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Use of Waste Heat From Geothermal Power Plants Focusing on Improving Agriculture in Developing Countries

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ABSTRACT

The concept of this paper is to make geothermal power producers and country governments think about the tremendous value in waste heat from power generation.

Globally, several countries with high or medium temperature resources plan to build new geothermal power plants. Based on resource temperatures of around or over 250°C, they will be "flash" plants and convert energy from 250 down to 150°C into electricity. This will make a lot of waste heat accessible. This paper provides indicative estimates of the amount of waste heat available from a typical 50 MWe flash plant and how this waste heat of around 100 MWth could be used.

The findings are that a 50 MWe power plant could provide waste heat to operate:

- A 5 to 10 MWe binary plant to generate additional power,
- A 100,000 m^2 freezing and cooling plant, the size of 14 football fields,
- A canning factory producing 200 tons per hour and filling 100 containers per day, or
- A fruit drying plant producing 50 tons per hour and filling 25 containers per day.

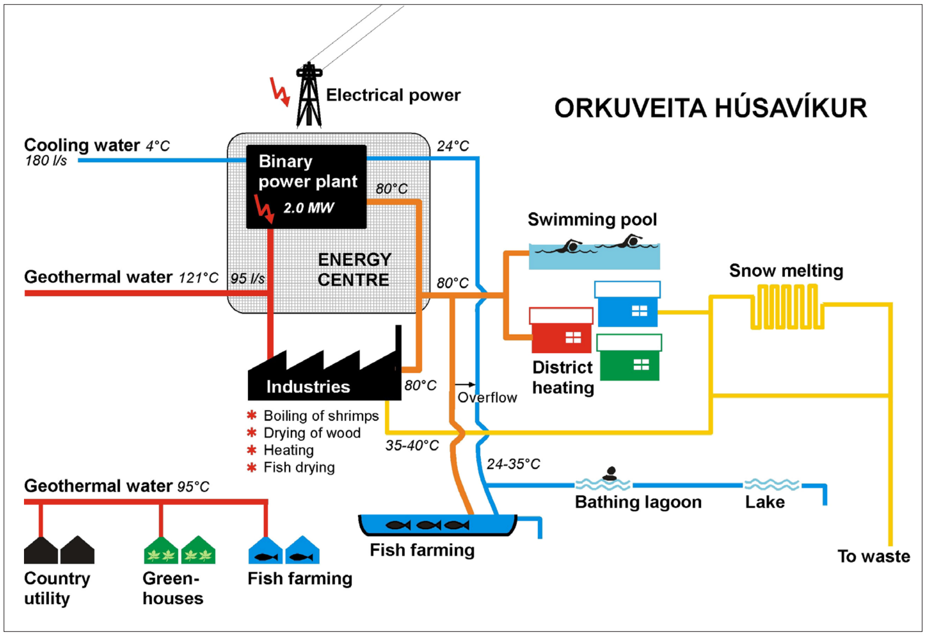

Figure 1. Idealized diagram showing multiple use of geothermal energy (ISOR, 2005).

Overall, the paper shows that revenue creation from waste heat use could be several times the revenues from power generation. At the same time, the use of waste heat supports regional development through job creation and new agricultural opportunities, e.g. through marketing of new

products. Finally, this would imply additional tax revenues to the country, increased value of food products and potential new export products.

Options of Waste Heat Utilization

What makes geothermal different from all other renewable energies, is its availability factor of 90% or higher for new and modern power plants. With usually over 8,000 hours per year of operating time, geothermal power plants provide renewable base load power. Additionally, once a geothermal power plant is operational, it can also be used in multiple ways to enhance the projects overall economic result. This is called multiple use, cascaded use, or utilization of residual- or waste-heat. Furthermore, the acronym CHP (combined heat and power) has become increasingly popular.

