Geothermal Renewable Energy for Electrical Power Production

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Nobel Peace Prize winners **Al Gore** and **Rajendra Pachauri** and **Jonathan Mann** CNN in Oslo Dec 10, 2007 discussing decentralized, personal generation of electrical power:

GORE: [....] Some of the new technological breakthroughs that we don't automatically think of could play a major role. Think of the computer revolution, for example. There used to be a half dozen computers in the world, each the size of a small building, and you had to go that place to use it. Now there are supercomputers by that measure by the hundreds of millions all around the planet. We still, however, think that we have to get our electricity from large, big structures that burn lots of coal or whatever, when actually some of the new breakthroughs that have much more efficiency, higher levels of conservation, make it possible to use breakthroughs that have massively distributed generating capacity. Small windmills, small solar panels of the next generation.

MANN: A personal generator.

PACHAURI: That's correct. As spread all around. Sharing through a smart grid that allows people, when they're used less, to sell unlimited quantities into the grid at a price that's set by [the deregulated market or] a public authority so that we might in many areas never need another central station generating plant.

Introduction

Environmental considerations have gained momentum in the last decades and concerns with global warming are not only shared by a small group of environmentalists but by the majority of the public. More pressure is on increasing renewable energy production. Still, large power projects in Hydro and Geothermal energy have been under attack from environmentalists for decades as these large structures in unspoiled nature may appear offensive to the environment. Most resistance is for large reservoirs of big Hydro projects.

Recently Geothermal Projects have increasingly come under the attention of environmental groups. People complain about large power house structures with on-surface steel pipes for collection of steam from boreholes to the power houses also being offensive to the environment.

Large power house structures with adjoining buildings for steam separation and water cooling and miscellaneous other infrastructures are concentrated on a single spot. The production holes are all in the vicinity of the powerhouse or within a circle of 2 km in radius. In recent years it has become evident that this could lead to overloading of the geothermal reservoir so it could not be recharged fast enough. This leads to lowering pressure in geothermal reservoirs, resulting in reduced power production over the years. Thus unexpectedly too slow recharge of the geothermal reservoir could be the result of overloading of small geothermal fields and inadequate management of the underlying resources. The powerhouses are thus left with less production and can not be moved or reduced in size even though energy production may have decreased drastically.

Another approach is now being proposed by the Icelandic/Norwegian company, Kaldara Green Energy. This is to build smaller power structures, placed over a more extended area thus avoiding overloading of a small area. The Kaldara concept is to place a miniature powerhouse in standard sized containers next to the production boreholes. Because of smaller sizes, the containers could be placed hidden into hillside areas or placed underground to avoid offensive structures in a sensitive environment. This would support the views of environmentalists who dislike large structures in nature that could have non-recoverable influences on nature. Secondly, this would be a better resource management of reservoirs, giving longer lifetime to the whole project and making it more economical.

Groups of small, interconnected **KAPS** (**Ka**ldara **P**ower **S**ystem) powerplants could be arranged in Geo-Farms.

This article explains some issues at hand if one moves away from large centralized power structures to a more decentralized structure by moving the production capability to the borehole. Transfering the power generated from geothermal energy will then be achieved by electrical current in subsurface el-cables instead of by steam in large diameter conduit pipes on the surface to centralized power structures.

The analogy with the computer revolution in the 80's and 90's will be used to explain the difference in setup architecture, but in that period personal computers replaced the non-flexible centralized mainframe computer. The slogan: "The Net is the Computer" is so much alive to-day as the Internet is reaching maturity.

With the KAPS in the geothermal world the **DPG D**ecentralized **P**ersonal (Power) **G**enerator replaces the **CMG C**entralized **M**ainframe **G**enerator.

In this article we first take a look at energy prices and see how KAPS-units compare with some Icelandic and Brazilian energy prices. It is clearly seen that geothermal renewable energy is cheaper than coal for electrical power production. Then it is observed that some advantages of the Decentralized power production approach is more considerate treatment of delicate natural areas and more possibilities open up to extend the geothermal harnessing of the earth's internal heat, for the benefit of all mankind. Last, we take a closer look at some decisional and operational issues involved in the new decentralized approach.

