Deep borehole heat exchanger, possible solution to use dry well

Geothermal application to direct use

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H&G WORKGROUP

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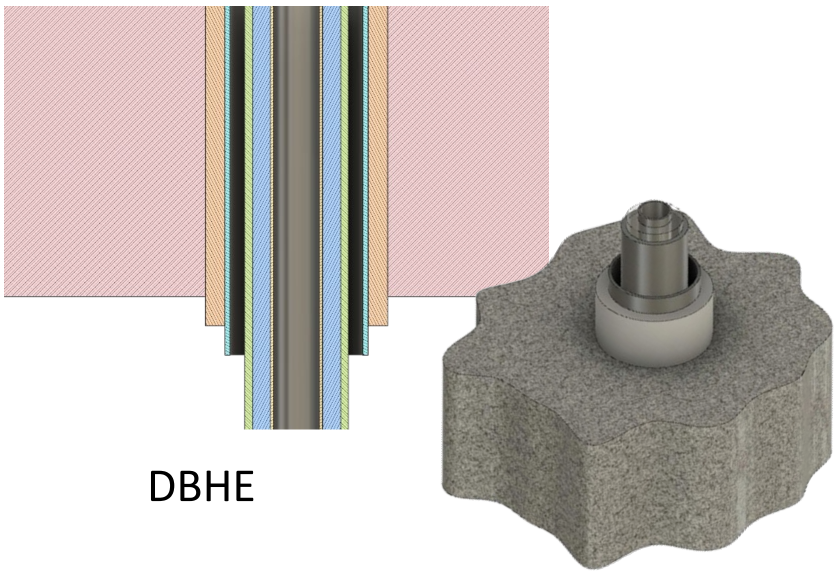
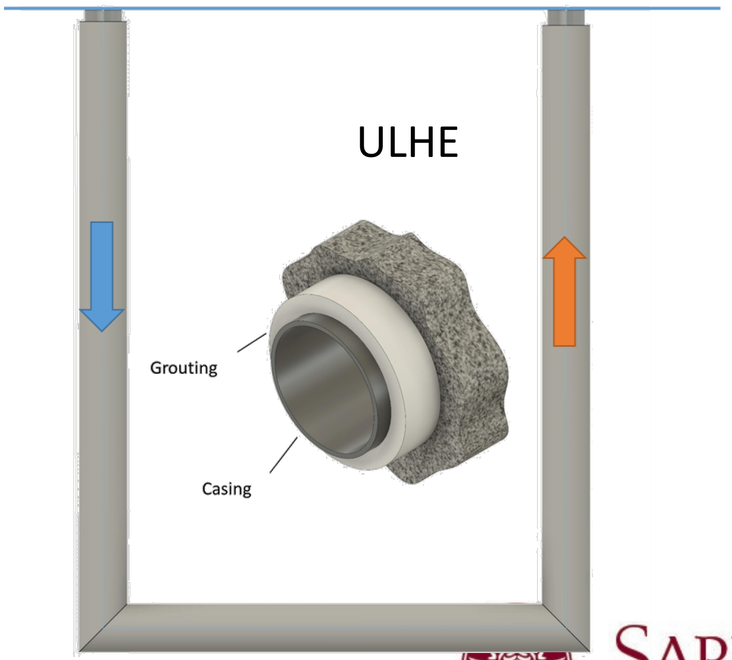
CLOSED-LOOP GEOTHERMAL ENERGY SYSTEMS

Two main types of closed-loop are under development

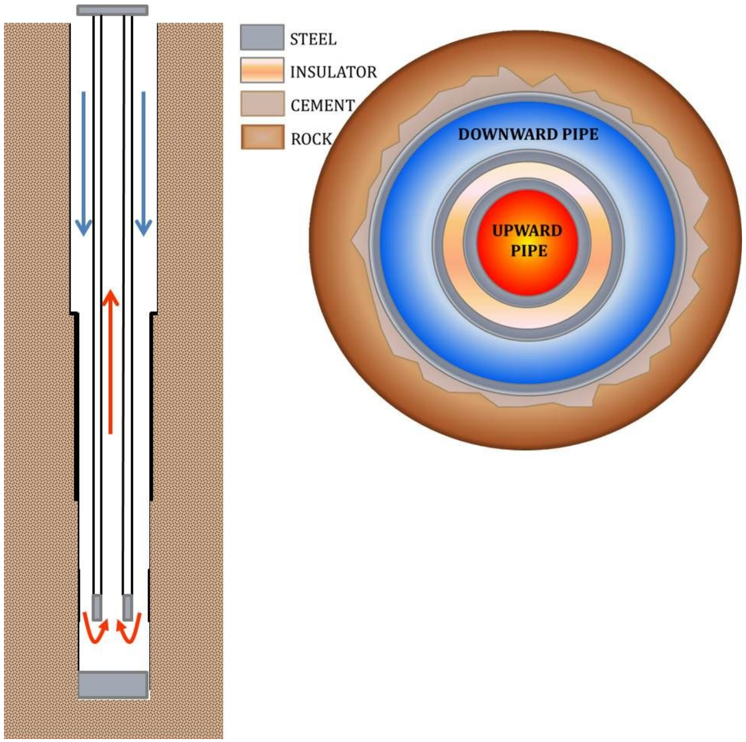
The first is the concept of a coaxial exchanger, which can be vertical (DBHE) or developed with a horizontal terminal part (DBHEh)

The second is the U-loop scheme, which includes a geometry composed of two pseudo-vertical sections joined by a horizontal branch (ULHE).





WHY THE DEEP BOREHOLE HEAT EXCHANGER?



- **Reservoir Temperature > 150 °C**
- Thermal power production
- Binary power plants
- Opportunity for unconventional geothermal systems
- The application of DBHE into existing wells, is attracting the interest of oil companies

In the last 20 years, several studies have been conducted on the possibility to produce geothermal energy **without production of brines** by single well solutions

A deep borehole heat exchanger (**DBHE**) (≥1000 m) extracts heat by conduction and it is made of two coaxial tubes

In the external annulus is injected a working fluid which is heated going deep

At the bottomhole the fluid enters in the internal tube, and it flows up to the wellhead (*thermosiphon effect*)

Low efficiency in heat recovery respect to the conventional geothermal plants, no fluid extraction

LITERATURE REVIEW

60 papers published between 2002 and 2020

The analysis has been focused on three key aspects:

- modeling of heat flow from reservoir to the DBHE
- modeling of heat flow through to the DBHE
- Performances of the DBHE

New papers have been published until today

The analyzed papers are heterogeneous both for the thermal properties of the formation and of the heat carrier fluid, as well as for the operation condition of the DBHE

Outlet temperature 5 ÷177 °C

Inlet temperature 0 ÷80 °C.

Produced thermal power 100 kW÷3 MW

Electrical power 25 kW÷364 kW

Conclusions

- Use of water as working fluid
- Importance of internal pipe insulation. For the entire length or for a limited length.
- Optimal residence time of the fluid to obtain maximum performance
- At fixed flow rate the optimal residence time is function of the wellbore diameter and of the casing diameter
- The internal tubing diameter increases, the thermal power decreases
- Thermal radius 10 ÷50 m
- Steel for the coaxial pipes. High density polyethylene and technopolymer for the internal pipe
- The circulation of a heat transfer fluid (water) or in case of ORC plant the direct circulation of the low boiling point fluid (iso-pentane, iso-butane, R134a and R245fa)
- The ORC plant is the most proposed conversion plant to electricity
- Several authors recommend the direct use

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GEOPIPE: DBHE AND GEOTHERMAL SOURCE MODELING

To simulate the performance of the DBHE the software GEOPIPE was developed (Alimonti & Soldo, 2016). An analytical solution of the Fourier equation for the heat transfer into the ground source, assumed as a purely-conductive medium. A semi-analytical approach based on thermal resistances is adopted.

The software considers a layered rock system with different thermo-physical properties, geometry, and geothermal gradient for each section. Different working fluid can be used.

The temperature profiles within the downward and upward ducts read:

$$\begin{cases} \dot{m}_w c_w \dfrac{dT_{w,dw}}{dz}(z) = \dfrac{T_s(z) - T_{w,dw}(z)}{R_a} - \dfrac{T_{w,dw}(z) - T_{w,uw}(z)}{R_b} \\ -\dot{m}_w c_w \dfrac{dT_{w,uw}}{dz}(z) = \dfrac{T_{w,dw}(z) - T_{w,uw}(z)}{R_b} \end{cases}$$

R_s is the effective transient thermal resistance between the external well casing surface and the undisturbed ground. It accounts for the actual thermal influence due to the heat extraction.

$$R_s = \frac{1}{2\pi\lambda_s} \ln\left(\frac{2\sqrt{\alpha_s t}}{r_{o,1}}\right)$$

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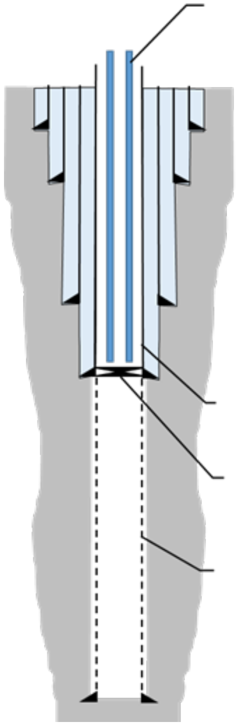
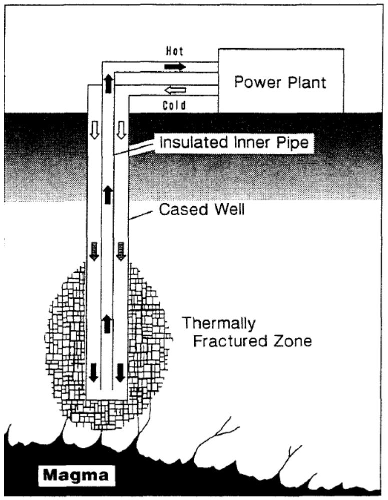
HAWAII 1992 – DEMONSTRATION TEST

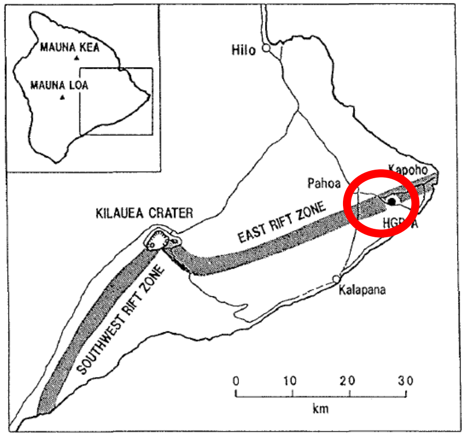


- The test done in the Hawaii has been conducted on an existing well (1962 m deep).
- The well was drilled on a magmatic body
- The concept of the DBHE has been proved



To test GEOPIPE and evaluate its reliability, the results obtained during the experimental test on the DBHE been carried out in Hawaii was used.

The tested well where test was near the Kilauea crater on the rift zone. The well was 1962 m depth with a slotted liner in the last thousand meters. Thus, a bridge plug was put at 879 m depth. The section interested by the test was completed with a 7" casing and the insulated inner pipe of 3" ½ was used. The bottom hole temperature was 110.3 °C.