Figure 1 is an idealized diagram showing cascaded use of geothermal energy, based on the example of a small (2 MWe) binary power plant in Iceland, which, located as far as 18 km from its wells, uses the residual heat of the fluid (after power generation) for nearby industries (food industry), for domestic heating for the entire town, for fish farming and finally for snow melting in streets. As a result, the energy contained in the fluids is nearly completely used. In addition, geothermal power plants can also be connected to industries that produce a lot of heat, such as steel mills, biomass power plants or waste incinerators. Their produced heat can be used to enhance the temperature of the geothermal fluid in order to increase power production.

The options of multiple use of the energy and the fact that small modular units with up to 5 MW capacity are readily available and easy to install and operate, makes geothermal power generation also a feasible option for smaller installations in remote and even off-grid locations, especially when they replace existing and more costly fossil fuel generation.

In general, the revenue stream from the use of the residual heat (waste heat) can improve the overall financial viability of both small size and industry scale (over 25MWe) power projects, with additional revenue coming from:

- Bottoming cycles, i.e. usually binary units utilizing waste heat of >130°C from flash turbine. Bottoming cycles usually add around or over 10% to the power generation of a flash plant.
- Sale of flowers, plants or vegetables grown in greenhouses. Not only heat, but also CO_2 can be extracted from geothermal fluids.
- Canning factory for vegetables, fruit (e.g. jam, juices) or fish, meat, dairy products.
- Fish or shellfish farming, or other aquaculture products.
- Dehydration (drying) of fruits, nuts and other food products.
- Desalination of seawater to pure drinking water.
- Cold storages or freezing plants.
- Use of waste heat for industrial processes, e.g. chemical and biological, food industry.
- Sale of hot water for district heating or district cooling purposes.
- Extraction of valuable minerals and salts from the geothermal fluids, e.g. silica, manganese, zinc and lithium. As a gas, CO_2 can be used for industrial purposes, e.g. the soft drink industry.

These options are site dependent; some geothermal sites will offer using several of these options simultaneously while others offer none. A more comprehensive overview on how geothermal fluids and steam can be utilized over their temperature range is given by the figure below.

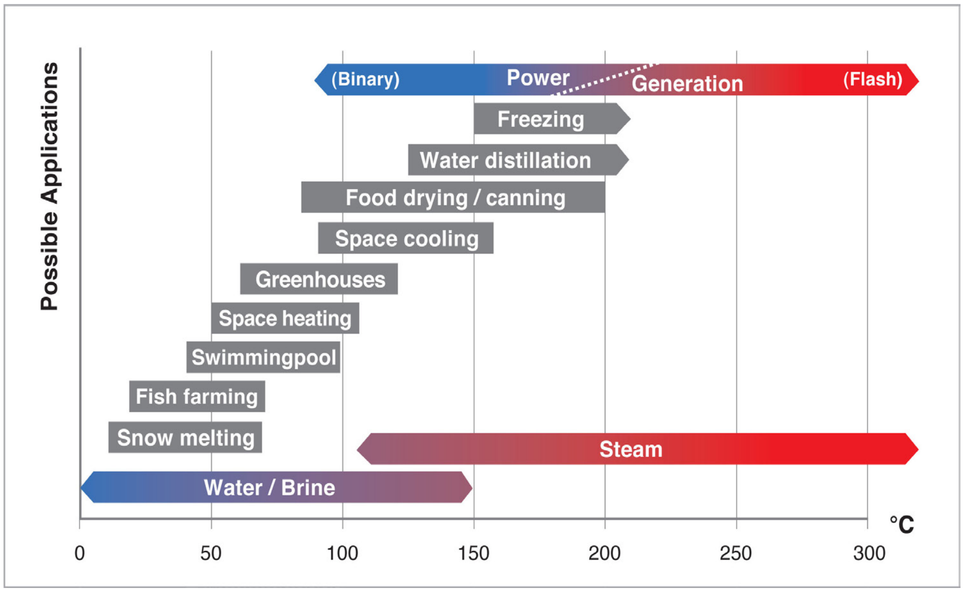

Figure 2. Modified Lindal diagram showing applications for geothermal fluids (Gehringer & Loksha, 2012).