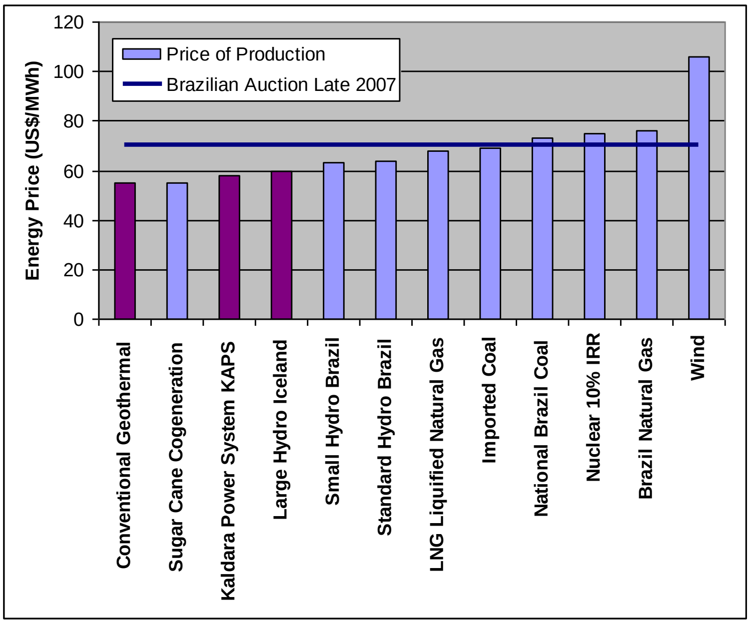
Kaldara Green Energy is an Icelandic company. Holding company is Green Energy Group AS in Norway. KAPS Kaldara Power System units are mass produced, modular geothermal power plants, installed in a number of standard but modified 40/20 ft shipping containers, that can be transported by means of conventional transport to production sites.

Energy Prices

Figure 1 shows Brazilian and Icelandic energy prices (USD/MWh of firm energy) for various fuel types, subjected to the plant's constructing cost and a given investment rate of return on equity (13%, in real terms) for the duration of the contract (25 years for thermals and 30 years for hydro). Blue columns are numbers from Brazil and Red-Brown columns are from Iceland.

Public power companies in Iceland use considerable lower interest rate or 5-7%.

Figure 1
Energy prices estimates (USD/MWh). Source: PSR
Investment rate of return: 13%



The figures presented show an outstanding economic attractiveness for production from renewable fuel like geothermal, cogeneration based on sugarcane bagasse (bio-electricity) and hydro, with prices much lower than for coal. The auction cap on the Brazilian Electricity Auction Market Late 2007 was 70 USD/MWh, already assuring IRR of 13%. These prices may show a high variability according to the parameters of a specific project, such as investment costs, financing conditions, gas prices, transmission tariffs, tax incentives, etc.

Use of lower-temperature water from the geothermal electrical power plants in Iceland for heating and cooling add considerable benefits to the geothermal energy projects.

Iceland and Brazil's case of renewable energy production is challenging. Both countries are in a unique "win-win" situation of having the lowest cost generation of renewable energy technologies also being the most environmentally friendly.