Test Data	
Length	876 m
Flow rate	80 l/min
Tin	30 °C
Power max net	370 kW_{th}
Power min net	76 kW_{th}
Bottohole temp.	110 °C
Duration	10 days

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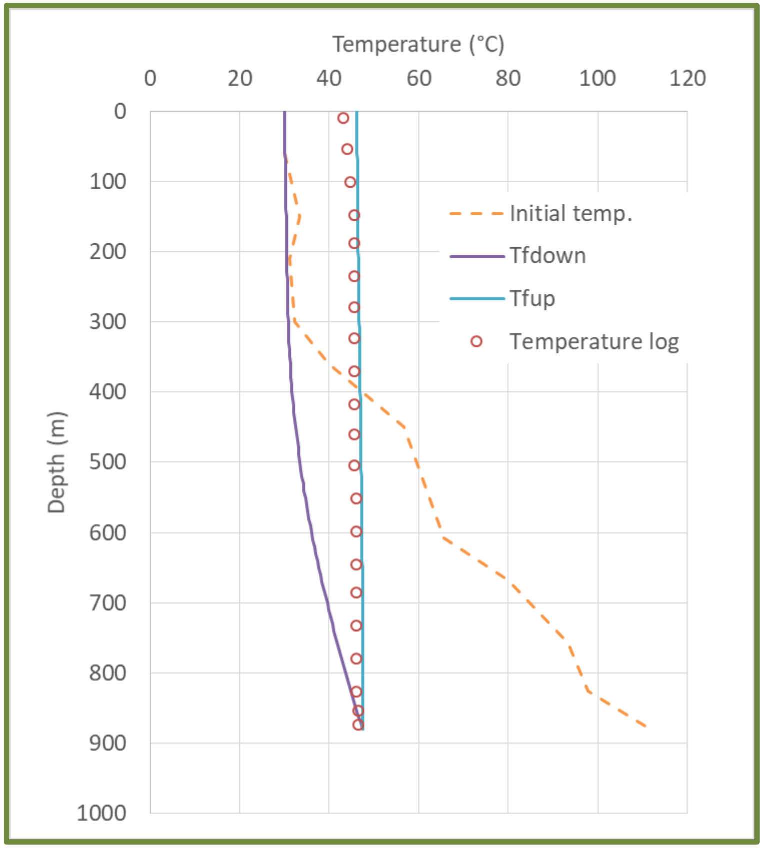
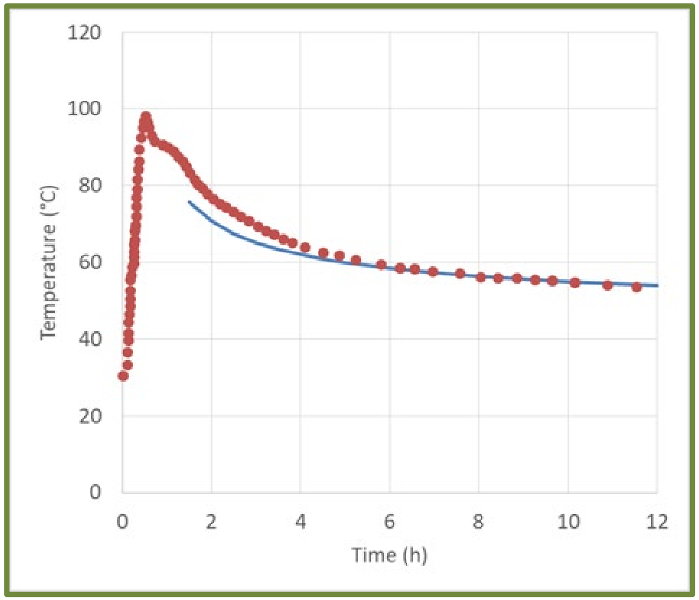
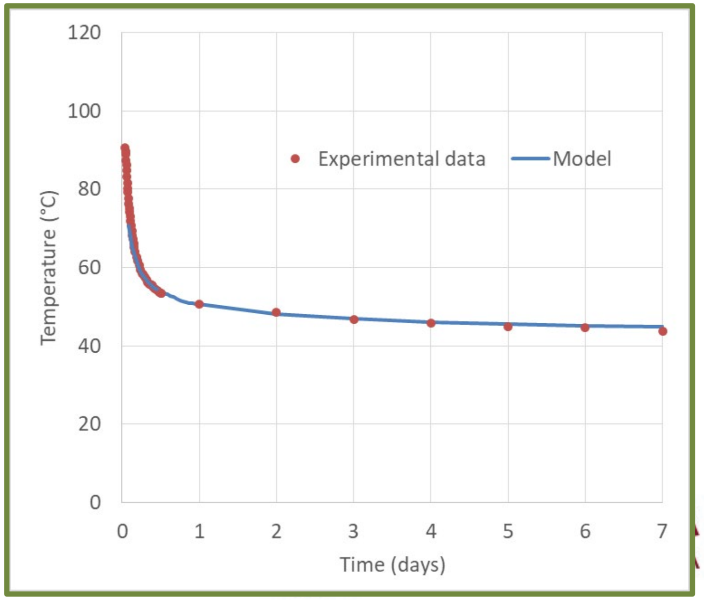
GEOPIPE MODEL VALIDATION

Comparison between measured data and calculated temperature profile with GEOPIPE is done after 93 hours from the start.
The analysis of the model results in the simulation of the Hawaiian test allow us to be confident with the model.



Comparison between experimental data (red dots) and GEOPIPE model forecast (blue line)





COUPLING THE DBHE AND RESERVOIR SIMULATION

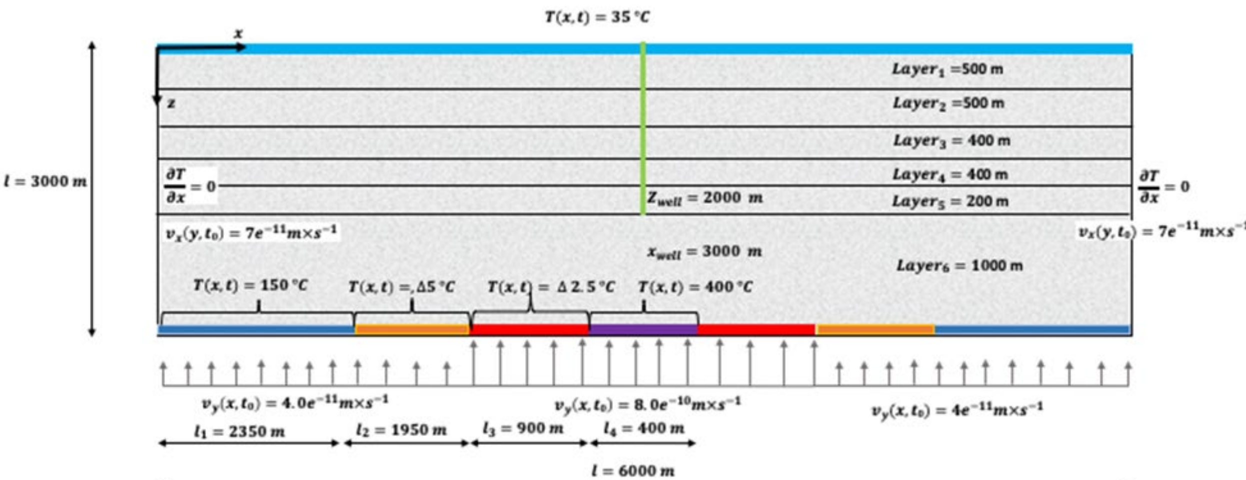
The hypothesis of **purely conductive** heat transfer may be a **strong limitation** in some geothermal systems. The magmatic structures and the fluid circulation should produce a recovery action with respect to the heat extracted.

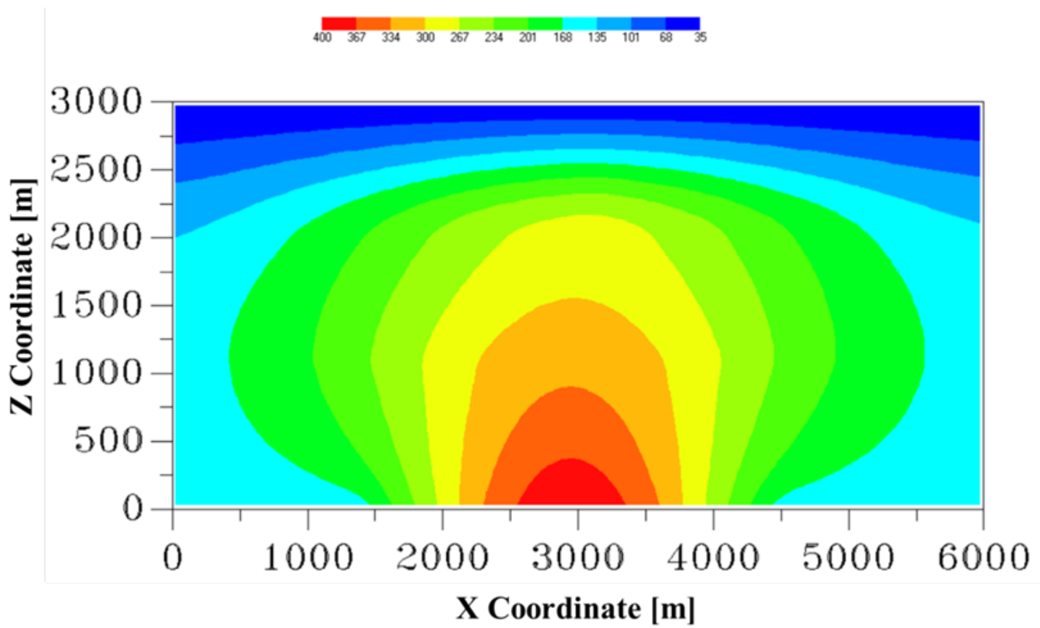
TARGET: compare the results obtained with a pure conductive model of the DBHE and with a coupled model composed by a numerical reservoir model and a semi-analytical model of the DBHE.

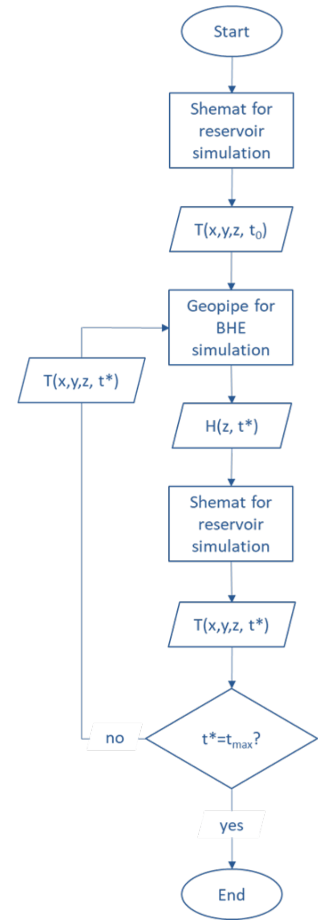
A **first attempt** was conducted with the SHEMAT software showing the increase of more than 2 times of the thermal power extractable from the geothermal system.

A **second stage** has been the inclusion of the DBHE in a finite element model (Sepede et al., 2022). For this integrated Reservoir-DBHE system an analysis was conducted simulating 200 years of operation. After this time the system is still not stabilized. The maximum temperature change at 200 years along the well wall corresponds to 107.3 °C. The time of 65 years can be taken as a reference as the time limit for sustainable extraction of geothermal energy using the DBHE system.