Co-Production by Extraction from Geothermal Fluids

Co-production, i.e. the production of silica and other marketable products from geothermal brines, could become a viable source of additional revenue for power plant owners or related industries. It is also a key technique for improving power plant economics by reducing operation and maintenance costs. The removal of silica may allow additional geothermal energy extraction in bottoming cycles (usually binary power plants using the waste heat from the flash / conventional steam cycle) or additional uses of low-grade heat that are presently prohibited due to scaling problems.

Precipitated silica has a relatively high market value (US$1-10 per kg) for such uses as waste and odor control, or as an additive in paper, paint and rubber. Besides this, silica removal has the additional benefit of helping to minimize fluid reinjection problems, and, at the same time, opens the door to the extraction of, for example, zinc (ZN), manganese (MN), and lithium (LI), all with relatively high market values. The first commercial facility for the recovery of zinc from geothermal brine was built in the Salton Sea geothermal area of southern California in 2000. The facility was designed to produce 30,000 metric tons of 99.99% pure zinc annually at a value of approximately US$50 million, while the market value of extracted silica was estimated at US$84 million a year. The plant was unfortunately decommissioned due to depressed zinc prices and some operational difficulties.

CO_2 can be a valuable byproduct of geothermal fluids. Firstly, it can be used to enhance growth of plants in greenhouses. Examples show that roses growing in CO_2 saturated environment may grow four times faster than in normal air. Secondly, CO_2 can be a compressed, filled in gas containers and sold for industrial uses. Kizildere for example, the oldest Turkish geothermal power plant from 1973 that had an installed capacity of 15MWe for most of its lifetime, had in 2006 a CO_2 content of 11% by volume. To capture this gas before it could enter the turbine, the German company Linde built a CO_2 factory next to it and sells the CO_2 to all soda drink providers of Turkey, incl. Coke and Pepsi.

In cases were the CO_2 cannot be sold as described above, there are several options, e.g. methanol (fuel) production or to compress and re-inject it into the ground at a suitable location outside of the reservoir.

Geothermal Power Generation Combined with Agriculture

From the above, it seems obvious that waste heat from geothermal power plants can be used for various kinds of food production and food processing industries. Outside of the capital city area, most developing countires seem to be focused on farming and food production. If waste heat from geothermal power plants could open new job opportunities, facilitate the creation of new products or enable keeping products fresher and more valuable through better storage options, it might become a tempting vision to try to utilize the waste heat from all geothermal projects. Needless to say, the heat from low-temperature geothermal fields (<150°C) can of be used for the same purposes as waste heat from power plants. This is called direct use.

There are many ways to improve the economic and financial viability of a geothermal power project by using the waste heat from power plants. Besides increasing profits from operations and providing additional tax revenues, these activities in many cases also save operation costs for the power plants by reducing the amount of fluids that have to be cooled down by cooling towers. In other words, the power plant operator also benefits from utilizing the energy from the hot waste fluids, because he then saves the costs for cooling the fluids down by cooling towers, at dire cost. Therefore, all stake holders seem to benefit from using waste heat energy. However, it must be ensured that the waste fluids stay within the geothermal field, since they will have to be re-injected into the reservoir to stabilize the reservoir pressure in the subsurface and avoid reservoir depletion. In total, the use of waste heat should improve the overall project benefits for the entire country as well as for the people in the region by the creation of additional jobs and the provision of new opportunities. All a power plant operator will have to do, is to make the waste heat from the plant available to waste heat users, e.g. a developer of a canning factory, instead of cooling it down and re-inject it right away. This requires two interfaces for the waste heat users; one, where the waste heat is received from the power plant, and another one where the fluids are returned to the power plant operator after the heat has been extracted. This process reduces the usage of cooling towers, but for security reasons, the cooling towers still have to be installed and be instantly operational. For this hassle, including providing the two interfaces, the power operator will have to be compensated well enough to ensure his firm and continued interest in providing his waste heat to connected waste heat users.

