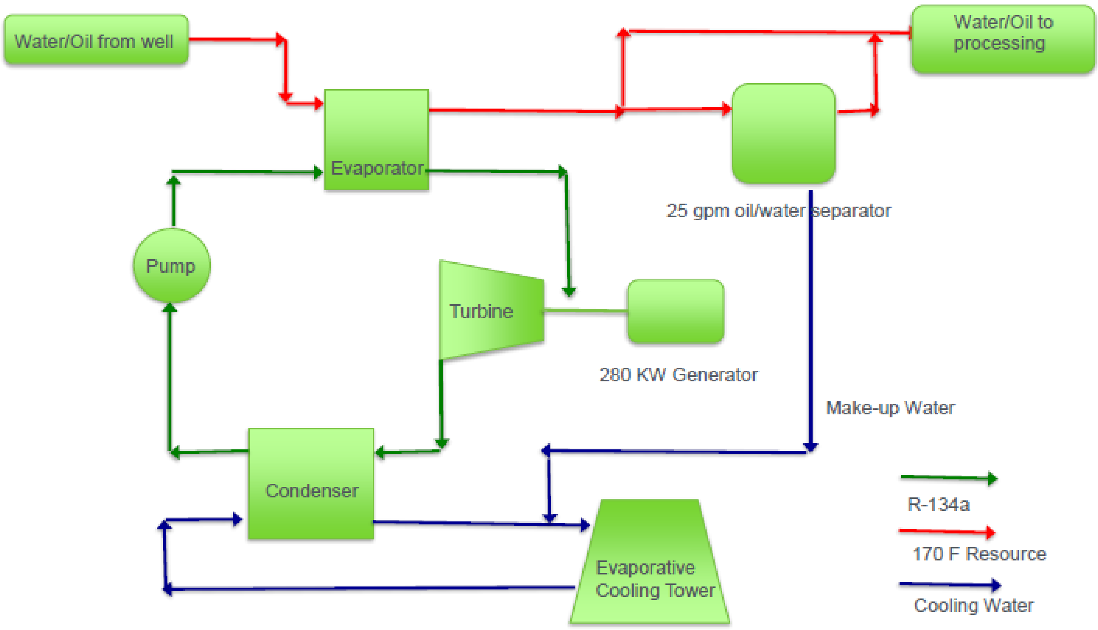


Figure 6: ORC module schematic design at Chena

Well Head Generating Unit from High Enthalpy Well

The Los Azufres Unit 6 of Mexico is an example of small scale generation from the wellhead generating unit from a high enthalpy well. This small scale module is a 5 MW geothermal turbine (back pressure type) and capacity factor of 99.3% which first operated in 1987. It successfully is in continuing service for over 29 years. Another example of small scale generation from a wellhead generating unit is located at the Waita Geothermal Plant in Japan which recently started in December 2014. Its output is 2000kW.

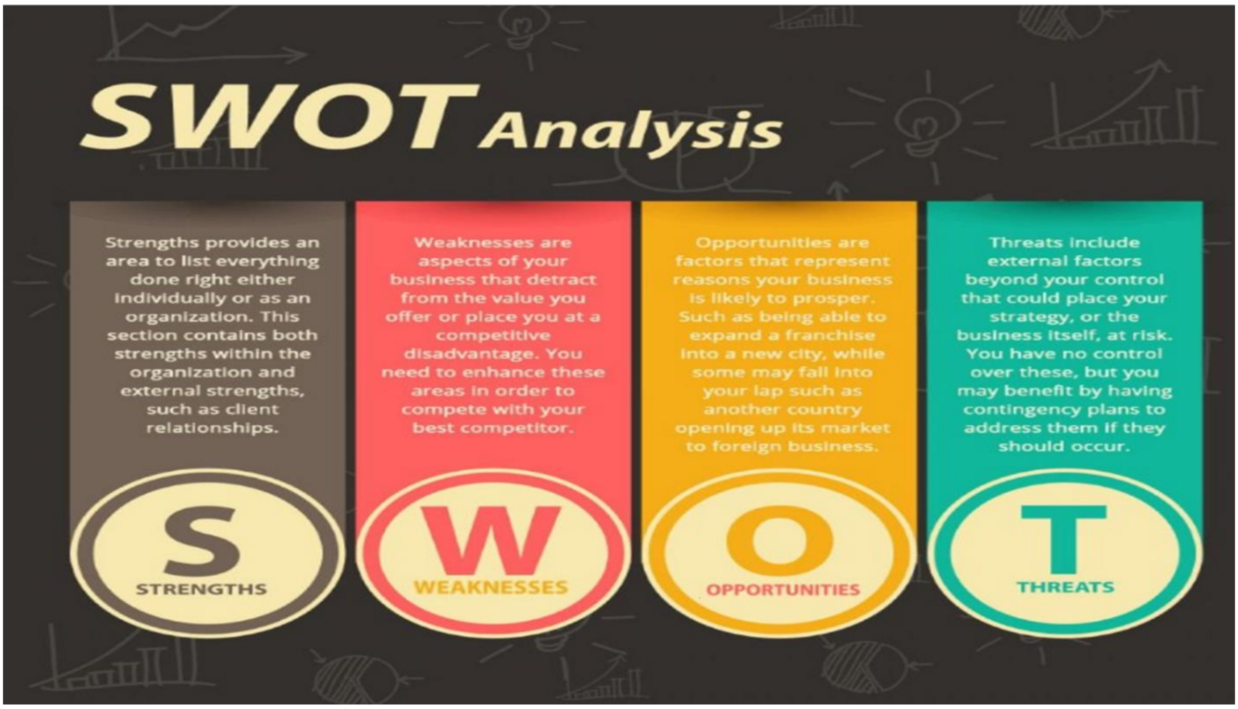
Figure 7: Well head generating unit small scale application in Los Azufres Unit 6 Mexico

Figure 8: Waita geothermal plant,Japan

2 ASSESSMENT

2.1 SWOT ANALYSIS

In the assessment of the small scale power plant we chose to use the SWOT analysis method. Elements of the SWOT analysis consist of the Strength, Weakness, Opportunities, and Threats. We intend to examine and investigate the positive factors that may work together and the potential problems that may need to be addressed.



Strengths provides an area to list everything done right either individually or as an organization. This section contains both strengths within the organization and external strengths, such as client relationships.

Weaknesses are aspects of your business that detract from the value you offer or place you at a competitive disadvantage. You need to enhance these areas in order to compete with your best competitor.