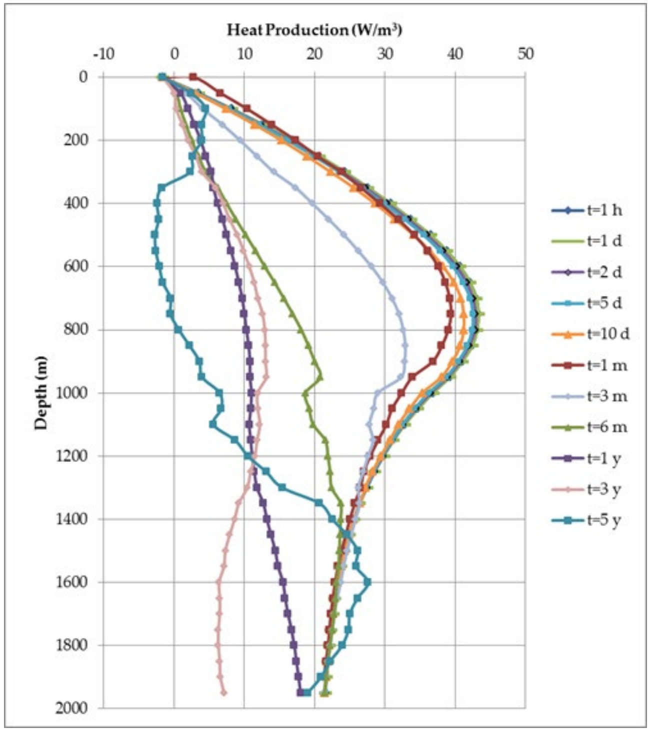
GEOPIPE AND SHEMAT COUPLING

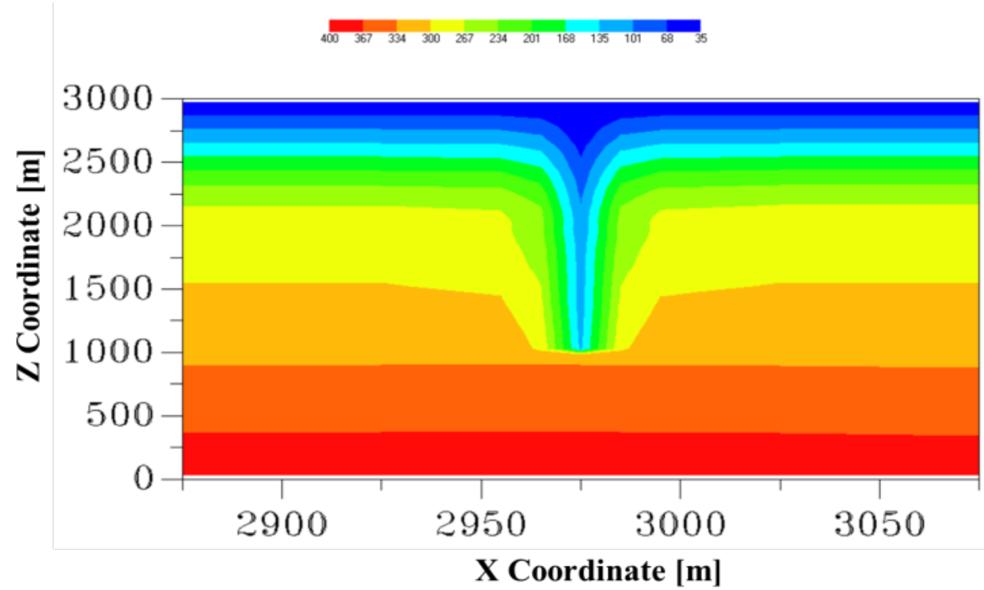


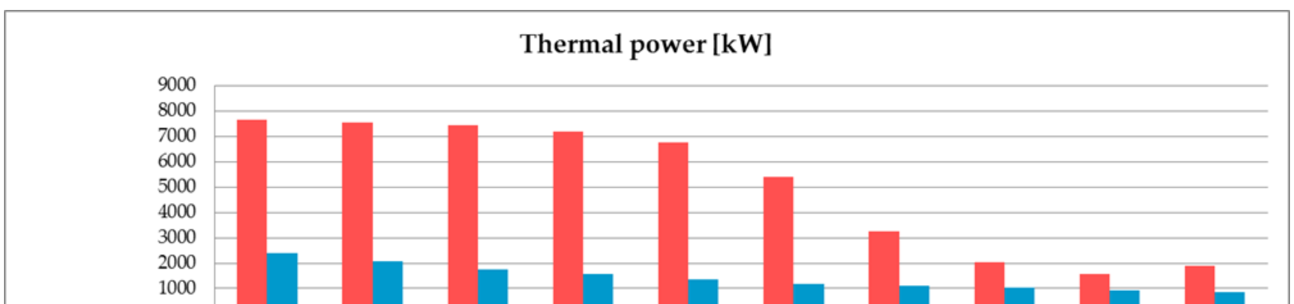




CONSTANT FLOW RATE 20 m^3/h







	1 d	2 d	5 d	10 d	1 m	3 m	6 m	1 y	3 y	5 y
Shemat - Geopipe	7652.02	7558.38	7462.05	7185.45	6758.81	5398.66	3251.29	2028.84	1571.39	1900.6
Geopipe	2395	2058	1742	1561	1342	1177	1092	1017	919	867

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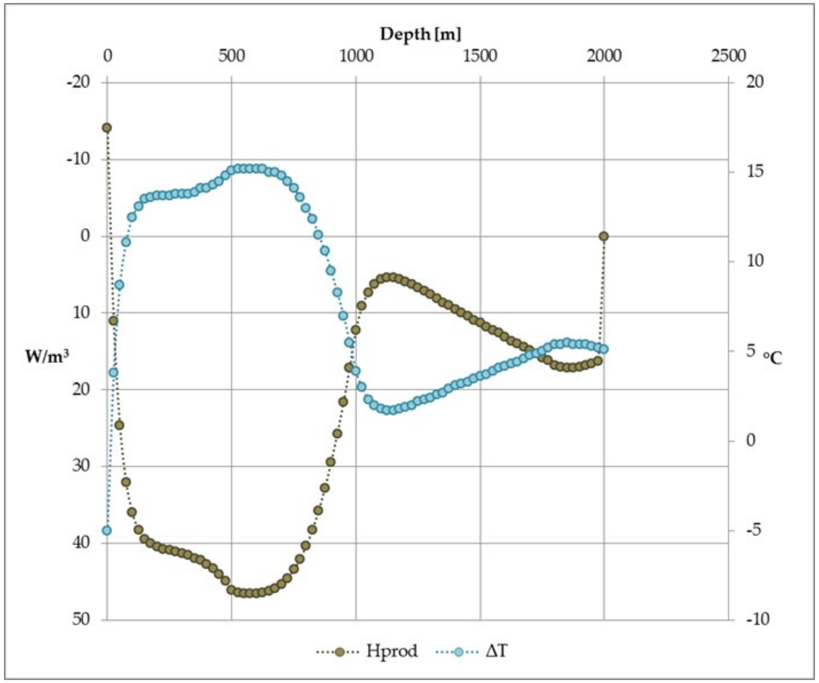
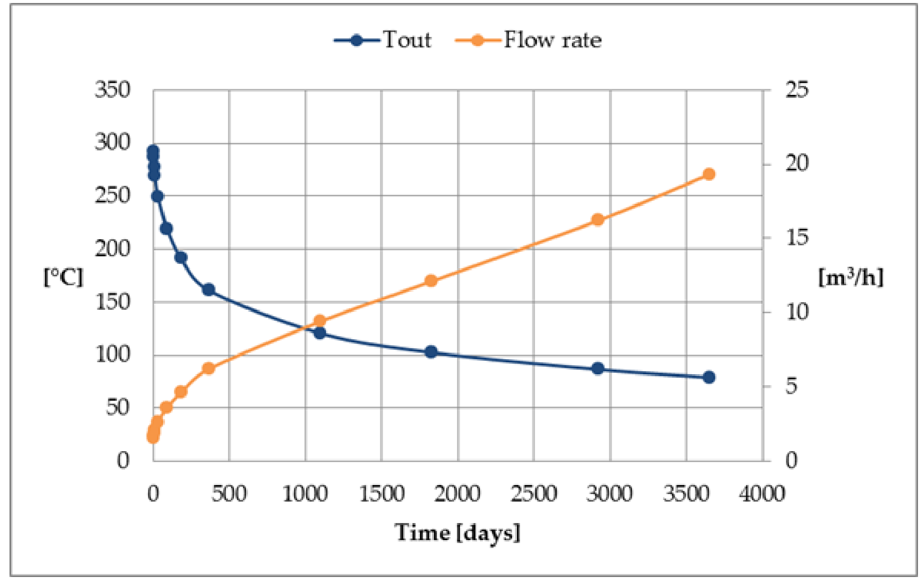
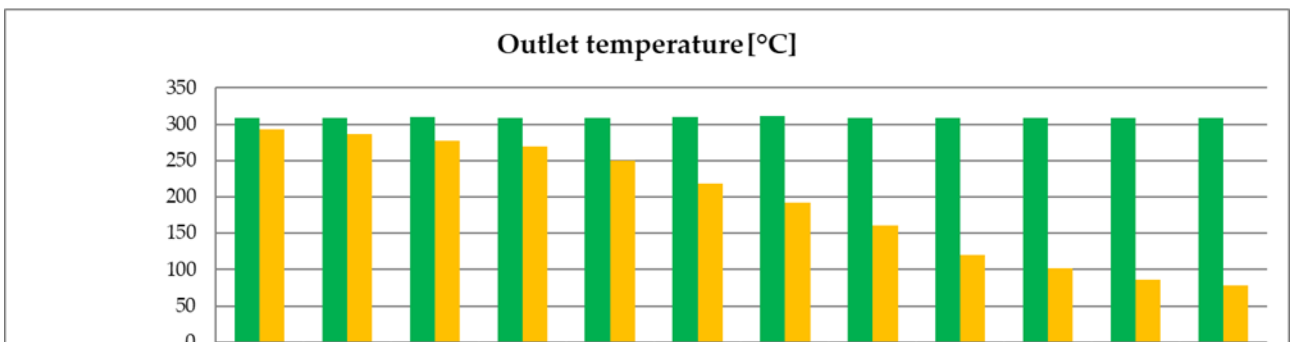
COSTANT POWER 850 kW







	1 d	2 d	5 d	10 d	1 m	3 m	6 m	1 y	3 y	5 y	8 y	10 y
Shemat-Geopipe	309.21	309.19	309.78	308.56	308.37	309.51	310.8	308.92	309.27	309.09	309.1	309.11
Geopipe	292.4	286.6	277.6	269	249.6	218.9	191.7	160.9	120.6	102.4	86.4	78.8

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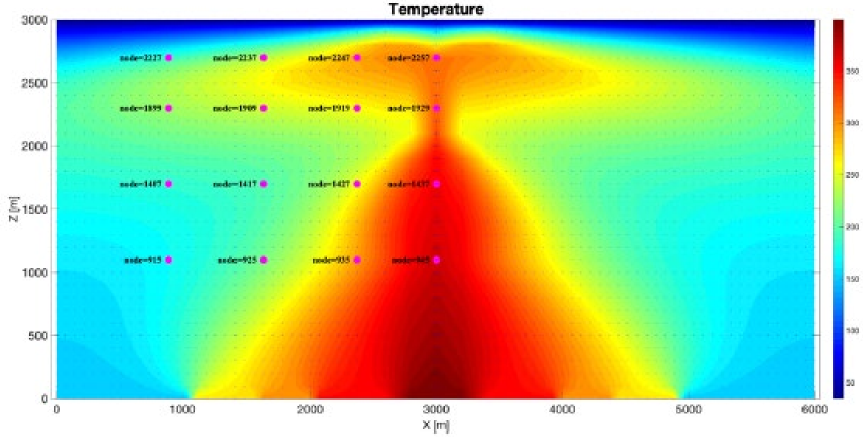
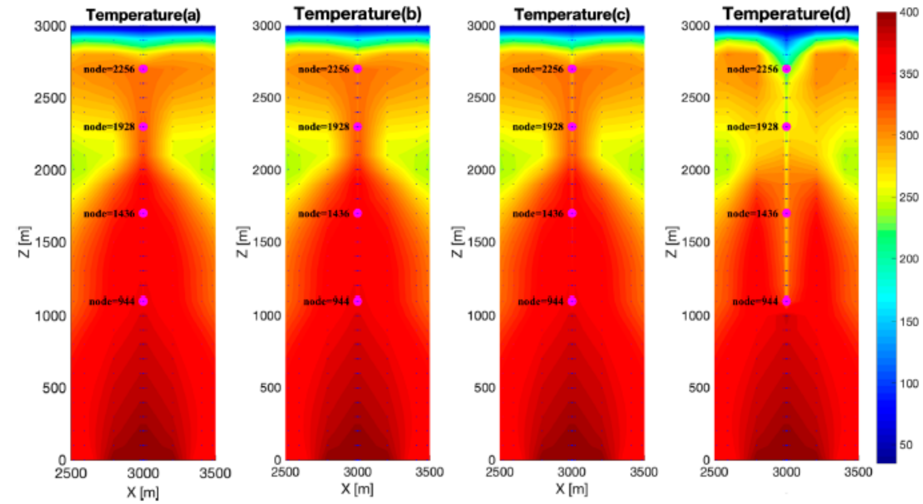
COUPLING THE DBHE AND RESERVOIR SIMULATION