Power Generation and Energy Flow in Flash Plants

The following pages try to provide practical examples on how much waste heat will be available for various uses. The following process diagram shows a single flash power plant with a thermal process efficiency of 30%, generating 50 MWe (electric) net power out of a total energy from geothermal steam of 182 MWth (thermal). Wellhead temperature is around 250 °C, and the temperature into the turbine, after separation of the two-phased fluids (fluids and steam) is 230 °C while steam temperature out of the turbine, available for waste heat use, is around 150°C. The delta-T of this plant is therefore 80°C, the flow into the turbine is 65 kg/s and total gross power output (installed capacity) is therefore around 55 MWe.

The energy available for waste use is here calculated as 100 MWth which is an indicative figure, since real figures will be project dependent due to the impact of climate (average temperatures and humidity) and cooling options for the cooling towers.

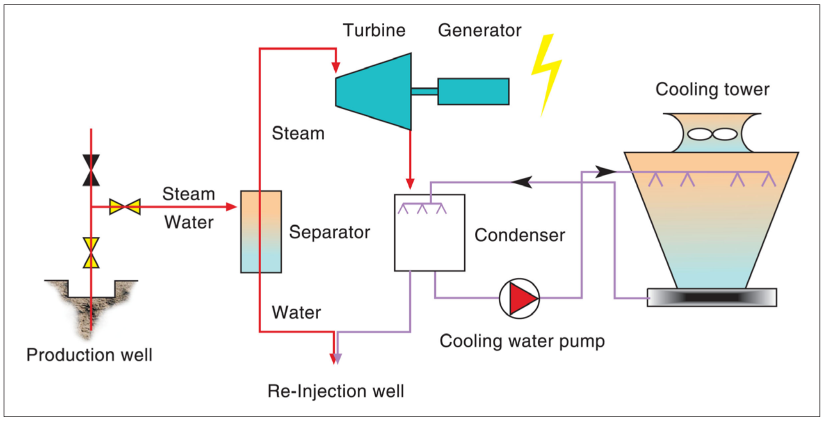

Figure 3. Process diagram for geothermal flash power plant (Gehringer& Loksha, 2012)

Bottoming Cycles (Binary)

The most apparent use of waste heat is the use of a binary power plant to generate additional power from the waste heat from the flash turbine. The rule of thumb is that such a bottoming cycle can generate between 10 and 20% of the power generated by the flash turbine. This depends again on climate and cooling options, but also on fluid chemistry. The delta-T of all geothermal power plants depends very much on the scaling potential of the fluids. Usually, a higher silica or mineral contents will have a limiting impact on the delta-T of the plant, i.e. less of the energy of the fluids can actually be used for power generation. The graph below shows a binary bottoming cycle generating 10% or additional 5 MWe net power from the waste heat of the flash turbine.

The use of a bottoming cycle extracts a significant amount of energy from the geothermal fluids, and this energy cannot be used again for other waste heat uses. Therefore, it is a matter of project economy whether the use of a bottoming unit should be preferred to other uses. For example, in countries where power tariffs are generally low, the installation of a bottoming cycle might not be commercially viable since it might increase the overall power generation costs per kWh from the combined plant. Also, direct thermal uses may be more practical and economic for the region and the entire country.

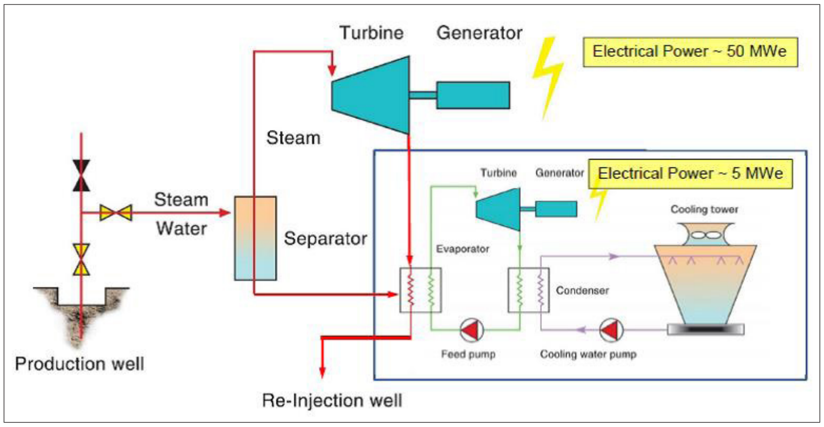

Figure 4. Flash power plant with binary bottoming cycle (Bjarnason & Gehringer, 2014)