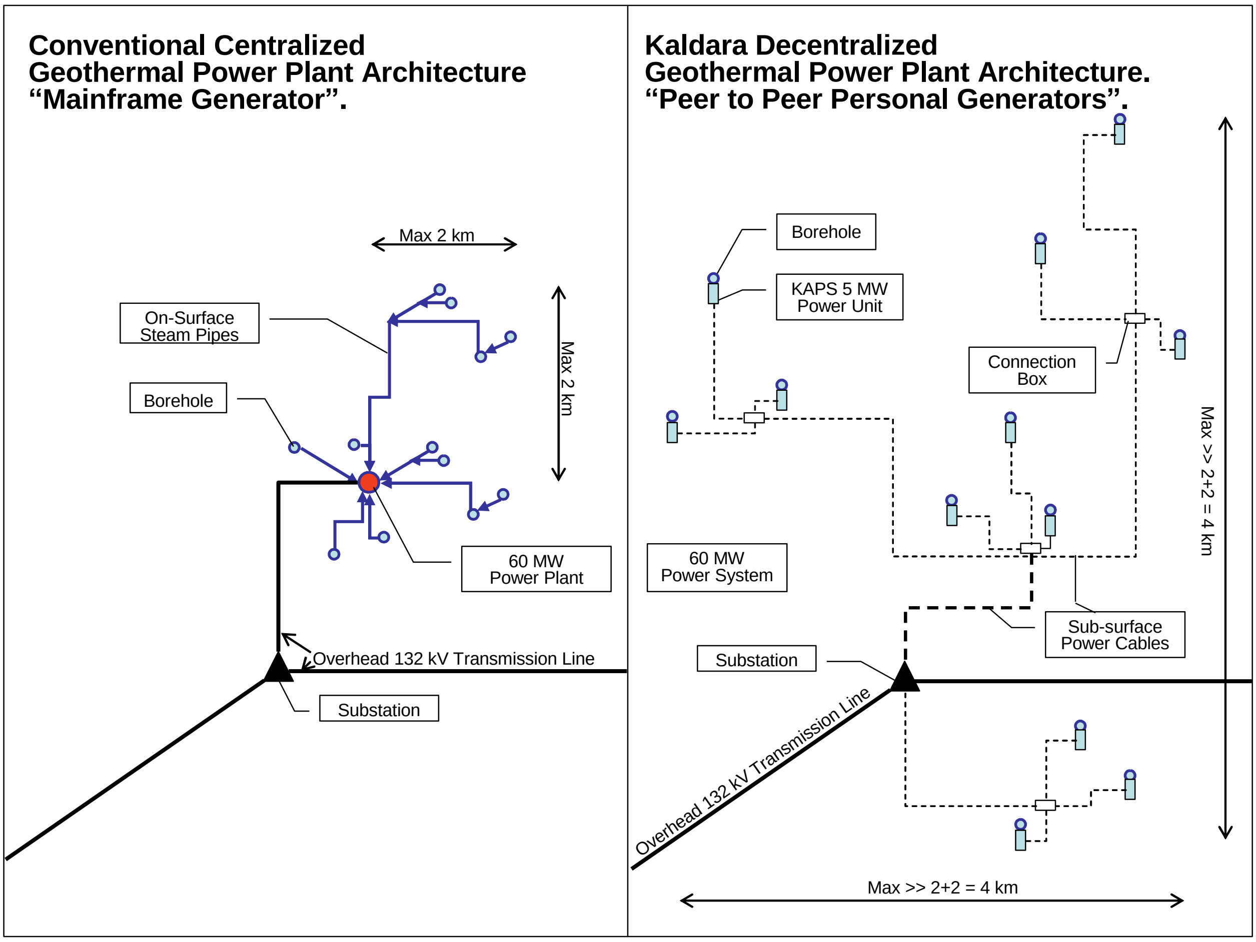
Centralized or Decentralized Setup for electricity production?

Figure 2 shows two layouts of harnessing boreholes in high-temperature geothermal areas, the conventional model and the decentralized model.

With the conventional centralized model steam from boreholes are conduited from boreholes to the power plant in steel pipes. Electrical power produced at the power plant is transmitted to the sub-station by overhead transmission power line. In the computer industry similar layout is called a 'main-frame' layout and therefore we could call this power plant architecture a "**Centralized Mainframe Generator**", CMG.

With the new decentralized model small geothermal power plants are placed next to the boreholes and electrical power is transmitted to the substation by sub-surface electrical cables. In the computer industry a similar layout is called a 'peer to peer network of decentralized personal computers' and therefore we call this power plant architecture "**Decentralized Personal Generators**", DPG.