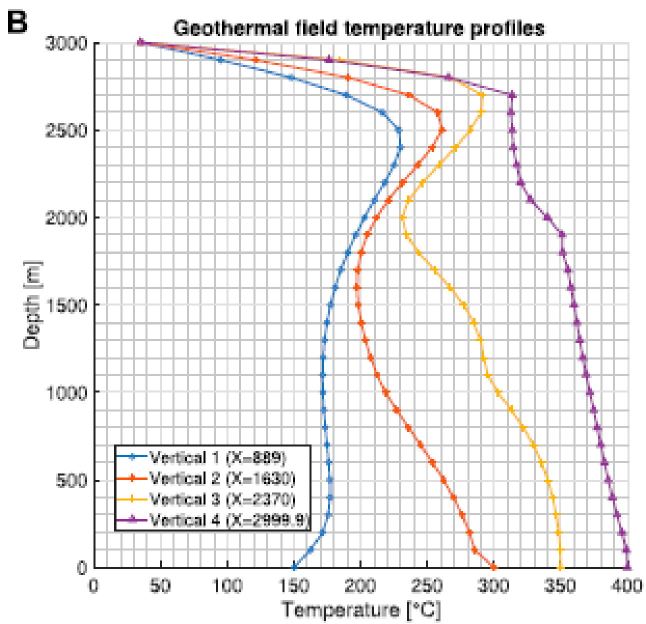
Without DBHE

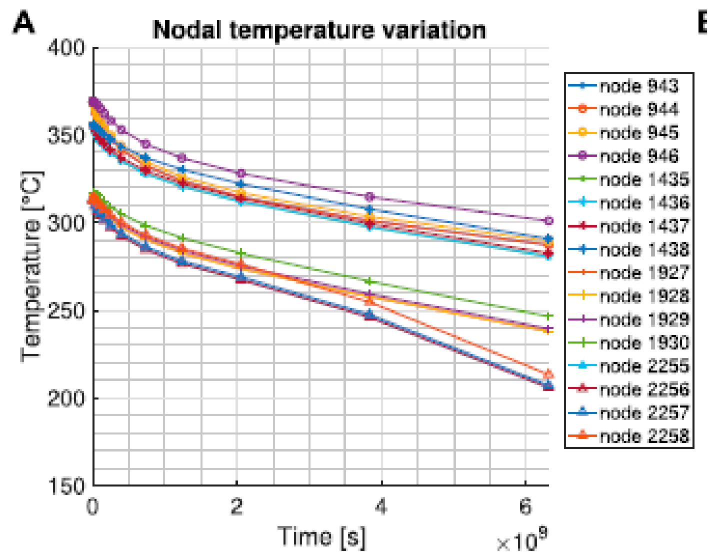


With DBHE

1y *3y* *12y* *200y*







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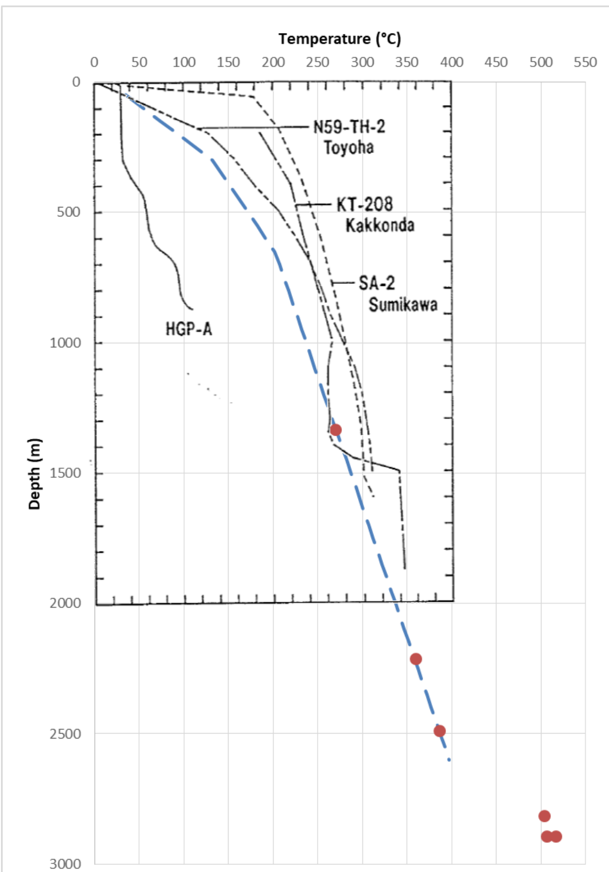
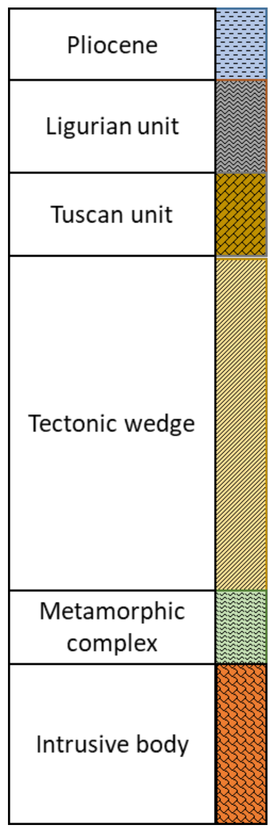
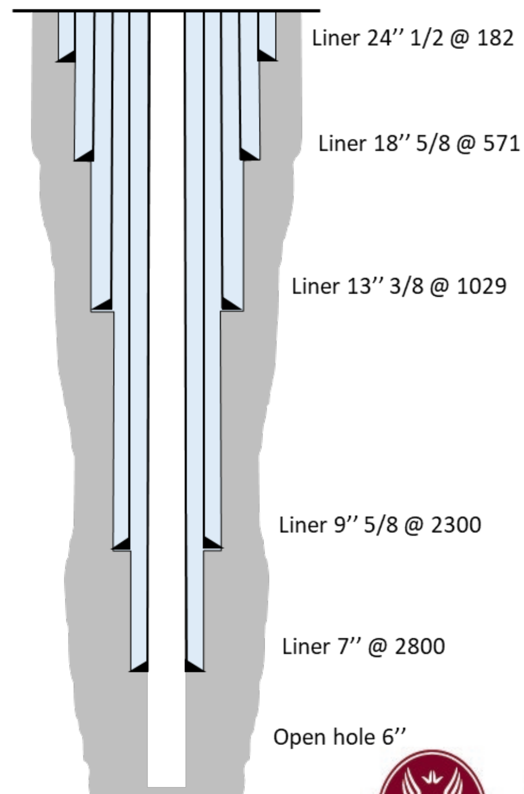
VENELLE 2 CASE STUDY
FIRST HIGHLIGHTS

The existing well VENELLE_2 in Larderello (Tuscany,Italy) was the candidate to be deepened from its previous depth of 2.2 km down to 3.0 km. The targeted fluid was supposed in high pressure and high temperature conditions (450 bar and 450 °C), much higher than those present in the exploited metamorphic basement (30-50 bar and 300°C). While drilling have been measured temperature and pressure in order to control the drilling activity and goal







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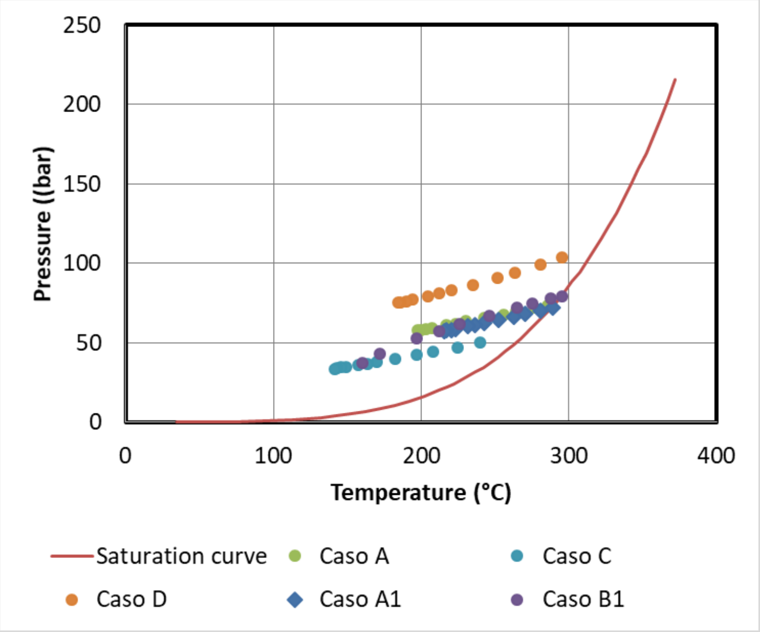
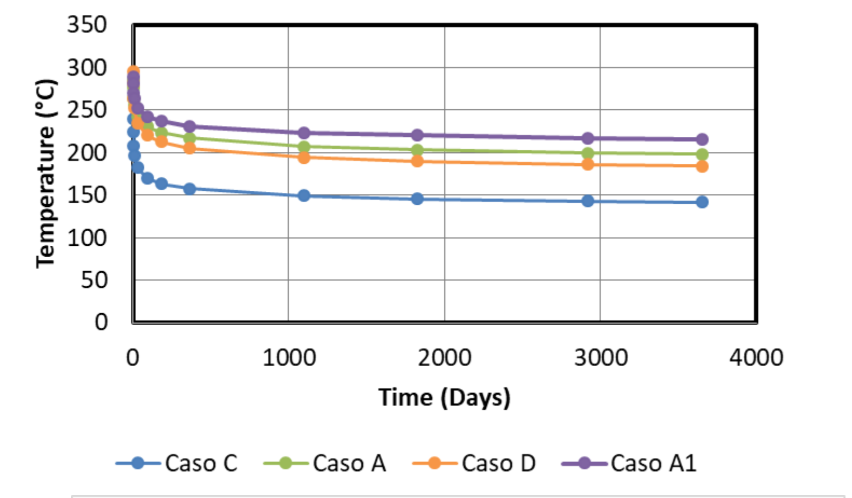
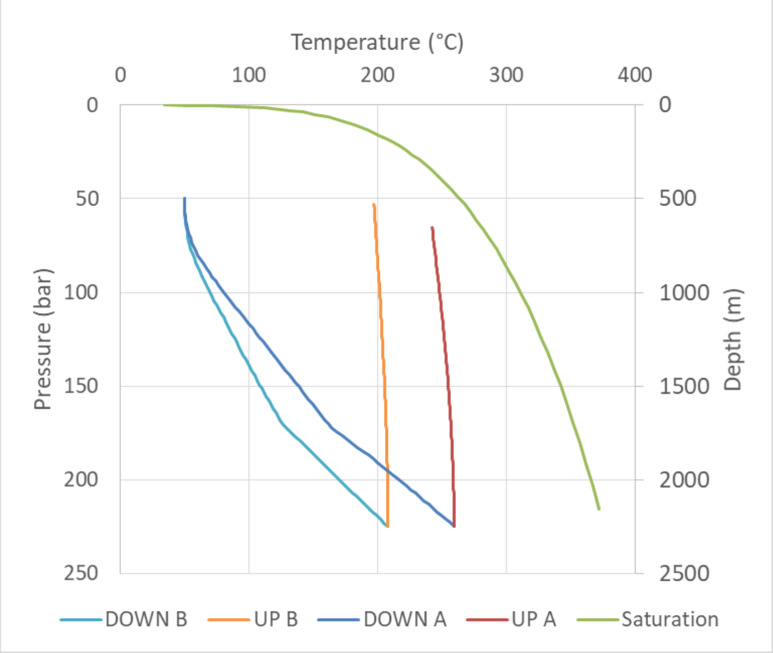
VENELLE 2 CASE STUDY
FIRST HIGHLIGHTS

- Main assumption is liquid water flow
- High pressures due to single phase flow assumption
- At low pressure flash occurs in internal pipe