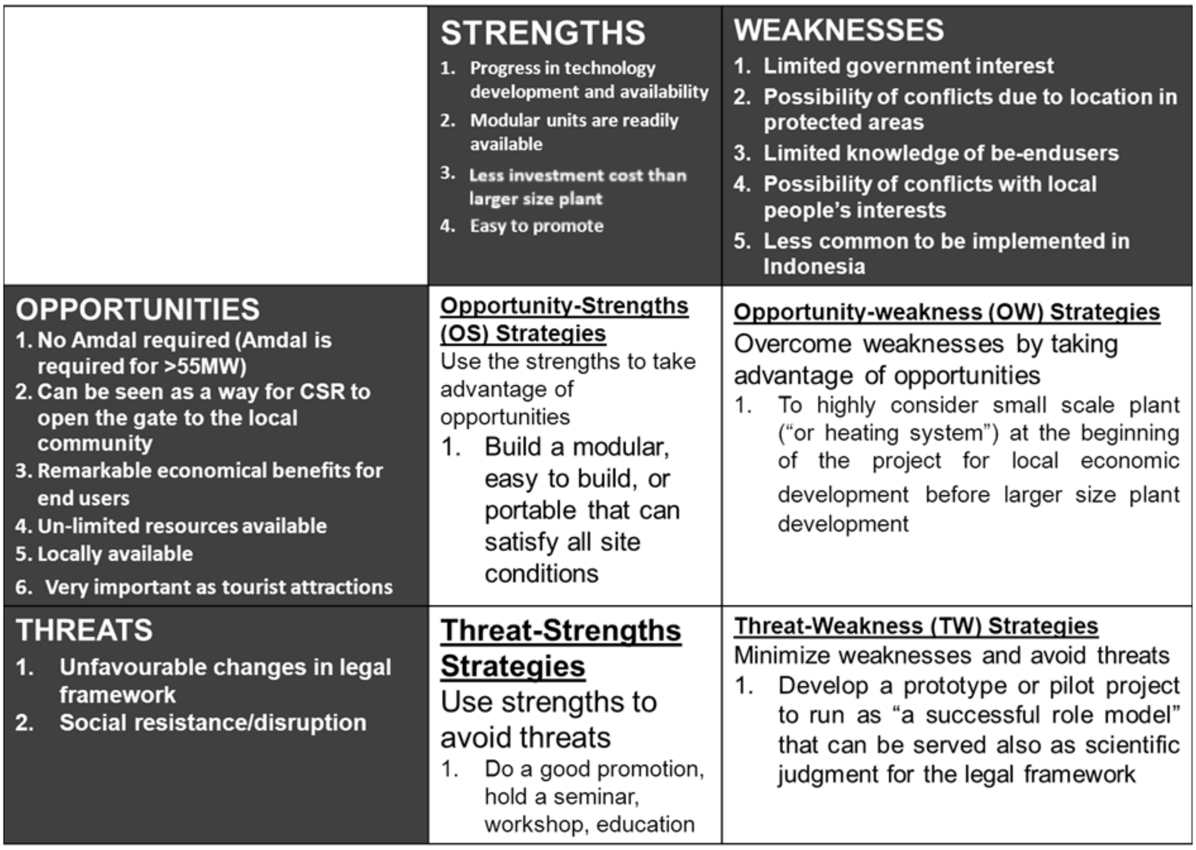
Opportunities are factors that represent reasons your business is likely to prosper. Such as being able to expand a franchise into a new city, while some may fall into your lap such as another country opening up its market to foreign business.

Threats include external factors beyond your control that could place your strategy, or the business itself, at risk. You have no control over these, but you may benefit by having contingency plans to address them if they should occur.

Figure 9: SWOT Analysis Method

Enlisted in the table below are the potential possibilities that were identified for the initiating development of a small scale power plant.

Table 1: Identified possibilities of SWOT elements



	STRENGTHS 1. Progress in technology development and availability 2. Modular units are readily available 3. Less investment cost than larger size plant 4. Easy to promote	**WEAKNESSES** 1. Limited government interest 2. Possibility of conflicts due to location in protected areas 3. Limited knowledge of be-endusers 4. Possibility of conflicts with local people's interests 5. Less common to be implemented in Indonesia
OPPORTUNITIES 1. No Amdal required (Amdal is required for >55MW) 2. Can be seen as a way for CSR to open the gate to the local community 3. Remarkable economical benefits for end users 4. Un-limited resources available 5. Locally available 6. Very important as tourist attractions	**Opportunity-Strengths (OS) Strategies** Use the strengths to take advantage of opportunities 1. Build a modular, easy to build, or portable that can satisfy all site conditions	**Opportunity-weakness (OW) Strategies** Overcome weaknesses by taking advantage of opportunities 1. To highly consider small scale plant ("or heating system") at the beginning of the project for local economic development before larger size plant development
THREATS 1. Unfavourable changes in legal framework 2. Social resistance/disruption	**Threat-Strengths Strategies** Use strengths to avoid threats 1. Do a good promotion, hold a seminar, workshop, education	**Threat-Weakness (TW) Strategies** Minimize weaknesses and avoid threats 1. Develop a prototype or pilot project to run as "a successful role model" that can be served also as scientific judgment for the legal framework

notes: AMDAL : Analisis Mengenai Dampak Lingkungan or Environmental Impact Analysis

2.2 CASE STUDY

Binary cycle power plants have been widely applied to several fields that are categorized as low-medium enthalpy. In water dominated high enthalpy geothermal field, binary cycles have also been applied to extract the energy from brine to generate electricity. The main components of a basic geothermal binary cycle power plant are the preheater, evaporator, turbine, condenser and feeding pump. The schematic process of a binary cycle is shown in Figure 10.

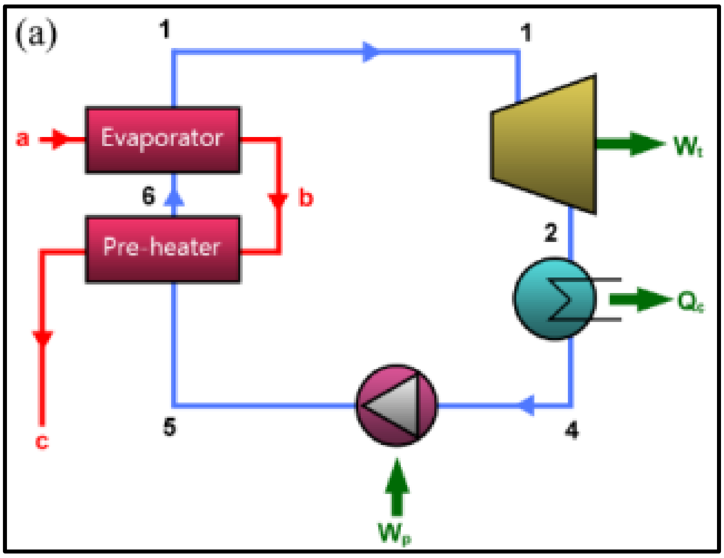


Figure 10 The schematic of binary cycle power plant (Reference: Fuad, 2015)

Figure 11: Cisolok Hot Springs and Awibenkok-Salak brine

2.2.1 Technical Aspect

Geothermal Fluids

This report discusses about the utilization of geothermal manifestation in the Cisolok and brine output from separator in Salak geothermal power plant. Those areas located in West Java.

Cisolok Area

The geothermal manifestation in Cisolok area appears at 106°27’13.4” E and 6°56’0.5” S in the Cisolok River. Currently, the geothermal manifestation of Cisolok is used as public bathing place. The thermal water discharging in the Cisolok River has high temperature near boiling temperature, with neutral pH and relatively high discharge rate.

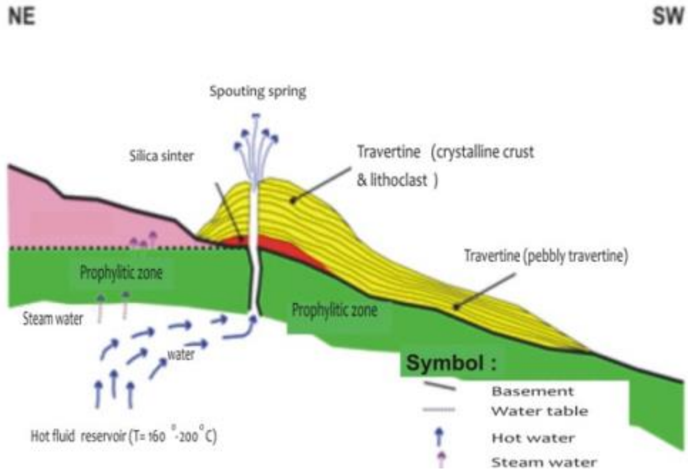


Figure 12 Sketch of NE-SW sections of geothermal manifestations along Cisolok Rivers (without scale). (Reference: Mandradewi, W., and Herdianita, N.R, 2010)

Under the resource assessment (WP 3.1a) survey to Cisolok hot spring has been made. Figures of the field survey are given in Figure 13, Figure 14, and Figure 15. Locations of measurement are divided into 4 areas, which are named 1 (MAP_CSK_1), 2 (MAP_CSK_2), 3 (MAP_CSK_3), 4(MAP_CSK_4).