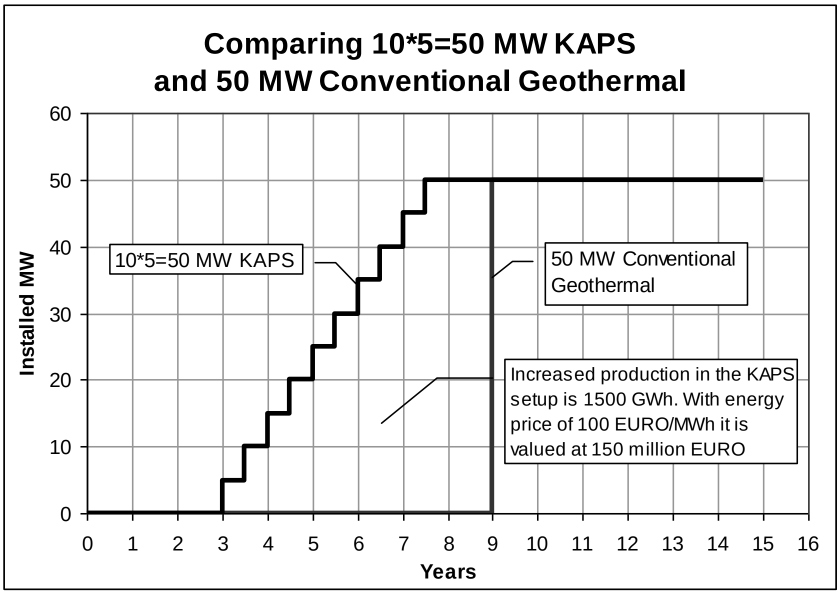
Figure 2
Geothermal Layout Architecture



The decentralized personal generator DPG approach offers various advantages over the centralized mainframe generator CMG approach as the following points emphasize:

1. The DPG approach is environmentally more friendly as large powerhouse structures and on-surface steam pipes are avoided.
2. DPG is environmentally more feasible as the small power units can easily be fully or partially hidden in sub-surface structures which is definitely preferred in environmentally delicate areas and in the vicinity of national parks.
3. In environmentally delicate areas, large on-surface power structures with the CMG model could probably be forbidden in the future. With the DPG model larger geothermal areas could be harnessed for benefit of more green power production in the world.
4. Applications for power production permits to governmental bodies could be made easier and therefore less expensive for smaller structures. In many countries deregulation of electricity allows for simpler application procedure for smaller power plants (less than 10 or 20 MW). This would only benefit the DPG approach.
5. By the DPG model geothermal harnessed areas could be made substantially larger than for the CMG model. This leads to more flexible and efficient operation and therefore more efficient utilization and longer lifetime of the geothermal water reservoirs.
6. Mass production of standard sized DPGs will make the turbines more reliable and efficient and additionally production costs will be lower.
7. The DPG model is more scalable in size. By arranging a number of interconnected KAPS units in swarms any total production capacity of Geo-farms could be achieved.
8. If production capability of a borehole diminishes too much, then by the DPG model, KAPS units can easily be transported to another active borehole as is not possible with a CMG geothermal power plant. This flexibility is a new and valuable alternative to the conventional Geothermal industry.

Figure 3 **Production Start-up**



9. With the DPG model, boreholes can be harnessed at an earlier stage or within weeks after drilling is completed, whereas the CMG model requires borehole evaluation and power house construction for a period of 6-7 years before commencing power production. In cases of high market prices of electricity, the increased production of the DPG approach could even pay for the total cost of the on-surface equipment of the KAPS-units. See figure 3.
10. Reliability could be enhanced by adding extra cables between KAPS units in Geo-Farms to create alternative paths of electricity in case of cable failure. This can be an important addition in larger DPG systems with many interconnected KAPS Units. Similar precautionary measures are employed for the Computer Internet.
11. One of the characteristics of today's deregulated power market is variable demand, which means that profitability often depends on the ability to efficiently operate at partial loads. Geothermal power plants are not flexible to adjust production to short-term variable load and

are usually operated in full power mode and power production in hydro plants take care of load balancing. Production variation is more easily obtained with many small geothermal power plants by simply shutting down individual plants or starting the plants up in full production mode.