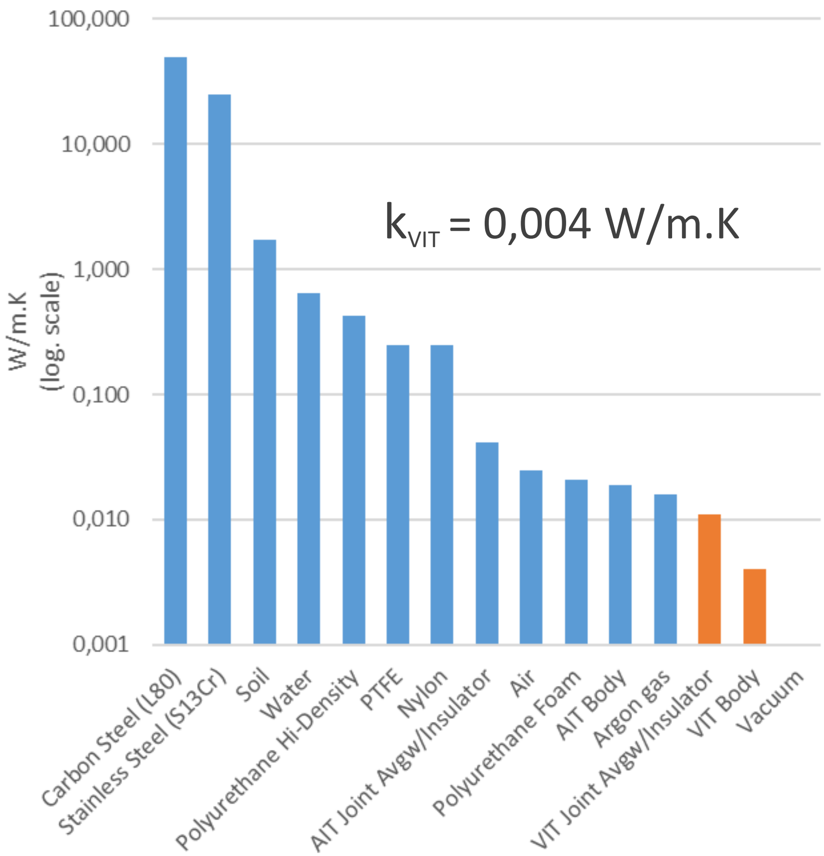
Test	Pin (bar)	Tin (°C)	Flow rate (m3/h)	Depth (m)	Thermal Power (MW)
A	50	50	5	2000	Variable
A1	100	100	5	2000	Variable
B	50	50	6	2000	Variable
C	60	50	10	2000	Variable
D	100	50	10	2500	Variable
B1	50	50	Variable	2000	1

TECHNOLOGY PILLS

A technology cross-over with the O&G industry is the **Vacuum Insulated Tubing** (VIT) developed to ensure the flow thermal segregation between upward and downward.

3 main components to limit thermal transfers

- Vacuum + Getters ⇨ limit conductive transfer
- Multi-Layered Insulation ⇨ limit radiative transfer
- Centralizers ⇨ avoid thermal bridges



Coaxial closed loop design successfully tested in the US and in Asia in the past 2 years using this technology

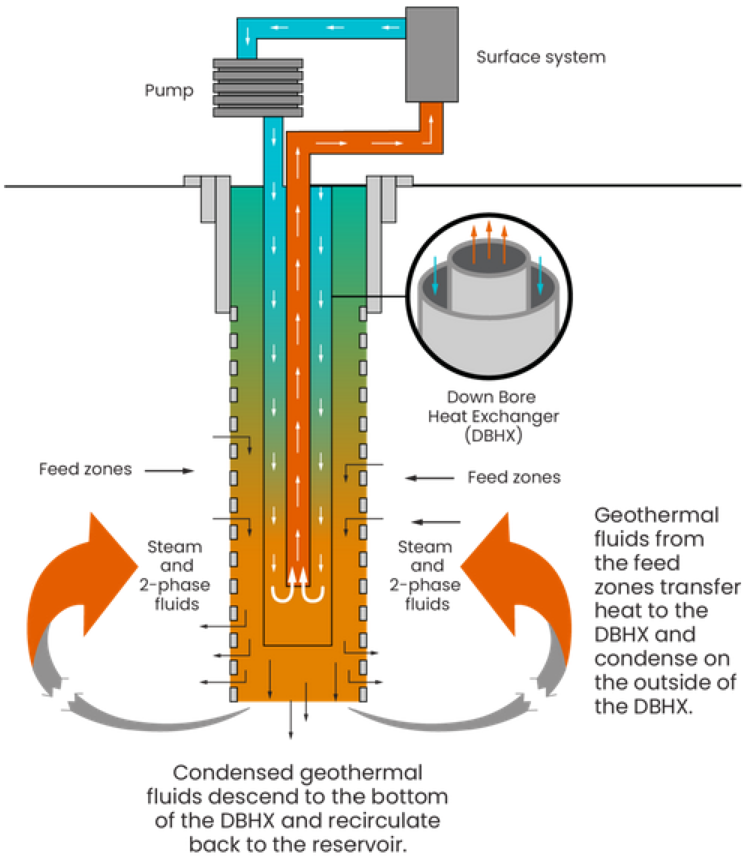
TECHNOLOGY PILLS

Steam GreenLoop Design and 2-Phase GreenLoop Design were developed for steam-dominated and 2-phase geothermal resources.

A GreenLoop Design includes the physical attributes of a closed-loop system including the depth of the well, the architecture of the pipe system, the sizes and specifications of materials, and the type of working fluid to be employed.

The concept is to insert an insulated coaxial DBHX in an existing or new well to reach the feed zones of that resource and pick up the latent heat of vaporization when the steam in the resource condenses on the DBHX.

The DBHX then brings that heat to the surface by running the working fluid inside insulated tubing. (VIT)



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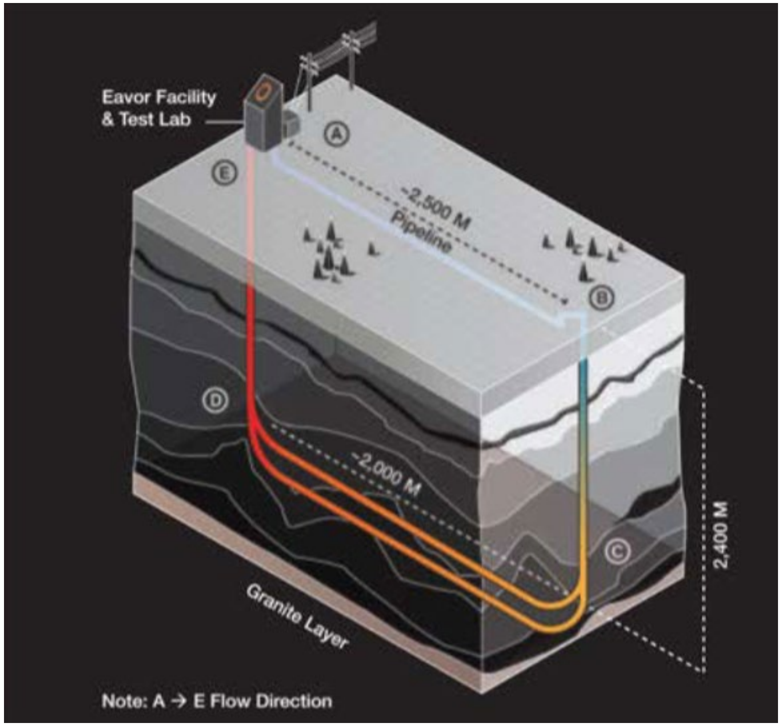
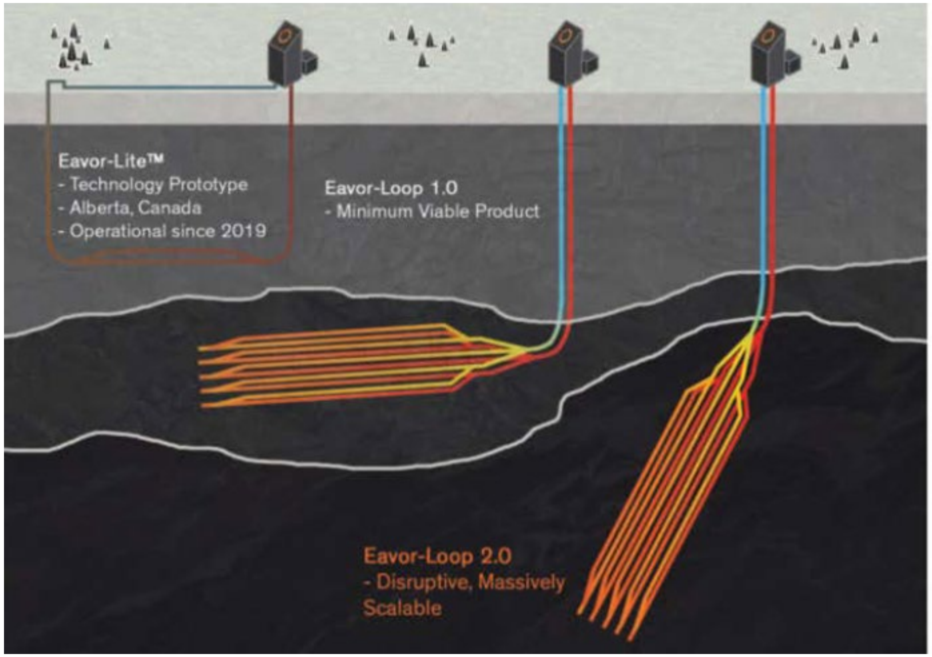
TECHNOLOGY PILLS

Closed Loop Geothermal Systems are in very early stage – R&D and pilot projects

The technology consists in the connection of two vertical wells with many horizontal multilateral wellbores creating a closed sealed radiator-like system.





Closed-loop geothermal is an encapsulated system within which a proprietary working fluid is contained and circulated to harvest heat from deep in the earth to be used for commercial heating applications (ex: greenhouses or district heating) or to be used to generate electricity using conventional heat to power engines.

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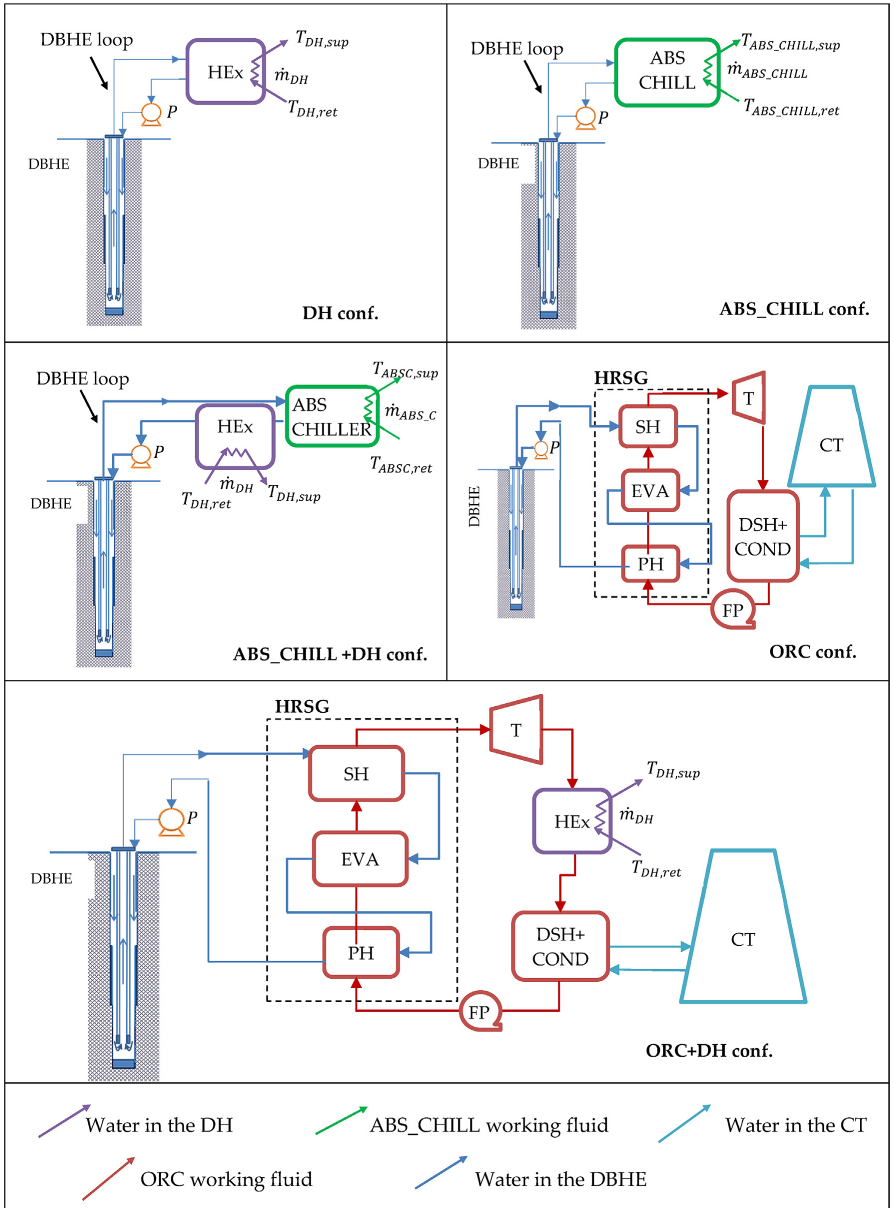
COUPLING DBHE AND APPLICATIONS



EXERGY ANALYSIS

New approach for the sector of deep borehole heat is proposed: to provide design tools that ensure the maximum exergy performance (Soldo et al. 2019, Alimonti et al., 2019, Alimonti et al. 2020, Alimonti et al., 2021).