Figure 13 Spouting springs in Cisolok

Figure 14 Spouting Springs (MAP_CSK_1)

Table 2 Measurement result in MAP_CSK_1

Variable	Spouting Spring (MAP_CSK_1)		
Coordinate (UTM)	X= 0660552; Y= 9233322		
Location	A	B	C
Elevation	93	-	-
Temperature (^{o}C)	94,6	-	96,8

Variable	Spouting Spring (MAP_CSK_1)		
pH	7,55	-	7,55
Diameter (cm)	10	2	10
Area (m^2)	0,00785	0,000314	0,00785
Averaged velocity (m/s)	2,06	0,33 m	0,633
Mass flow rate (m^3/s)	0,016223	0,000105	0,004972

Figure 15 Spouting spring (MAP_CSK_3)

MAP_CSK_2 and MAP_CSK_3 are eliminated because the flow rate is relatively small. Table 3 shows data for MAP_CSK_4.

Table 3 Measurement result in MAP_CSK_4

Variable	Spouting Spring (MAP_CSK_4)
Coordinate (UTM)	X= 0660570; Y= 9233370
Elevation (m)	78
Temperature (°C)	98,8
pH	7,69
Diameter (cm)	5

Variable	Spouting Spring (MAP_CSK_4)
DHL (mV)	108,7
Averaged velocity (m/s)	2,5
Mass flow rate (m^3/s)	0,004906

Based on data from the survey, a temperature of 95 ˚C and mass flow rate of 5 kg/s is used in this study for the Cisolok hot spring.

Salak Area

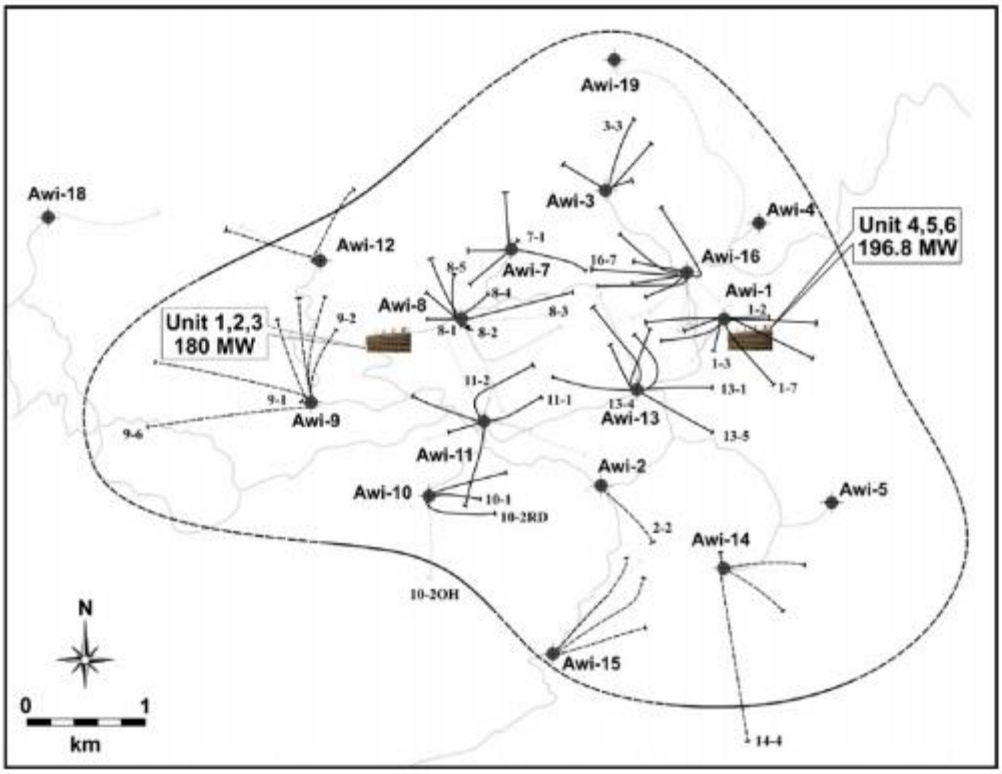


Figure 16 Map of Awibengkok-Salak geothermal field. (Acuna et al., 2008)

The Salak geothermal is categorized as two phase geothermal system. The field is generated by single flash system. According to Acuna et al., 2008, The Salak geothermal field has been producing the steam required for 110-377 MW of power generation for 16 years, with approximately 14,000 to 18,000 kph injected in the production area during this time. Production well produces steam with 10-20% of steam fraction, the total brine production is approximately 1900 kg/s. The wellhead pressure is around 11-12.4 barg. While fluid flows to the separator, the pressure decreased to 8.27-8.62 barg and fluid is separated from brine in water phase, steam directed to the inlet of the turbine. The brine temperature out from separator is 170°C and the pressure is almost same with separator pressure, after that the brine is re-injected through reinjection well.

Secondary Fluids

The concept of binary cycle power plant refers to an organic working fluid used in a secondary, closed loop. The organic working fluid has a lower boiling point and higher vapor pressure than water or brine (primary fluid). Hot spring water passes through a heat exchanger and heats up the secondary fluid in a closed loop. Heat from the geothermal water causes the secondary fluid to flash to vapour, which then drives the turbines, and subsequently the generators. The vapour is condensed back to liquid, closing the cycle.

The binary cycle is divided into two cycles: the primary cycle which contain the geothermal fluid and the secondary cycle which contains an organic working fluid. In preparing the plant design, a selection of working fluid for the system is one of the most important considerations. Several criteria must be considered during the working fluid selection: a good thermodynamic property, a compatibility with fluid characteristic used, especially in medium-high temperature ranges. Other important considerations are critical temperature and pressure and safety (non-flammable, non-toxicity, ozone depleting potential).

Hydrocarbons such as butane, pentane and propane are good working fluids, in addition to some refrigerants. An appropriate selection of working fluid will result in a high efficiency system, as well as safe and economical operation. The WP 3.06 study concludes R 245-fa as a preferable working fluid. In this study, we also consider n-pentane as a working fluid.