12. Geothermal power is a reliable, continuously available (24 hours/day - 7 days/week) base load energy source. Except for short outages to repair equipment and conduct overhauls, geothermal facilities have very high availability and capacity factors; they typically operate 90 to 98 percent of the time. The DPG approach compares favorably to the CMG approach as only a small percentage of the total production capability is unavailable during downtime. The same goes for preventive maintenance periods.
13. Conventional Commercial utilities can be vulnerable during wartime. If a power plant of the CMG type comes under attack by the enemy it could mean risking a collapse of the whole electrical supply chain. With DPG arranged power units, enough prime power generators are available at all times to provide electricity. If one KAPS unit is down, alternative paths for electrical energy are instantaneously available from other KAPS units. The same consideration is valid for protection against terrorism.
14. With fast installed and economical capacity, KAPS is a new alternative in geothermal power production in our fast changing world.
15. Power Companies in Iceland will test the first KAPS unit on existing boreholes in the summer of 2009.

Large geothermal plants by the Centralized approach leads usually to better economy of size. The above mentioned benefits could make the Decentralized approach more attractive as a viable alternative in electrical geothermal power production.

Figure 4 **Harnessing outlier boreholes**

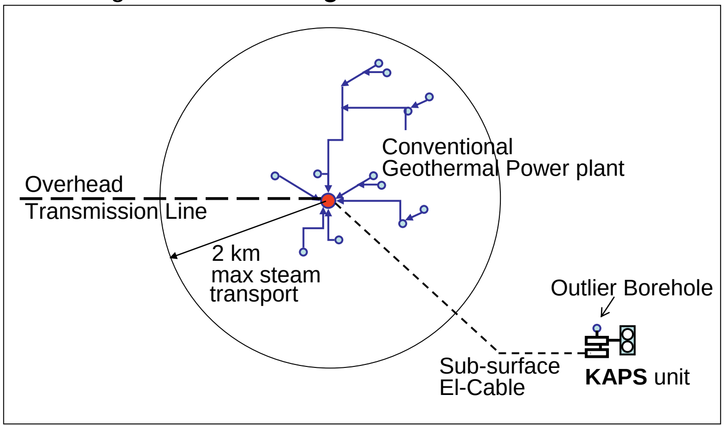
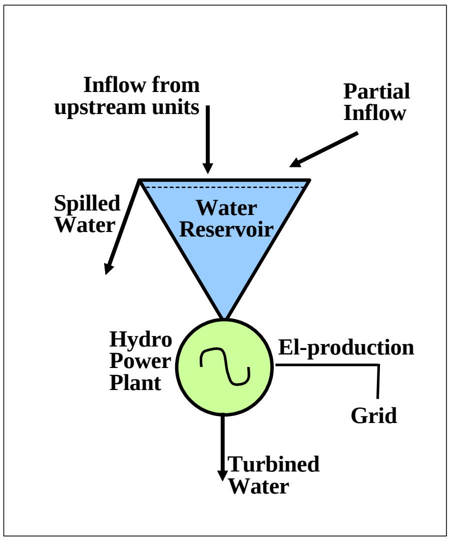


Figure 4 shows a mixed solution of CMG and DPG model.

It is noteworthy that with the computer revolution of the 80's and 90's the 'peer to peer network of decentralized personal computers' replaced the 'mainframe' layout. Could the same thing happen in the electrical geothermal power industry?

Figure 5 **Hydro Power Plant**



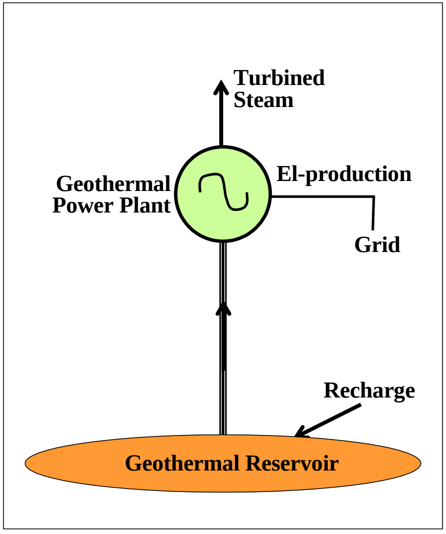
Power System Models

Power System modelling of interconnected hydro, geothermal and thermal power plants is a widely researched area and has been successfully used in the production environment all over the world, including Iceland and Norway. The models use simulation and optimization to find the best operational practice, including long term management of water reservoirs, to evaluate feasibility of new power projects.