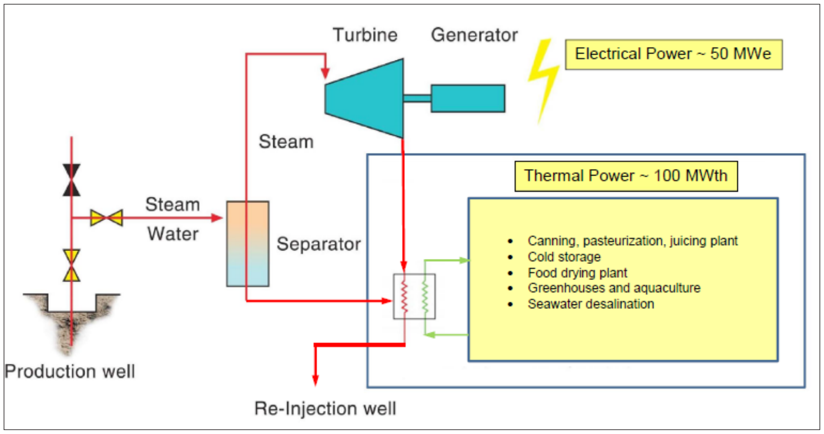

Figure 5. Energy Flow to waste heat users.

Since the binary bottoming cycle in the graph generates 5 MWe net power, it can be expected that the output heat from this unit would still be around 100°C, and therefore still usable for canning, fruit drying and cooling purposes as described below. However, the use of a bottoming cycle like this would like reduce the energy input to other uses by 50 to 60%.

Examples of Waste Heat Uses from a 50 MWe Flash Plant

Figure 5 shows, without the deployment of a bottoming cycle that a geothermal flash plant with a capacity of 50 MWe net produces around 100 MWth thermal energy.

How this amount (100 MWth) of thermal energy could be used will be shown by the following examples. In many developing countries, more than 50% of all produce (vegetables and fruits) rotten before they reach the market. In fact, the shortage of ways to preserve food limits significantly the options for farming in these countries. Many crops, vegetables and fruits are not grown because the transport to the next market is just too time consuming and the production per farmer too little to justify a direct transport.

To prevent the food from being spoiled before and during containment, a number of methods are used: pasteurization, boiling (and other applications of high temperature over a period of time), refrigeration, freezing, drying, and vacuum treatment to name a few.

The waste heat can theoretically be transported over quite a distance, e.g. 10 km or more, before it reaches the user of the heat energy. However, in order to save water, the transport medium for the heat, a closed loop cycle might be needed. Since the pipelines are costly it might be worth trying to locate the facilities using the waste heat as close to the power plant as possible.

Canning and Pasteurization

Figure 6. Example products from Langeberg & Aghton Canning Company, South-Africa.

Canning is a method of preserving food in which the food contents are processed and sealed in an airtight container. Canning provides a shelf life typically ranging from one to five years, although under specific circumstances it can be much longer. A freeze-dried canned product, such as canned dried lentils, could last as long as 30 years in an edible state. From a public safety point of view, foods with low acidity (a pH more than 4.6) need sterilization under high temperature (116-130 °C). To achieve temperatures above the boiling point requires the use of a pressure canner. Foods that must be pressure canned include most vegetables, meat, seafood, poultry, and dairy products. The only foods that may be safely canned in an ordinary boiling water bath are highly acidic ones with a pH below 4.6 such as fruits, pickled vegetables, or other foods to which acidic additives have been added.

The available energy of 100 MWth from the example 50 MWe power plant would allow the operation of a canning company with a capacity of

- 200 ton per hour of canned products
- 100 cargo shipping containers per day could be filled and shipped.

Depending on the sales products and based on a sales price of $0.5 to 1 per kilogram (two cans), a production of 4,500 tons per day might induce revenues from US$ 2 to 4 million per day.