Table 4 The parameter comparison of working fluid

Fluids	Pcritical (bar)	Tcritical (°C)	ODP*	GWP**	Flamm-ability	Toxicity	Price (USD/kg)	Avail-ability
n-pentane	3.37	196.4	0	20 (low)	High	High	1-3	High
R 245 fa	3.65	154	0	950(high)	Low	Low	8-15	Low

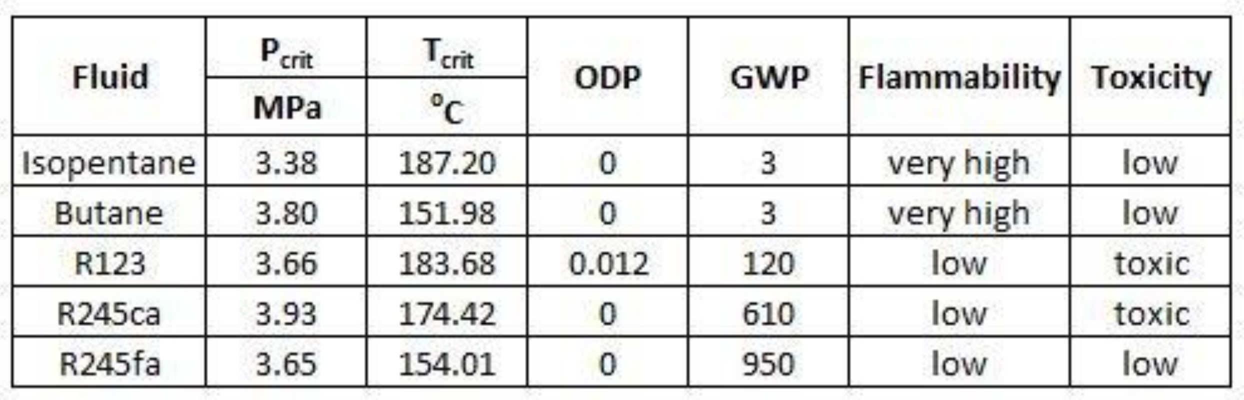
Notes

* ODP : Ozone Depletion Potential

**GWP: Global Warming Potential

The results based on the assumptions mentioned together with the various working fluids for the ORC Schematic design are demonstrated in the following figure.

Table 5: Results of various working fluids for the ORC Schematic Design



Fluid	P_{crit}	T_{crit}	ODP	GWP	Flammability	Toxicity
	MPa	°C				
Isopentane	3.38	187.20	0	3	very high	low
Butane	3.80	151.98	0	3	very high	low
R123	3.66	183.68	0.012	120	low	toxic
R245ca	3.93	174.42	0	610	low	toxic
R245fa	3.65	154.01	0	950	low	low

The sensitivity of flow rate and temperature to net power generation for the hot spring and waste brine case study are demonstrated in the figures below.

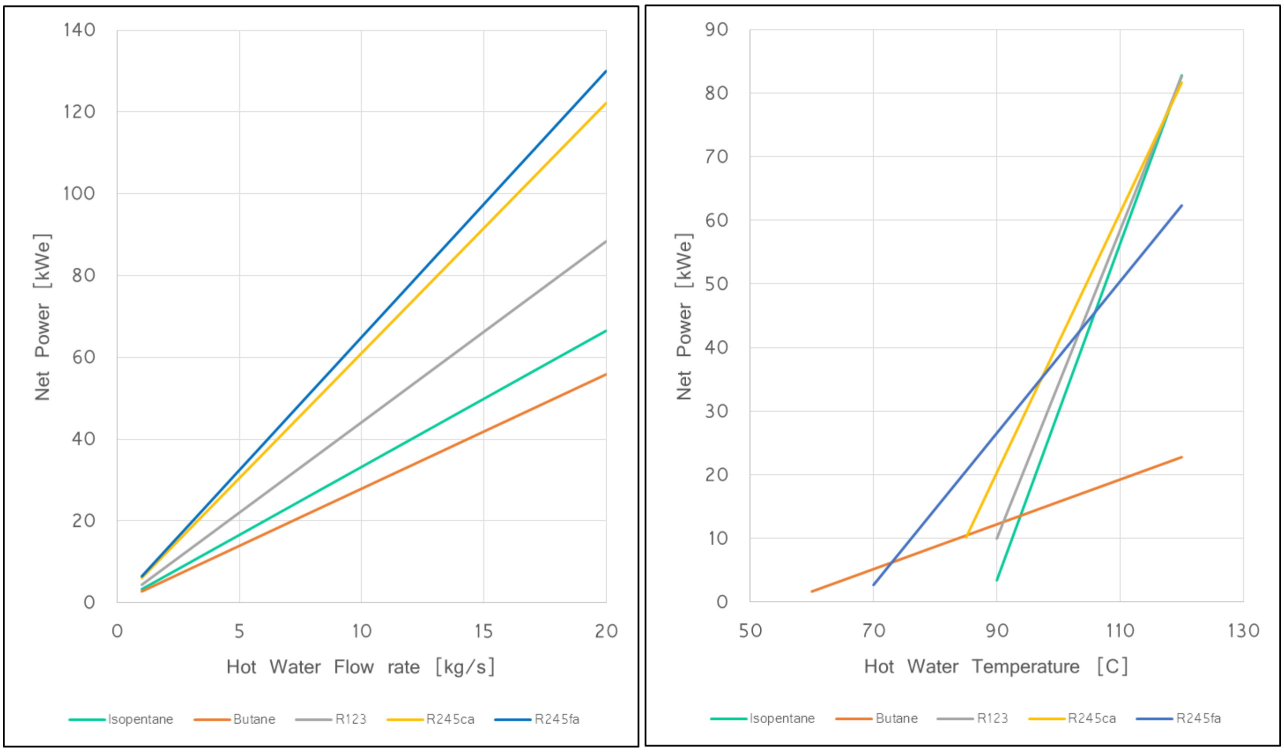


Figure 17: Left: The sensitivity of flow rate at temperature of 100°C to net power. Right: Sensitivity of temperature at flow rate of 1.5 kg/s to net power