The energy includes a part that cannot be transformed in work, whereas the exergy is the available work. It is a measure of the maximum work output that could theoretically be obtained from a system interacting with a given environment.

All system components are accounted: ground source, DBHE, ORC plant, and cooling system. Globally, we tested 225 different configurations for each of the 5 layouts. For each one of the tested configurations, the energy and the exergy balance of each component are evaluated through an in-house MATLAB® code

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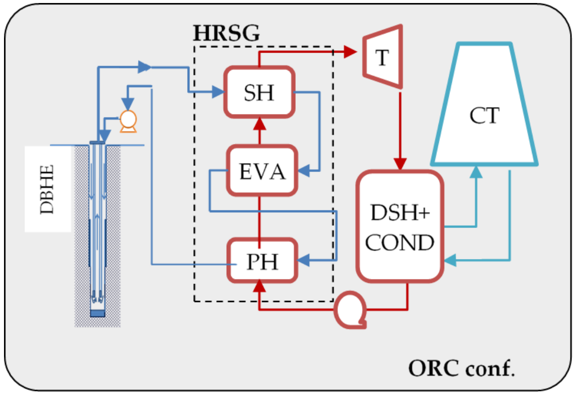
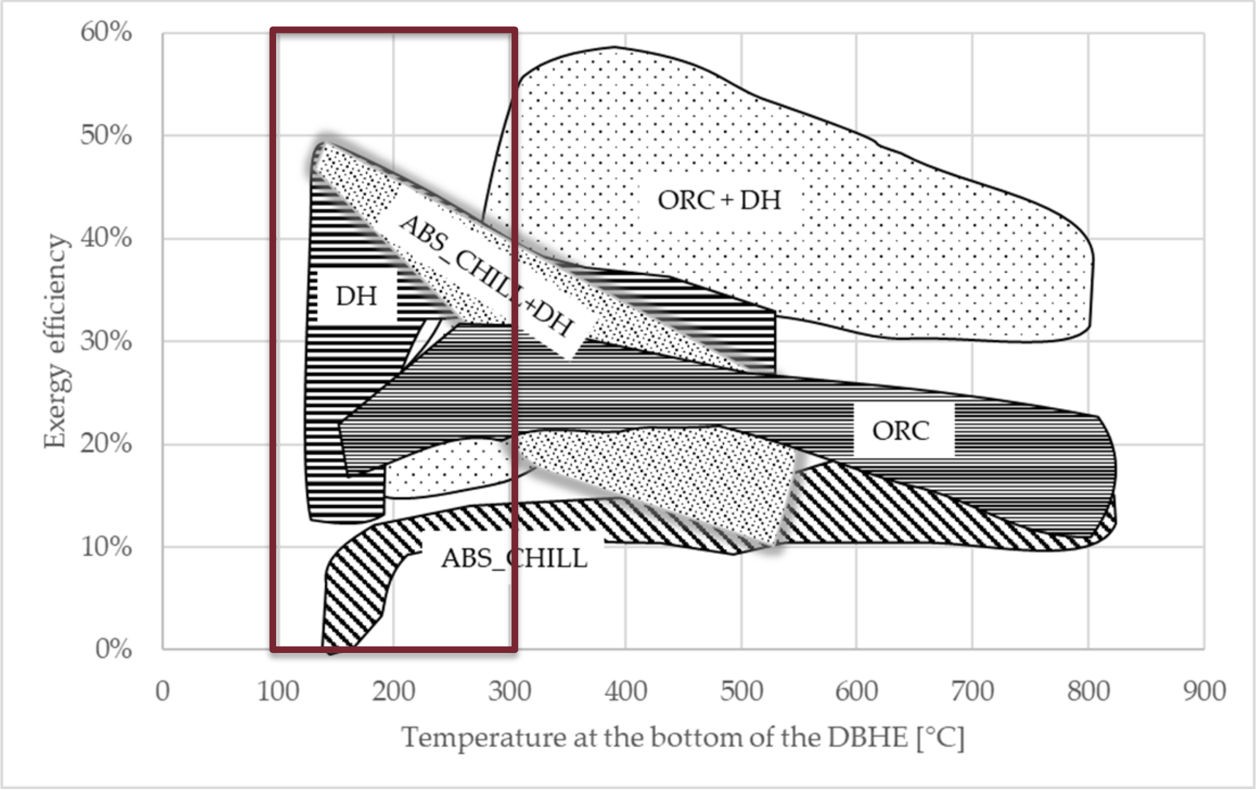
COUPLING DBHE AND EXERGY ANALYSIS





ABS_CHILL: lowest values of exergy efficiency (max about 20 %)

ORC configuration: 20 % ÷ 30 %.

DH: max exergy efficiency 40 % ÷ 50%, but η_{DH}^{II} decreases at high source temperatures.

The presence of a District Heating plant in **the cascade layouts** produces an impressive positive effect, by doubling the upper limits of exergy

HOW TO FIND A GOOD REASON TO PROCEED?

SWOT analysis

Strength	Weakness
No fluid extraction Limited energy consumption	Low efficiency Not suitable for Electrical energy
Decarb target Recovery of n.p. wells	Innovative solutions
Opportunities	Threats

THE DIRECT USE OF GEOTHERMAL RESOURCES

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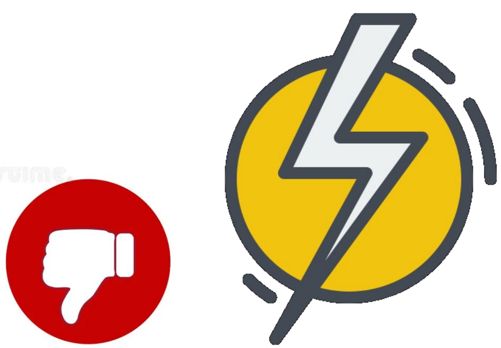
DIRECT USE

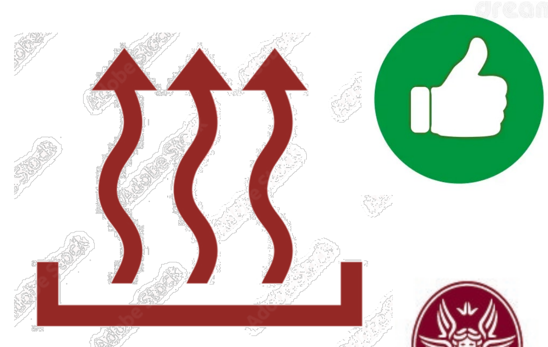
Beyond electricity, it is important to highlight that geothermal energy can contribute to reduced use of fossil fuels or electricity in some end-use sectors through the deployment of direct use applications.

The direct use of geothermal energy refers to the **non-electric utilization** of geothermal heat in residential, commercial, and industrial facilities that have an inherent need for a reliable supply of heat.

Direct use applications can also contribute to climate adaptation. For example, geothermal use in greenhouse heating, aquaculture and other agricultural practices could positively impact on **food security** and could **improve incomes**, which would help address the extreme poverty of rural communities.

Furthermore, geothermal can provide potable water through desalination or condensation of steam on the surface to address water shortages.





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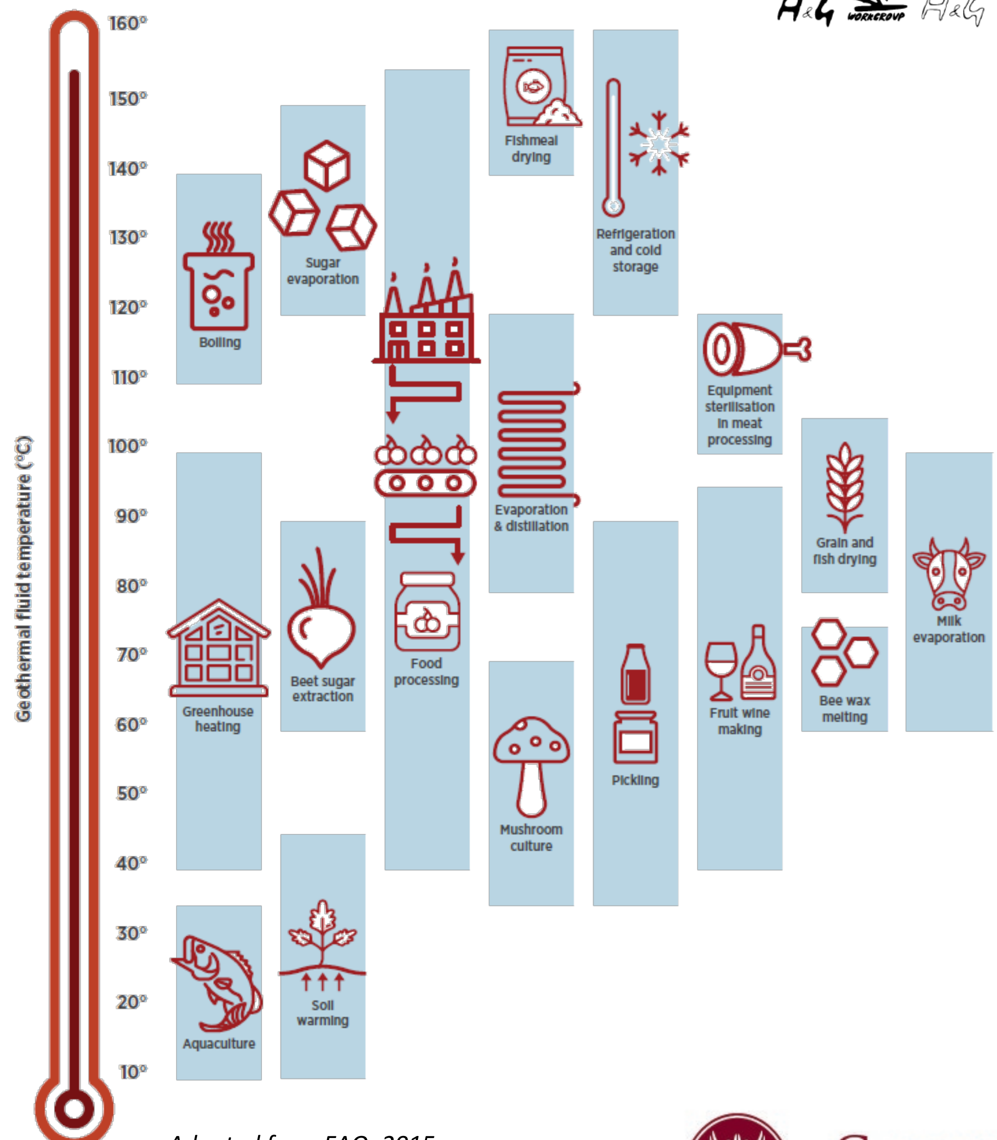
THE DIRECT USE OF GEOTHERMAL ENERGY

Most direct use applications require geothermal fluids in the **low-to-moderate temperature range** between 50 and 150 °C, and in general, the reservoir can be exploited by conventional water well drilling equipment.