Cold Storage

Refrigeration has had a large impact on industry, lifestyle, agriculture and settlement patterns. Refrigeration technology has rapidly evolved in the last century, while the increase in food sources has led to a larger concentration of agricultural sales coming from a smaller percentage of existing farms. Farms today have a much larger output per person

Figure 7. Cold Storage of Northland Inc., Wisconsin USA, size 25,000 m^2.

in comparison to the late 1800s. This has resulted in new food sources available to entire populations, which has had a large impact on the nutrition of society.

Dairy products are constantly in need of refrigeration, and it was only discovered in the past few decades that eggs needed to be refrigerated during shipment rather than waiting to be refrigerated after arrival at the grocery store. Meats, poultry and fish all must be kept in climate-controlled environments before being sold. Refrigeration also helps keep fruits and vegetables edible longer.

The waste heat from a 50 MWe flash power plant has been estimated as 100 MWth. This amount of heat energy is sufficient to operate an absorption chiller system that could provide freezing temperatures of -20°C to a cold storage (freezing plant) of a size of 100,000 m^2. Compared to Figure 9, this would be four of the cold storages shown above. With an estimated height of 10 meters, there would be plenty of room for cooled and frozen products for farmers and other industries from the entire region. This facility could also function as warehouse or market for national and international buyers.

Fruit Drying

Dried fruit is fruit from which the majority of the original water content has been removed either naturally, through sun drying, or through the use of specialized dryers or dehydrators. In our case, the dehydration process is based on geothermal waste heat.

Today, dried fruit consumption is widespread. Nearly half of the dried fruits sold are raisins, followed by dates, prunes, figs, apricots, peaches, apples and pears. These fruits are usually dried in heated wind tunnel dryers.

For drying uses, the heat energy from a 50 MWe geothermal power plant (100 MWth) would suffice for a factory which could

– Dry 50 ton of food per hour

– Fill around 25 cargo shipping containers per day.

Needless to say, this facility would likely encourage farmers to enter into previously unknown production of fruit and other kinds of food that can be dried.

Finally, the author wants to reiterate that all figures in this paper are indicative. For each country and geothermal field, it will have to be evaluated which uses of waste heat could present feasible options in terms of the infrastructure available, people and their needs and capacity in the areas. There might be various options which are not included in this overview and will have to be discussed in more detail in order to be integrated into the conceptual design of the power plant and the entire project.

Figure 8. Fruit / Food Drying equipment.

Waste Heat Use as Part of the Country's Legal Framework and PPA

In general, a country government would have three options on handling waste heat projects from geothermal (as well as other sources, like biomass or industries):

a) Reduce the tariff (to the IPP) for the generated power and add a payment for waste heat

b) Pay the normal tariff for power and pay an additional tariff for waste heat,

c) Pay the normal tariff for power and get the waste heat free

As previously discussed, the use of waste heat should improve the overall project benefits for the entire country as well as for the people in the region by the creation of additional jobs and the provision of new opportunities. All a power plant operator will have to do, is to make the waste heat from the plant available to waste heat users, e.g. a developer / operator of a canning factory, instead of cooling it down and re-inject it right away. This requires two interfaces for the waste heat users; one, where the waste heat is received from the power plant, and another one where the fluids are returned to the power plant operator after the heat has been extracted. This process reduces the usage of cooling towers and thereby actually can save operational and maintenance costs for the power plant operator. However, for security reasons, the cooling towers still have to be installed and be instantly operational. For this hassle, including providing the two interfaces, the power operator will have to be compensated well enough to ensure his firm and continued interest in providing his waste heat to other users.

Option c) above does not provide this interest of the power generator. Options a) and b) have to be investigated and negotiated on a project-by-project basis. For example, if the waste heat users are readily available and can guarantee a certain off-take of heat from the power plant, thereby providing guaranteed revenue to the power plant operator, option a) might be most beneficial for all stake holders of the project.