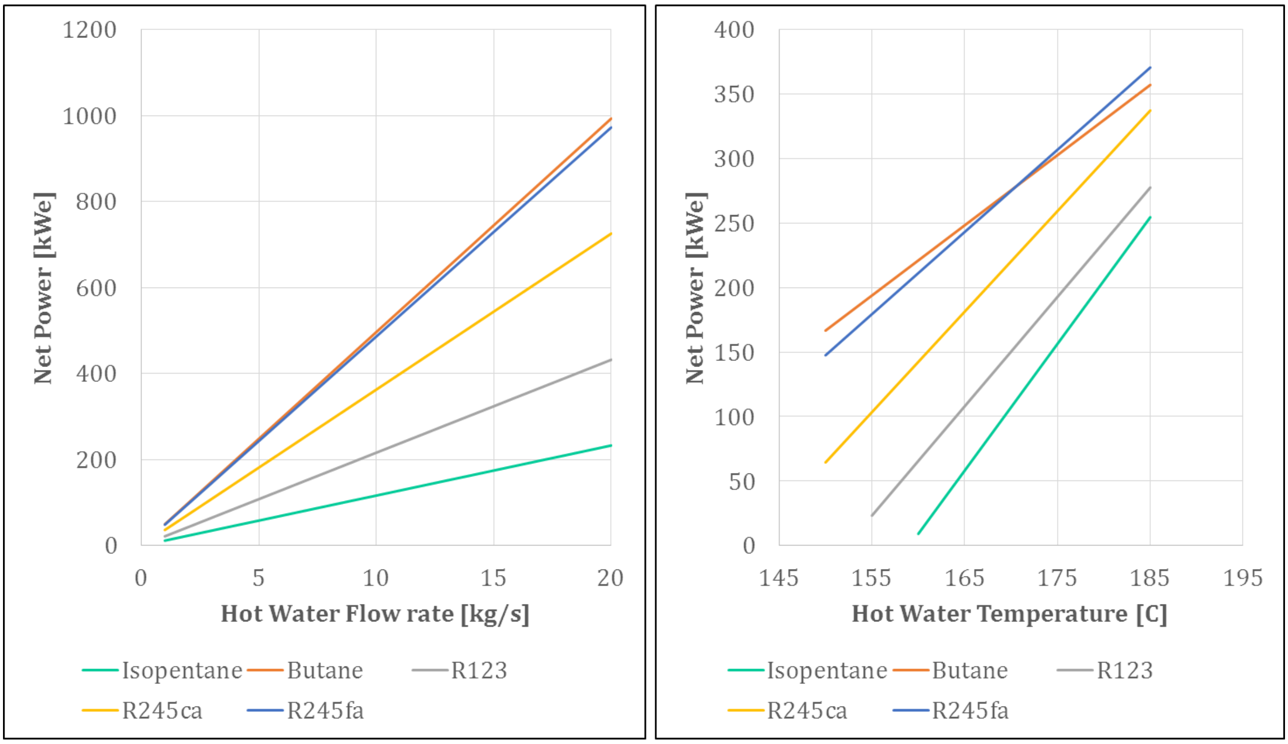


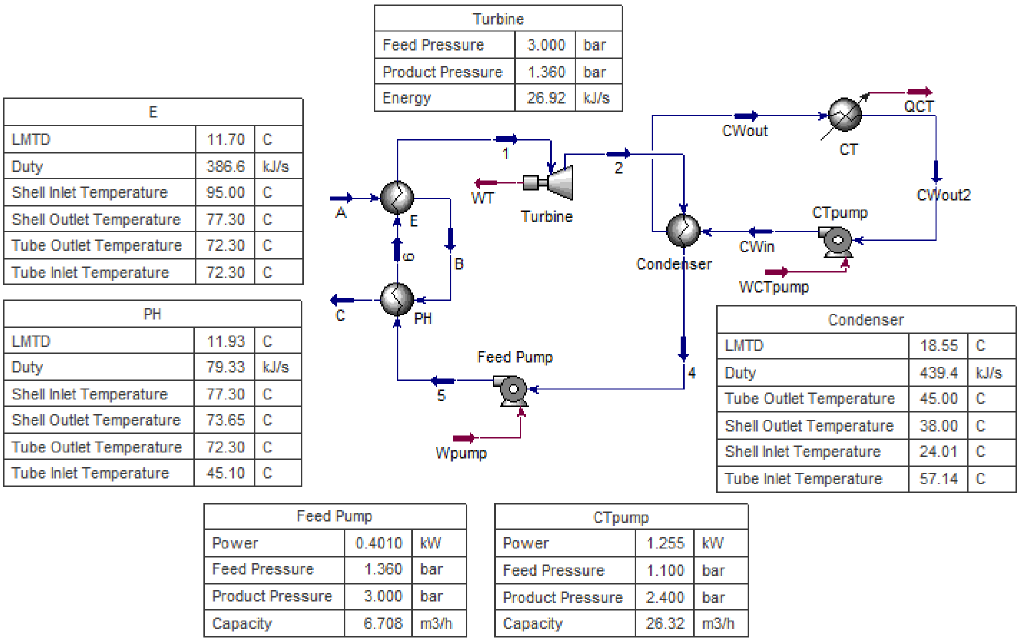
Figure 18: The sensitivity of flow rate and temperature to net power generation for waste heat brine

These figures show performance of the working fluids for the ORC systems in the Cisolok Hot Springs and Awibengkok-Salak Brine case study. Based on the diagrams, the selected working fluid deemed most appropriate for the Cisolok Hot Spring ORC system is R-245fa or pentane and Butane for the Awibengkok-Salak system. R-245fa and Butane for the respective case studies, both display higher net power generated among the other working fluids. From the perspective of HSE aspects, both selected working fluids are lower in toxicity and do not contribute to ozone depletion. A potential problem for Butane as a working fluid is that it is highly flammable, while R-245fa when emitted to the environment may pose as a potential cause for global warming. A financial analysis of the small scale power plant is conducted to determine the feasibility of this case study. In this financial analysis, financial parameters and power generation factor are the main constituents for consideration. The financial parameters include tax, royalty, interest, declining balance asset, tangible depreciation, and IRR. The declining balance here is calculated for the duration of 7 years. The power generation factor covers the life span of the system and capacity factor. Details for the individual financial parameters and power generation factors are stated below, followed by results of the financial analysis.

Calculation Result and Preliminary Design

Cisolok Power Generation

Figure 19 shows the process flow diagram of Cisolok binary cycle which built in HYSYS v8.8 software. The flow diagram describes the hot water, working fluid cycle, and cooling water line. The comparison operational conditions between n-pentane and R245fa working fluid and several assumptions that are used in the calculations are shown in Table 6. The selection of the turbine pressure design that is used in this system is 3 bar for n-pentane and 5 bar for R245fa, based on the optimization maximum power output. In this case, the additional feed pump is needed to transport the manifestation fluid to the plant. The parasitic load energy is described in Table 7.



Turbine		
Feed Pressure	3.000	bar
Product Pressure	1.360	bar
Energy	26.92	kJ/s

E		
LMTD	11.70	C
Duty	386.6	kJ/s
Shell Inlet Temperature	95.00	C
Shell Outlet Temperature	77.30	C
Tube Outlet Temperature	72.30	C
Tube Inlet Temperature	72.30	C

PH		
LMTD	11.93	C
Duty	79.33	kJ/s
Shell Inlet Temperature	77.30	C
Shell Outlet Temperature	73.65	C
Tube Outlet Temperature	72.30	C
Tube Inlet Temperature	45.10	C

Condenser		
LMTD	18.55	C
Duty	439.4	kJ/s
Tube Outlet Temperature	45.00	C
Shell Outlet Temperature	38.00	C
Shell Inlet Temperature	24.01	C
Tube Inlet Temperature	57.14	C

Feed Pump		
Power	0.4010	kW
Feed Pressure	1.360	bar
Product Pressure	3.000	bar
Capacity	6.708	m3/h

CTpump		
Power	1.255	kW
Feed Pressure	1.100	bar
Product Pressure	2.400	bar
Capacity	26.32	m3/h

Figure 19 Process flow diagram of Cisolok binary cycle

Table 6 The operational conditions of binary cycle using Cisolok Hot Spring

Parameter	Symbol	Value		Units
Working Fluid		Pentane	R 245 fa	
Hot Water Flow	M_A	5	5	kg/s
Hot Water Temperature	T_A	95	95	°C
Pinch Point	ΔT_{pp}	5	5	°C
Cp Hot Water	Cp_{hw}	4.2	4.2	kJ/kg-K
Turbine Inlet Pressure	P_1	3	6	bar

Parameter	Symbol	Value		Units
Turbine Inlet Temperature	T_1	72.3	69.4	°C
Condenser Temperature	T_4	45	45	°C
Condenser Pressure	P_C	0.14	0.34	MPa
Turbine Efficiency	η_t	80%	80%	
Generator Efficiency	η_{gen}	95%	95%	
Pump Efficiency	η_{pump}	80%	80%	
HE Effectivity	ε_{HE}	95%	95%	