Low-to-moderate temperature systems are typically much more abundant and located at shallower depths than the high temperature resources needed for power generation.

The use of the geothermal heat pumps is common in this type of applications.



Examples of direct-use applications for geothermal energy

Adapted from FAO, 2015.

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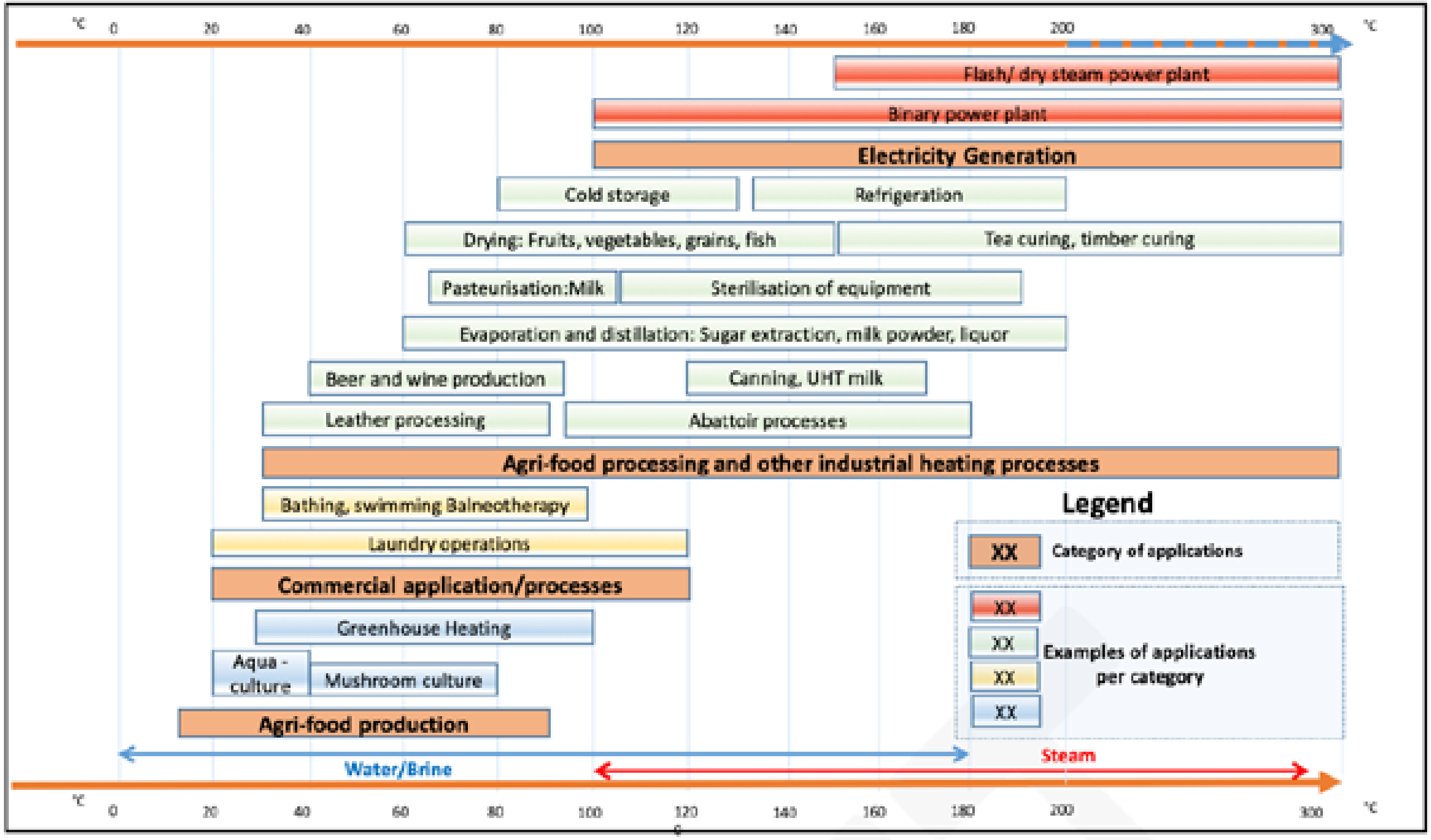
THE DIRECT USE OF GEOTHERMAL ENERGY



(modified from Lindal, 1973)

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GEOTHERMAL ENERGY PROS

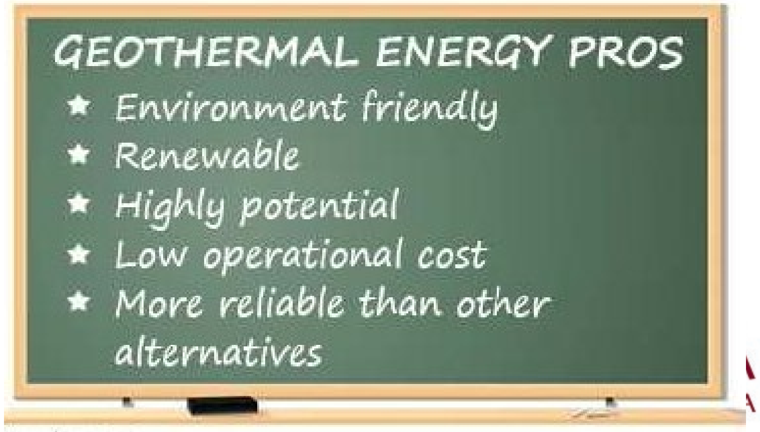
Renewable and Sustainable: Geothermal energy is a renewable and long-term energy source. It uses the internal heat of the Earth, which is constantly replenished by natural processes such as radioactive decay and residual heat from planetary formation. Geothermal energy will be available for as long as the Earth exists, making it a long-term energy solution

Low Carbon Emissions: Geothermal power plants emit very low levels of greenhouse gases, particularly in comparison to fossil fuel-based power plants. Geothermal energy produces almost no carbon dioxide emissions, which helps combat climate change and reduce air pollution.

Base Load Power: Geothermal energy is a reliable and consistent source of power. Unlike solar and wind energy, which are intermittent and dependent on weather conditions, geothermal power plants can operate 24/7, providing a stable base load of electricity. This characteristic makes geothermal energy an ideal complement to other renewable energy sources, helping to ensure a consistent power supply.

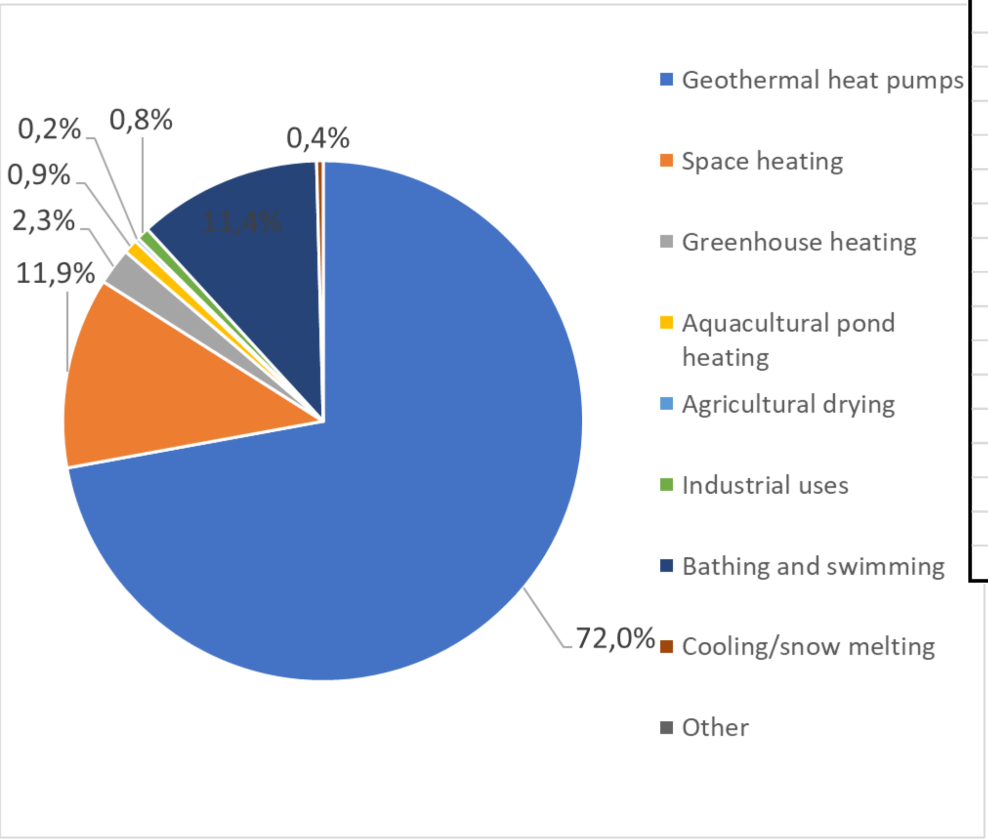
Local Economic Benefits: Geothermal projects create local jobs and stimulate economic growth in regions with geothermal resources. Developing geothermal power plants requires specialized expertise, providing employment opportunities for engineers, technicians, construction workers, and support staff. Additionally, royalties from geothermal energy production can contribute to local revenues.

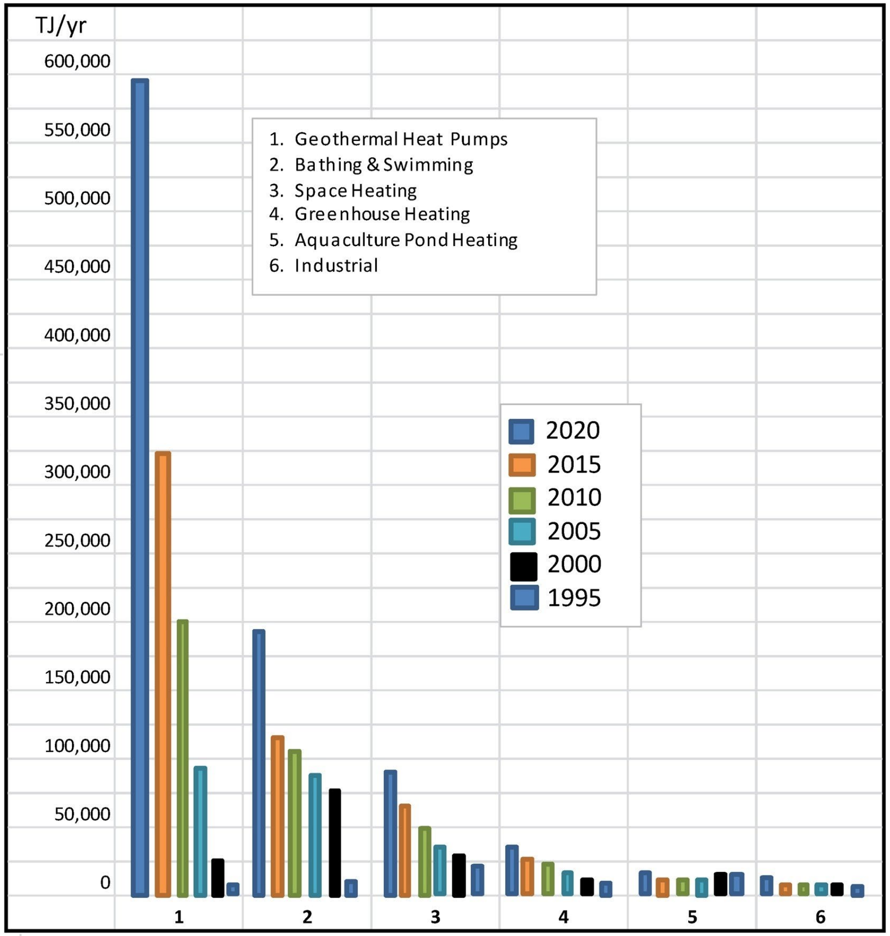
Environmental Benefits: Geothermal energy has a minimal environmental footprint. It does not require large-scale mining or drilling operations, and the land used for geothermal power plants can often be shared with other activities such as forestry or agriculture . Geothermal plants also have a small physical footprint compared to other types of power plants.