In most cases in developing countries, it will take time to identify industries willing to use the waste heat available, and the power plant operator has in fact little security when this will happen and how secure the payments from these industries will be. Therefore, option b) will likely be the most commonly used option. As said before, the tariff paid for every kW of waste heat should be just high enough to ensure the interest of the power plant operator to provide it at all times. The reliability of this service is very important, since all waste heat applications, especially the freezing plant and cold storages, will need access to the waste heat on a 24/7 basis.

The tariff paid to the power generator for every kW of waste heat should be lower than from all other sources. As a basic formula, it should include

i) Cost on providing and maintaining interface (fixed cost + maintenance)

ii) Labor cost to keep cooling towers in stand-by mode (minimal)

iii) Nominal return to power generator to insure interest (negotiated)

Savings from O&M of cooling towers could be deducted from this amount, thereby likely largely offsetting cost factor ii).

In any case, it might be a good plan to integrate referral prices for waste heat into the PPA of projects and have guidelines in the country's regulatory and legal framework, stating that the use of waste hat should be part of all geothermal power projects. It should also clarify responsibilities of all stake holders and provide an indicative frame for costs.

Example of Possible Waste Heat Use by an Industrial Park

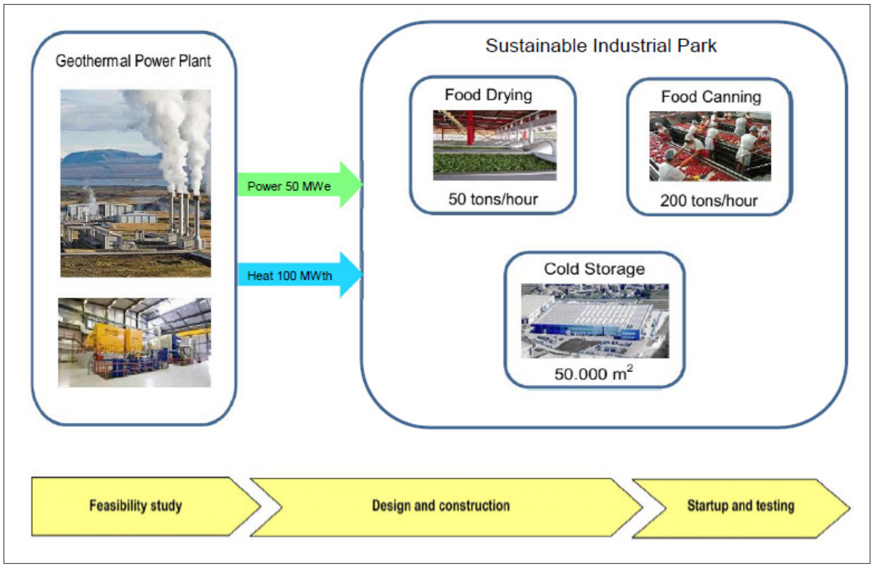

Figure 9. Waste heat use by industrial park (Consent Energy Thorhallur Bjarnason, 2014).

Figure 9 shows an indicative example of the waste heat from a 50 MWe geothermal power plant could be used with a near-by sustainable industry park. Using clean energy could be of first steps towards receiving environmental and sustainable certification for the producers and the products being made in these facilities. This would make the products suitable for rapidly growing global markets for sustainable and organic products and could increase their economic value even further.

The facilities included in the suggested Industry Park would have the following annual turnover (indicative figures):

- Canning: $3m/day …………………… → $200m/year
- Cold Storage: Inv. $ 200m …………… → $60m/year
- Drying: $1/kg ………………………… → $50m/year

The total Waste Heat Industry Park: …… → $310m/year

Total turnover of power generation 50 MWe:
50,000 kW * 8,000 hours * 10 US cents → $40m/year

Comparison on total turnover (revenues): Waste Heat : Electricity = 8:1

Conclusion

The above example of waste heat use by an industrial park shows that revenue creation from waste heat use could be several times the revenues from power generation. At the same time, the use of waste heat supports regional development through job creation and new agricultural opportunities, e.g. through marketing of new products. Finally, this would imply additional tax revenues to the country, increased value of food products and potential new export products.

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