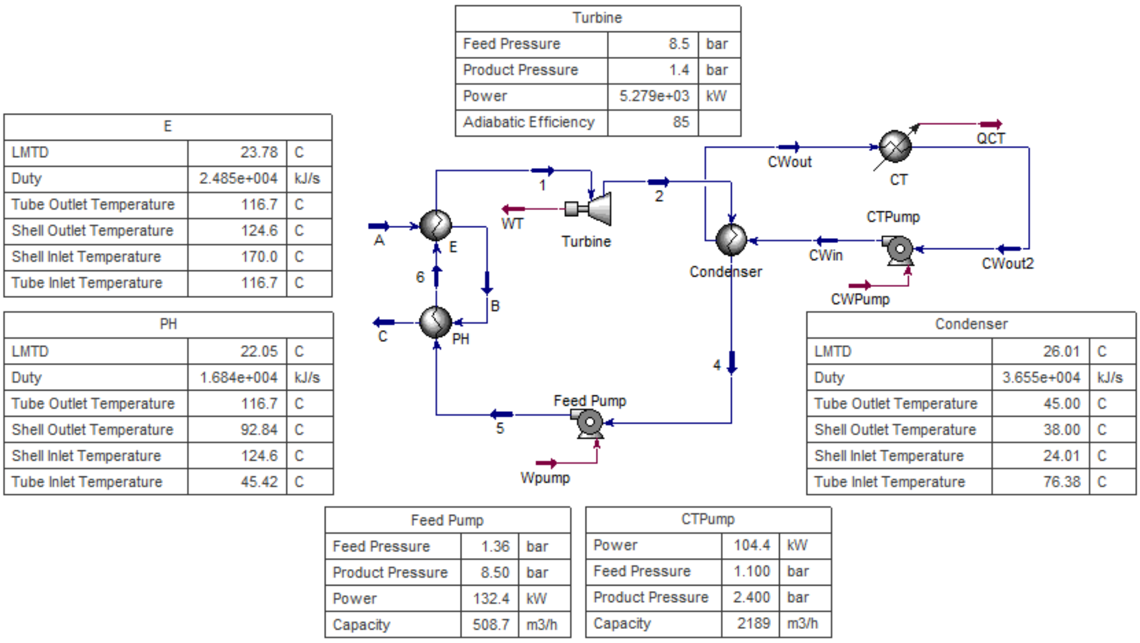
Table 7 The power generation and the utilization energy requirement in Cisolok power plant.

Fluids	Mwf	Net Power	ηthermal	Gross Power	Working Fluid Pump	Cooling Tower Pump	Manifest Pump
	kg/s	kWe	%	kW	kW	kW	kW
n-pentane	1.2	22.7	5.4	26.9	0.8	1.4	2
R 245 fa	3.6	21.8	3.9	25.8	0.4	1.6	2

The net cycle power that can be generated by Cisolok system is 23 kWe for n-pentane and 22 kWe for R 245 fa. With lower design turbine pressure and lower working fluid mass flow rate, n-pentane generates a net power output almost comparable with R245fa. Due to lower working pressures, less investment cost has to be spent for n-pentane. Besides, a comparison of n-pentane and R245fa parameters are given in Table 3. In conclusion, n-pentane is preferable to R245fa. The output parameters and the operational condition during evaporating, pre-heating, and condensing process as shown in Figure 19 are used as a base for designing and sizing the heat exchanger.

Salak Power Generation

The power generation in Salak is generated by utilizing the brine separation result from the separator. By simulating the binary cycle output using HYSYS software, the total power that can be extracted from the total brine output from the separator is approximately 13 MW, however, by referring to the small-scale project that we discussed, so the maximum power generation for this case is adjusted to 5 MW. The process flow diagram of Salak binary cycle is shown in Figure 20. The operational condition and several assumptions that we use to calculate the binary power cycle are showed in Table 8 and Table 9. The selection of the turbine pressure design that is used in this system is 8.5 bar for n-pentane and 12 bar for R 245 fa, based on the maximum 5 MW power output. The pressure of brine output from the separator is still high around 8 bar, therefore in this this case is no need to use the feeding pump to transport brine to the plant.



Turbine		
Feed Pressure	8.5	bar
Product Pressure	1.4	bar
Power	5.279e+03	kW
Adiabatic Efficiency	85	

E		
LMTD	23.78	C
Duty	2.485e+004	kJ/s
Tube Outlet Temperature	116.7	C
Shell Outlet Temperature	124.6	C
Shell Inlet Temperature	170.0	C
Tube Inlet Temperature	116.7	C

PH		
LMTD	22.05	C
Duty	1.684e+004	kJ/s
Tube Outlet Temperature	116.7	C
Shell Outlet Temperature	92.84	C
Shell Inlet Temperature	124.6	C
Tube Inlet Temperature	45.42	C

Condenser		
LMTD	26.01	C
Duty	3.655e+004	kJ/s
Tube Outlet Temperature	45.00	C
Shell Outlet Temperature	38.00	C
Shell Inlet Temperature	24.01	C
Tube Inlet Temperature	76.38	C

Feed Pump		
Feed Pressure	1.36	bar
Product Pressure	8.50	bar
Power	132.4	kW
Capacity	508.7	m3/h

CTPump		
Power	104.4	kW
Feed Pressure	1.100	bar
Product Pressure	2.400	bar
Capacity	2189	m3/h

Figure 20 Process flow diagram of Salak binary cycle

Table 8 The operational conditions of binary cycle using Salak brine separator output

Parameter	Symbol	Value		Units
Working Fluid		Pentane	R 245 fa	
Hot Water Flow	M_A	120	120	kg/s
Hot Water Temperature	T_A	170	170	°C
Pinch Point	ΔT_{pp}	5	5	°C
Cp Hot Water	Cp_{hw}	4.2	4.2	kJ/kg-K
Turbine Inlet Pressure	P_1	0.85	1.23	MPa
Turbine Inlet Temperature	T_1	114	119	°C
Condenser Temperature	T_4	45	45	°C
Condenser Pressure	P_C	0.14	0.20	MPa
Turbine Efficiency	η_t	80%	80%	
Generator Efficiency	η_{gen}	95%	95%	
Pump Efficiency	η_{pump}	80%	80%	
HE Effectivity	ε_{HE}	95%	95%	

Table 9 The power generation and the utilization energy requirement in Salak power plant

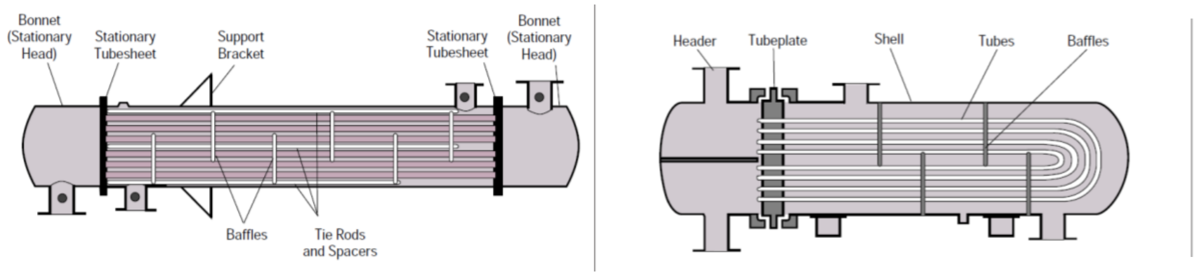
Fluids	Mwf	Net Power	ηthermal	Gross Power	Feed Pump Power	Cooling Tower Pump
	kg/s	kWe	%	kW	kW	kW
n-pentane	89	5042	11.3	5279	132	105
R 245 fa	183	5037	9.0	5294	164	93

By the power output result of the two system which is almost comparable, the system design using n-pentane as working fluid has lower design turbine pressure and working fluid flow rate requirement. Therefore, the selection of n-pentane as working fluid is more suitable than R-245fa due to less investment cost and the availability stock in the market.

The next step is the process equipment design and selection, which is based on the amount and requirement of heat and mass transfer. From the simulation result which is shown in Table 7 and Table 9, The sizing and design of the equipment is need to rate up to match the design requirement. The equipment that is to be reviewed is heat exchanger (HE) and pump. Table 10 to Table 13 show the equipment design of heat exchanger and pump for each case. The type of HE and pump used in this case are a shell and tube heat exchanger (STHE) and a centrifugal pump. The selection of the STHE is determined by the following aspects:

- Size: STHE has larger heat transfer surface area and has a shorter length due to the presence of multiple tubes.
- Heat Duty: STHE provide higher overall heat transfer coefficient so can handle wide temperatures and pressures.
- Versatility: the number of tubes and pitch can be selected according to the operating conditions and baffle cut and spacing can be used to influence the overall heat transfer coefficients.