Figure 5 shows a simplified model of a hydro power plant connected to the transmission network grid.

Sometimes bank storage and leakage is taken into consider-ation and in warmer countries it is also necessary to account for evaporation.

Figure 6 **Geothermal Power Plant**



Geothermal plants are traditionally modeled as run of river hydro plants with neither reservoirs nor upstream plants.

The decentralized approach, DPG, with earlier utilization of production boreholes and more spread over wider areas, lends itself to further studies of response functions for the underlying geothermal reservoirs. See model of a geothermal power plant in figure 6. The problem is that recharge of the geothermal reservoir can only be measured indirectly by drilling evaluation boreholes or from production characteristics (pressure, temperature and yield) of the reservoir. Also more than one borehole could be connected to the reservoir and interaction between the boreholes would then have to be taken into account.

Kaldara Green Energy will model the geothermal power system in the same fashion as the widely used hydro power systems models and take advantage of the extensive development work already performed[1]. This work will be implemented as the decentralized KAPS units will gain momentum in the field. It will lead to more effective resource management of the underlying geothermal reservoirs. Environmental considerations can also be tackled by the model as boundary restrictions are added to the models so as to minimize the disturbance of valuable natural areas. In the model, shadow prices are calculated all over the power system, in substations on the transmission grid, in hydro and geothermal stations including the KAPS-units. The shadow prices reflect the value of the resources everywhere and create guidelines for optimal operation of the power system.

This is actually a vision of a knowledge system where data from the production are constantly added to a database to create gradually a more and more powerful intelligence system of geothermal power production strategy and operation.

About Kaldara Green Energy and KAPS

Kaldara Green Energy is a Norwegian/Icelandic company, with focus on production of KAPS geothermal electrical power production equipment. Manufacturing of the KAPS is at Hindustan Turbomachinery in Bangalore India. Green Energy Group AS (GEG) is a Norwegian holding company, whose core business area is to seek financial opportunities within the geothermal green energy space. GEG holds 100% of the Equity in the Icelandic Kaldara Green Energy. Headquarters of Kaldara are in Reykjavik, Iceland.

KAPS Kaldara Power Systems are container based geothermal units that can operate stand-alone and are also capable of working together in geothermal power farms. Because of their small size, KAPS can be more easily adopted to the environment than large power plant structures. KAPS on-surface units can be used for all types of Wet/Dry and Binary/Flash Geothermal Systems. The KAPS concept is to place a miniature powerhouse in standard sized containers next to the production boreholes. The containers could be placed hidden into hillside areas or placed underground to avoid offensive structures in the environment, in full reconciliation with environmental groups. Using KAPS could therefore extend the reach of environmentally friendly exploitation for electrical power production worldwide. With the KAPS approach, boreholes can be harnessed at an earlier stage or within weeks after drilling is completed, whereas the conventional approach requires a borehole evaluation period of 3-5 years before power production. KAPS units can be organized in power farms of the same capacity as large geothermal power plants.

See the central unit of a 5 MW KAPS unit on figure 7. Shown: Generator, turbines and condenser. Not shown: Steam separator, vacuum system, cooling towers and piping.