Commonly there are two main combinations of shell and tube exchanger i.e. a fixed tube or a U-tube exchanger. In a fixed tube exchanger, the tube sheet is welded to the shell. This results in a simple and economical construction and the tube bores can be cleaned mechanically or chemically. However, the outside surfaces of the tubes are inaccessible except to chemical cleaning. In a U-Tube exchanger any of the front header types may be used and the rear header is normally an M-Type. The U-tubes permit unlimited thermal expansion, the tube bundle can be removed for cleaning and small bundle to shell clearances can be achieved. However, since internal cleaning of the tubes by mechanical means is difficult, it is normal only to use this type where the tube side fluids are clean. The design of a shell and tube exchanger and centrifugal pump are shown at Figure 21 and Figure 22. The requirements and design of the heat exchanger and pump are summarized in Table 10 and Table 11.



A b

Figure 21 Shell and tube heat exchanger type. (a) Fixed-tubesheet heat exchanger (b) U-tube heat exchanger

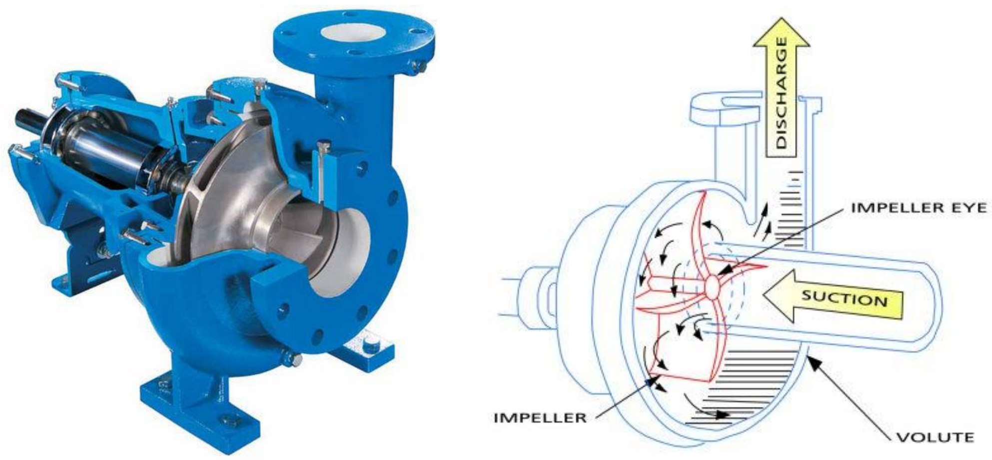


Figure 22 Centrifugal pump design

Table 10 The design of pump in Cisolok binary cycle

	Feed Pump (working fluid)	**CT Pump**	**Feed Pump (manifest Pump)**
Flow rate (m^3/s)	10	30	30
Power (kW)	1	2	2
Quantity	1	1	1

Table 11 The design of heat exchanger in Cisolok binary cycle

	Evaporator	**Pre-Heater**	**Condenser**
Type:	HE Shell and Tube 1-2 Pass	HE Shell and Tube 1-1 Pass	HE Shell and Tube 1-2 Pass
Quantity:	1	1	1
Dimension:			
Heat transfer area:	16 m^2	5.5 m^2	15.5 m^2
Shell:	ID 8 inch	ID 8 inch	ID 8 inch
	Baffle Spacing 0.04 m	Baffle Spacing 0.04 m	Baffle Spacing 0.04 m
Tube:	OD 3/4 inch	OD 3/4 inch	OD 3/4 inch
	ID 0.62 inch	ID 0.62 inch	ID 0.62 inch
	BWG 16	BWG 16	BWG 16
	Triangular pitch 1-5/16 inch	Triangular pitch 1-5/16 inch	Triangular pitch 1-5/16 inch
	Number of tube per pass 32	Number of tube per pass 36	Number of tube per pass 32

Table 12 The design of pump in Salak binary cycle

	Feed Pump (working fluid)	**CT Pump**
Flow rate (m^3/h)	510	2200
Power (kW)	135	105
Quantity	1	1

Table 13 The design of heat exchanger in Salak binary cycle

	Evaporator	Pre-Heater	Condenser
Type:	HE Shell and Tube 1-4 Pass	HE Shell and Tube 1-4 Pass	HE Shell and Tube 1-4 Pass
Quantity:	1	1	1
Dimension:			
Heat transfer area:	623	951	473
Shell:	ID 31 inch	ID 37 inch	ID 27 inch
	Baffle Spacing 6.2 inch	Baffle Spacing 7.4 inch	Baffle Spacing 5.4 inch
Tube:	OD 1 inch	OD 1 inch	OD 1 inch
	ID 0.87 inch	ID 0.87 inch	ID 0.87 inch
	BWG 16	BWG 16	BWG 16
	Triangular pitch 1-1/4 inch	Triangular pitch 1-1/4inch	Triangular pitch 1-1/4 inch
	Number of tube per pass 430	Number of tube per pass 632	Number of tube per pass 302

Overall, the study result of brine utilization from surface manifestation or brine separator output is reliable to conduct the generation. In comparison, between R245fa and pentane working fluid, the higher geothermal fluid temperature the more significant R245fa working fluid requirement. Therefore, the use of pentane as the working fluid for higher temperature operation is more suitable. In designing the process equipment for sizing, the difference value between temperature in and out of hot and cold side determines the bigger or smaller of the required heat transfer area. the heat transfer during evaporation process is larger than pre-heating process.

2.2.2 Financial Analysis

Cisolok Financial Calculation

The financial calculation for Cisolok is done using several assumptions as:

- Power generated 22.7 kW (rounded to 23 kW) based on previous analysis
- No loan required
- No added area required, all equipment is in existing area

- No drilling well

Investments required to build a geothermal binary at the manifestation in Cisolok can be found in Table 14.

Table 14 Investment for Cisolok Small Scale Geothermal Power Plant

No	Equipment	Specification	Price (USD)		
			Cost /Unit	Unit	Total Cost with VAT 10%
1	HE Evaporator	Shell/Tube, Carbon Steel, 172.223 ft^2	8,500	1	9,350
2	Pre-Heater	Shell/Tube, Carbon Steel, 58.2 ft^2	2,000	1	2,200
3	Condenser	Shell/Tube, Carbon Steel, 166.8406 ft^2	8,200	1	9,020
4	Pumps				
	a. Manifest Feed Pump	Series Centrifugal Pump, 3 Phase, 85 GPM, 3500 rpm, 1 hp	1,000	1	1,100
	b. Working Fluid Feed Pump	Series Centrifugal Pump, 3 Phase, 85 GPM, 3500 rpm, 1 hp	1,000	1	1,100
	c. CT Pump	Series Centrifugal Pump, 3 Phase, 132 GPM, 3500 rpm, 1 hp	3,140	1	3,454
5	Piping System	-	8,000	1	8,800
6	Binary Turbine	Using single stage ORC cycle for up to 100^o C for 23 kW generation (up to 250 kW)	1,500,000	1	126,500
7	Pentane Liquid		10	10	110
				Total	**1,688,636**

The total investment to develop a 23 kW geothermal binary plant that utilizes the manifestation in Cisolok is USD 1,688,636. The number had considered the Value Added Tax 10% as applied in Indonesia. The binary turbine price is assumed for single stage ORC cycle with temperature up to 100^o C and up to 250 kW capacity as USD 1.5 Million (Iceida, 2014) costs USD 1.5 Million.

Calculation using above assumptions found that the minimum electricity price for this scenario is more than USD 100 cent/kWh. With electricity price USD 102 cent/kWh the IRR would be 9.79% per year. The price is very high and above the average of electricity price in Indonesia. The high price explains that this project is not feasible.

Salak Financial Calculation

The financial calculation for Salak is done using several assumptions as:

- Power generated 5 MW based on previous analysis
- No loan required
- No added area required, all equipment is in existing area
- No drilling well

Investments required to build a geothermal binary at the manifestation in Salak can be found in Table 15.

Table 15 Investment for Salak Small Scale Geothermal Power Plant

No	Equipment	Specification	Price (USD)		
			Cost/ Unit	Unit	Total Cost with VAT
1	HE Evaporator	Shell/Tube, Carbon Steel, 623 m2, 6706 ft2	160,600	1	176,660
2	Pre-Heater	Shell/Tube, Carbon Steel, 951 m2, 10237 ft2	214,000	1	235,400
3	Condensor	Shell/Tube, Carbon Steel, 473 m2, 5091 ft2	133,100	1	146,410
4	Piping				
5	Pumps				
	a. Manifest Feed Pump	Series Centrifugal Pump 510 m3 /h, 135 kW	8,300	1	9,130
	b. CT Pump	Series Centrifugal Pump 2200 m3 /h, 105 kW	11,900	1	13,090

6	Binary Turbine	Using single stage ORC cycle for up to 100o C for 23 kW generation	14,600,000	1	16,060,000
Total					16,640,090

The total investment to develop a 5 MW geothermal binary plant that utilizes the manifestation in Salak is USD 16,6 Million. The number had considered the Value Added Tax 10% as applied in Indonesia. The binary turbine price is assumed for single stage ORC cycle with temperature up to 100^{o} C and 5 MW capacity as USD 5 million/Mwh (Iceida, 2014).

Calculation using above assumptions found that the minimum electricity price for this scenario is USD 23.8 cent/kWh. With this price the IRR on Equity would be 9.70% for 30 years project time.

3 SOCIAL ENGAGEMENT AND PARTICIPATION

Social engagement and partnership is essential in development of projects, small scale power plants included. Participation from the community, partnership of the stakeholders involved, protection, and achieving a win-win solution for all are integral.

3.1 PARTICIPATION–GETTING THE LOCAL COMMUNITY INVOLVED

Another important part is the involvement of the local population. We need to approach the local community in a very early phase and develop the project together. This is very important as it not only creates a shared responsibility, but it also means that local knowledge about the area can be incorporated in the plans. The local people's participation can give valuable inputs. Because they live in the area, they know best. It can mean the difference between a successful and a failed project. A great participation from the local community also means whether we have proven this idea works and that makes the other projects easier. Community participation is important to achieve sustainable development. Building a strong relationship with the locals so that they know they have valuable energy resources in their living area in which they also can have access to some part of energy for their economic development.

Figure 23: The local community of Fujimaehigata, Japan participates in routine surveys of tidal flats to allow immediate detection of environmental change. Conducting this survey is a means to raise awareness on importance of conservation and wise use.

3.2 PARTNERSHIP-SOCIAL CAPITAL AND COMMUNAL DECISION MAKING

Shared responsibility is the key to “Social capital”, in which the local people also “invest” in the community development project using geothermal energy as the energy resource. Studies suggested that communities with high levels of social capital are more likely to have extensive community participation. In that way, the people will also feel they have their capital invested and therefore have eagerness to maintain the use of the system for sustainable system and future generation. Mutual benefit for related stakeholders, such as business entities, community groups, conservation organization, and local government, will gain by management strategies and proper business scheme.

3.3 PROTECTION

Geothermal is competitive with other energy technologies when environmental costs are considered (Kagel, 2007). These fact can be concern of the participating stakeholders involved consisting of businesses, community groups, and conservation groups. Partnership among stakeholders is maintained by looking after mutual interests.

3.4 WIN-WIN SOLUTION

Mutual benefits are maintained through the interest of the stakeholders involved. Regulations which attract investment will foster projects and geothermal development to meet the government projection. Community awareness of the surrounding environment is cultivated by the benefits gained from geothermal development. Community acceptance provides supportive outlook for the future development. Decision makers, investors, and the public form a strong partnership prepared with the knowledge and commitment to carry out their functions.

4 CONCLUDING REMARKS

The optimization of geothermal energy utilization is expected to encourage local economic development by adding value of geothermal heat for local commodities, generate income as tourist attraction, contribute to electricity supply, as an attempt to put an end to excess wasted thermal energy, and open opportunities for following geothermal projects to come. Other advantage is production of electricity at a competitive price and also become less independent form grid electricity at least in remote areas, the can produce more sustainable electricity at lower price.

Based on technical assessment, Cisolok Hot springs reaches temperatures of 95°C with flow rate of 5 kg/s. This parameter used to design small scale geothermal power plant. Based on secondary fluids selection study, preferable working fluid is Pentane. The selection of turbine pressure design that used in this system is 3 bar using the optimization maximum power output. The net cycle power that can be achieved by this system is 23 kWe. The heat exchanger and pump type that used in this case is shell and tube heat exchanger and centrifugal pump. Required investment for small scale geothermal power plant is 1.7 Million USD. Electricity price vs IRR sensitivity shows that 102 USD cent/kWh, IRR is 9.79%. Other case study uses Awibengkok-Salak which generated electricity by utilizing the brine separation result from the separator. By simulating the binary cycle output, the total power that can be extracted from the total brine output from the separator is approximately 13 MW, however, by referring to the small-scale project that discussed in previous section so the maximum power generation for this case is adjusted to 5 MW. The selection of the turbine pressure design that is used in this system is 8.5 bar with geothermal mass flow rate is 90 kg/s. The pressure of brine output from the separator is still high around 8 bar, therefore in this this case is no need to use the feeding pump to transport brine to the plant. The total investment to develop a 5 MW geothermal binary plant that utilizes the manifestation in Salak is USD 16.6 Million and minimum electricity price is USD 23.8 cent/kWh. With this price the IRR on Equity would be 9.70% for 30 years project time.

The optimization of geothermal energy utilization is expected to encourage local economic development by adding value of geothermal heat for local products, generate income as tourist attraction, contribute to electricity supply, as an attempt to put an end to excess wasted thermal energy, and open opportunities for following geothermal projects to come. Even more, produce their own electricity at a competitive price and also become (less) independent form grid electricity, giving a long-term stability. At least in remote areas, the can produce more sustainable electricity at lower price (compared to diesel generated electricity). It is expected that the development of small scale geothermal plants can expand the economy. For this to happen there needs to be continuous education of the public, investors and developers, and decision makers. The public can benefit by gaining in depth knowledge of the advantages and conditions of constructing a geothermal energy installation. Investors and developers should know how to effectively deal with the local community to avoid conflict.

This report concludes that small scale geothermal power plant in Cisolok and Awibengkok-Salak can be implemented depend on technical, financial and social assessment with several notes to be considered. It is expected that the development of small scale geothermal plants can expand the economy. For this to happen there needs to be continuous education of the public, investors and developers, and decision makers. The public can benefit by gaining in depth knowledge of the advantages and conditions of constructing a geothermal energy installation. Investors and developers should know how to effectively deal with the local community to avoid conflict.