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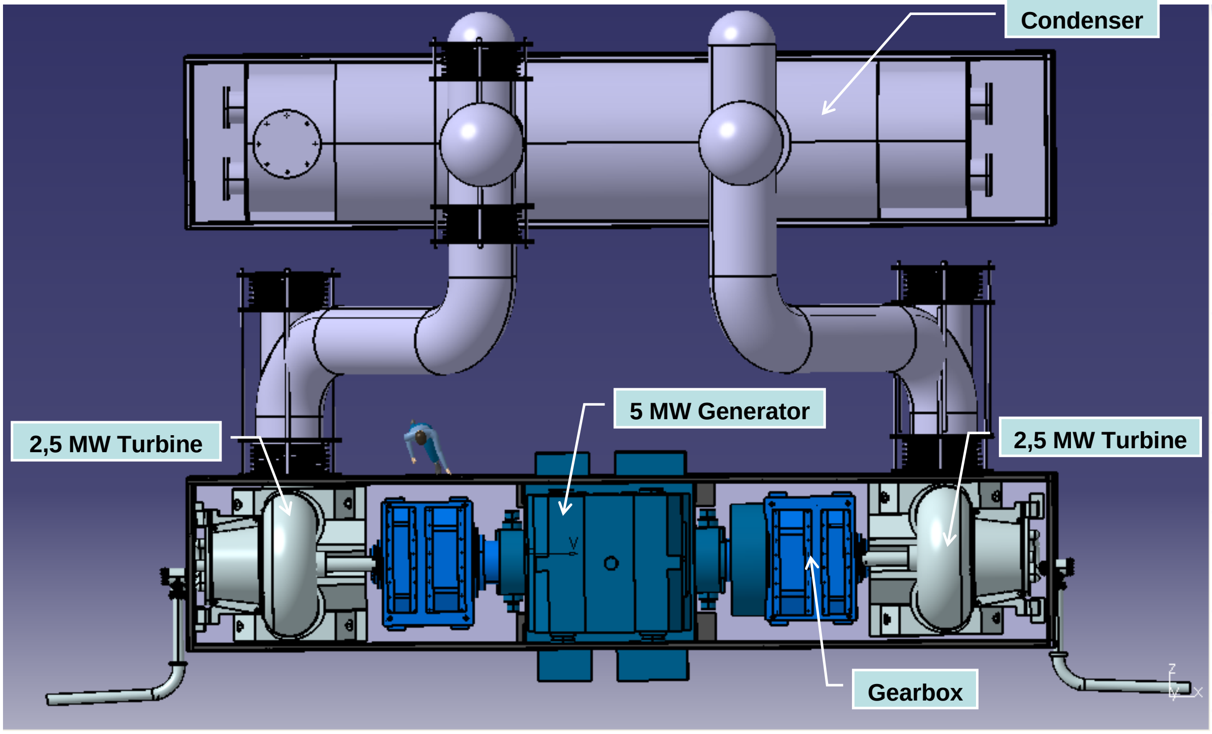
[1] Including HYENA Hydro Energy Simulator developed by Skuli Johannsson, one of Kaldara Energy's key Partner.

Figure 7 **Genset and Condenser of a 5 MW KAPS unit**



Availability of Geothermal Green Energy for more than 8000 hours/year allows for basic power, compared to occasional delivery of wind and solar power requiring reserve non-renewable backup power.

KAPS units are now economically viable by mass production in a highly qualified manufacturing process and can compete in price with larger size geothermal turbines/power plants but with better risk management. By getting involved in the manufacturing process of geothermal power plants, Kaldara has managed to shorten delivery time from 30 months (for Japanese manufacturers) to 6 months, thus shortening the time to start selling electricity and generate revenues.

Glossary

- Renewable energy arises from energy sources that are consumed at the same rate they are produced. Environmental impact of the harnessing technology is sustainable.
- Green energy is produced from clean, renewable energy resources.
- Sustainable development is the provision of energy such that it meets the needs of the present without compromising the ability of future generations to meet their needs. It has become a guiding principle for policy in the 21st century.
- Geothermal Green Energy has traditionally been classified renewable, as heat content of the global geothermal reservoirs is enormous or practically limitless.
- Three components are essential for Wet Geothermal development:
    - Sub-surface heat source
    - Fluid, water and/or steam, to transport the heat.
    - Faults, fractures or permeability within sub-surface rocks that allow the heated fluid to flow from the heat source to the surface. To facilitate this, deep sub-surface boreholes are drilled.
- For Dry Geothermal development water is provided from the surface.
- Wet Geothermal Systems are conventional but Dry Geothermal Systems (also called Hot Dry Rock or EGS: Enhanced Geothermal Systems) are still in experimental phases.
- With the geothermal fluid temperature of 120-180°C Binary-Cycle Power Plants are used and with temperature >180°C Flash Type Power Plants are used.

- **<u>KAPS</u>** (**Ka**ldara **P**ower **S**ystem) is a geothermal power plant produced by Hindustan Turbo-machinery for Kaldara Green Energy.