DIRECT USE: WORLDWIDE INSTALLED CAPACITY

Geothermal heat pumps is the type of plant that has increased more in the last 20 years reaching the 80% of the world-wide capacity of geothermal direct use applications





Reference: Lund and Toth "Direct Utilization of Geothermal Energy 2020 Worldwide Review". Proceedings World Geothermal Congress 2020+1 - Reykjavik, Iceland, April-October 2021

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DIRECT USES AND SUSTAINABLE DEVELOPMENT GOALS

Develop conditions that would allow local entities – city, village, county, co-operative or any kind of appropriate community-based organisation – to take the lead in developing direct use of geothermal resources.

DIRECT-USE PROJECT MODELS

Stand-alone direct-use systems

Stand-alone systems are individually developed projects that utilise geothermal heat and are not necessarily collocated with other geothermal energy utilisation projects. Stand-alone projects may access naturally occurring geothermal fluids or may require drilling of new geothermal wells.

Cascaded direct-use systems

Cascaded systems consist of two or more direct-use projects that utilise geothermal energy from the same stream of hot water or steam. The stream of hot water or steam must have adequate temperature and flow rate to meet the energy requirements of all the direct-use applications connected to it. In a cascaded system, the projects or thermal processes that require higher temperatures are located upstream, while those with lower temperature requirements are located downstream.

Integrated geothermal direct-use and electricity generation systems

In some cases, the stand-alone and the cascaded direct-use applications can be developed alongside electricity generation activities. The direct-use applications may utilise the excess energy contained in geothermal waters after electricity generation, energy from sub-commercial wells, energy from wells located at an uneconomical distance from the power plant, or excess steam and hot water that is not used for generating electricity.

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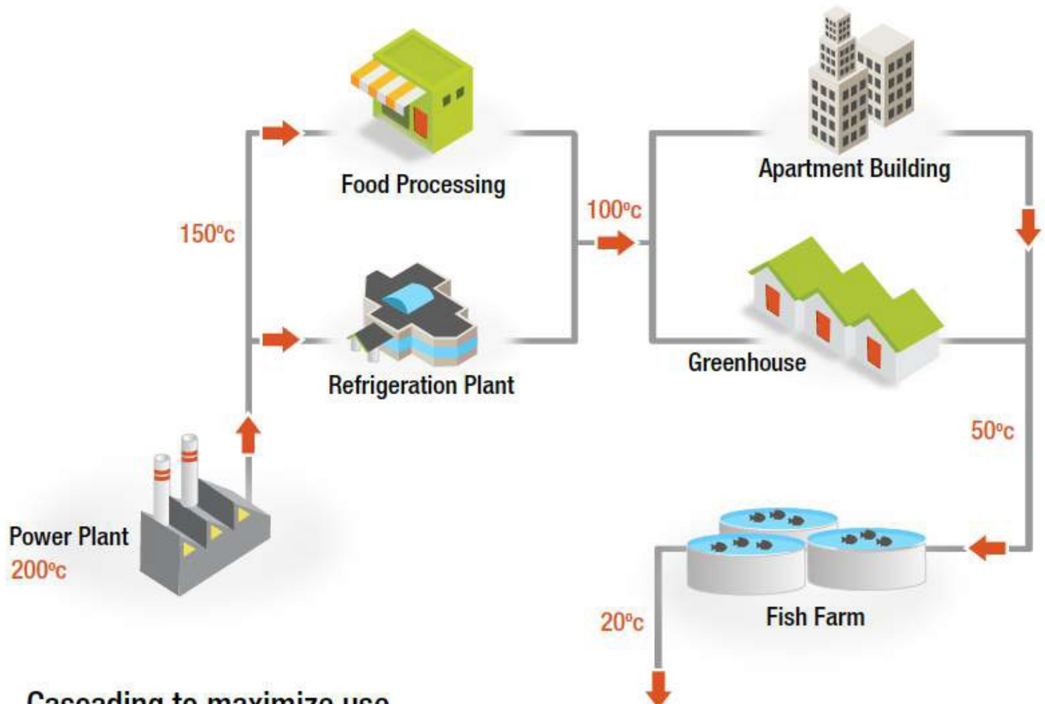
THE CASCADE SYSTEMS

This multistage utilization, where lower and lower water temperatures are used in successive steps, is called **cascading** or **waste heat utilization**.

The plants are connected in series, each utilizing the wastewater from the preceding plant (for example, electricity generation + greenhouse heating + animal farming).

Higher utilization efficiency of the geothermal resource.



Cascading to maximize use of geothermal energy

AN EXAMPLE: MONTE AMIATA, ITALY

In the geothermal area of Monte Amiata 22 ha of greenhouses are heated from geothermal wastewater from a 15 MWe power plant.

The plant uses 184 °C hot water, then cascades the wastewater at 86 °C and 2,000 tonnes/h to the greenhouses.

Both flowers and vegetables are grown by 300 employees (500 during peak periods). An adjacent drying facility employing 150 to 160 people produces 100,000 tonnes of dried vegetables annually. The markets for these products are primarily in Italy, Switzerland and Germany.

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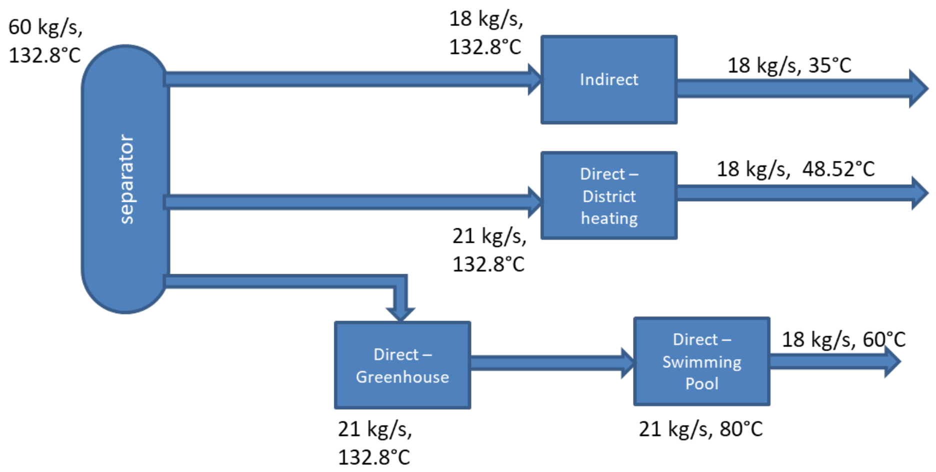
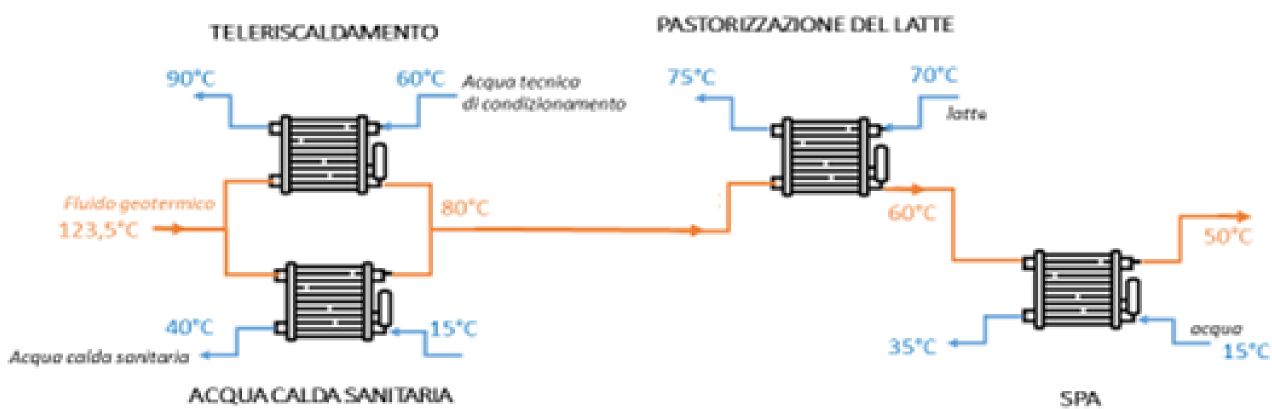
EXAMPLE FROM STUDENT PROJECTS



District heating

Milk pasteurisation

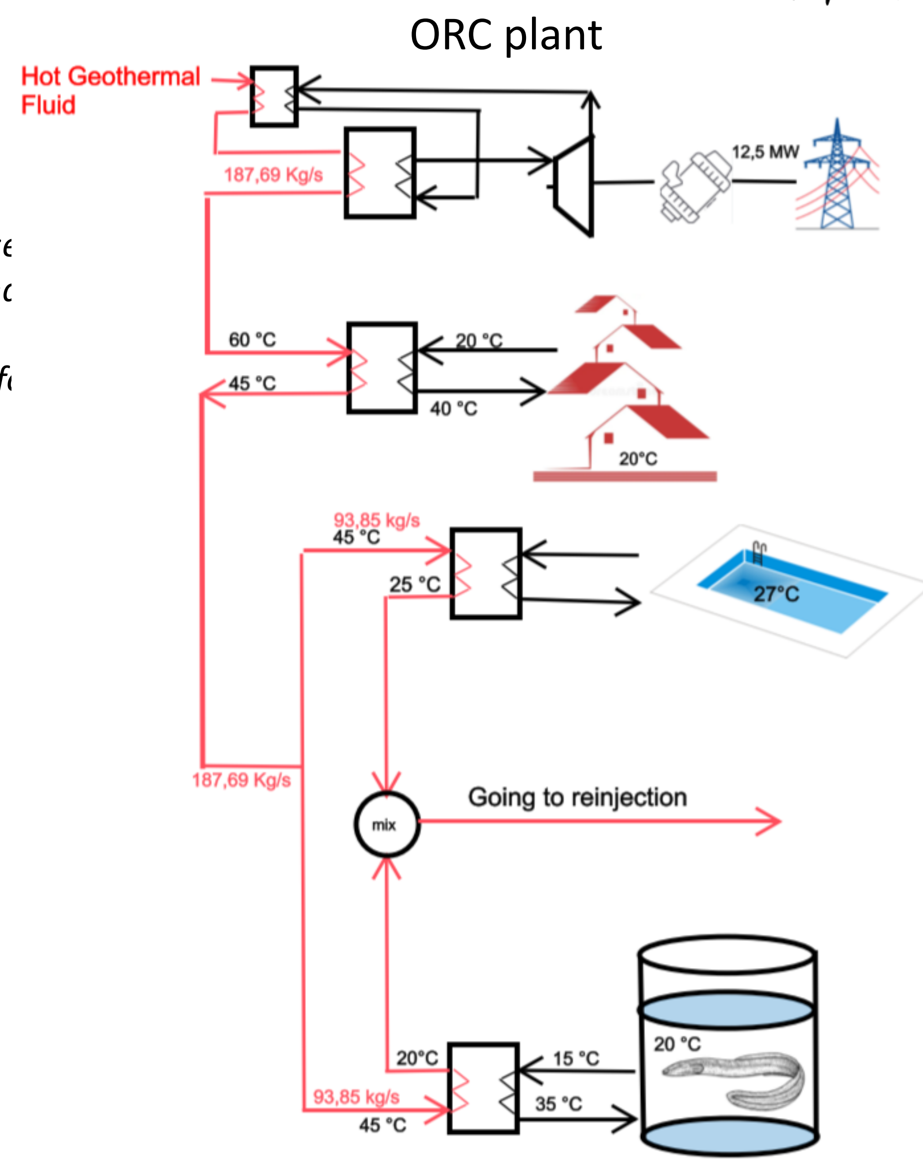


Hot sanitary water

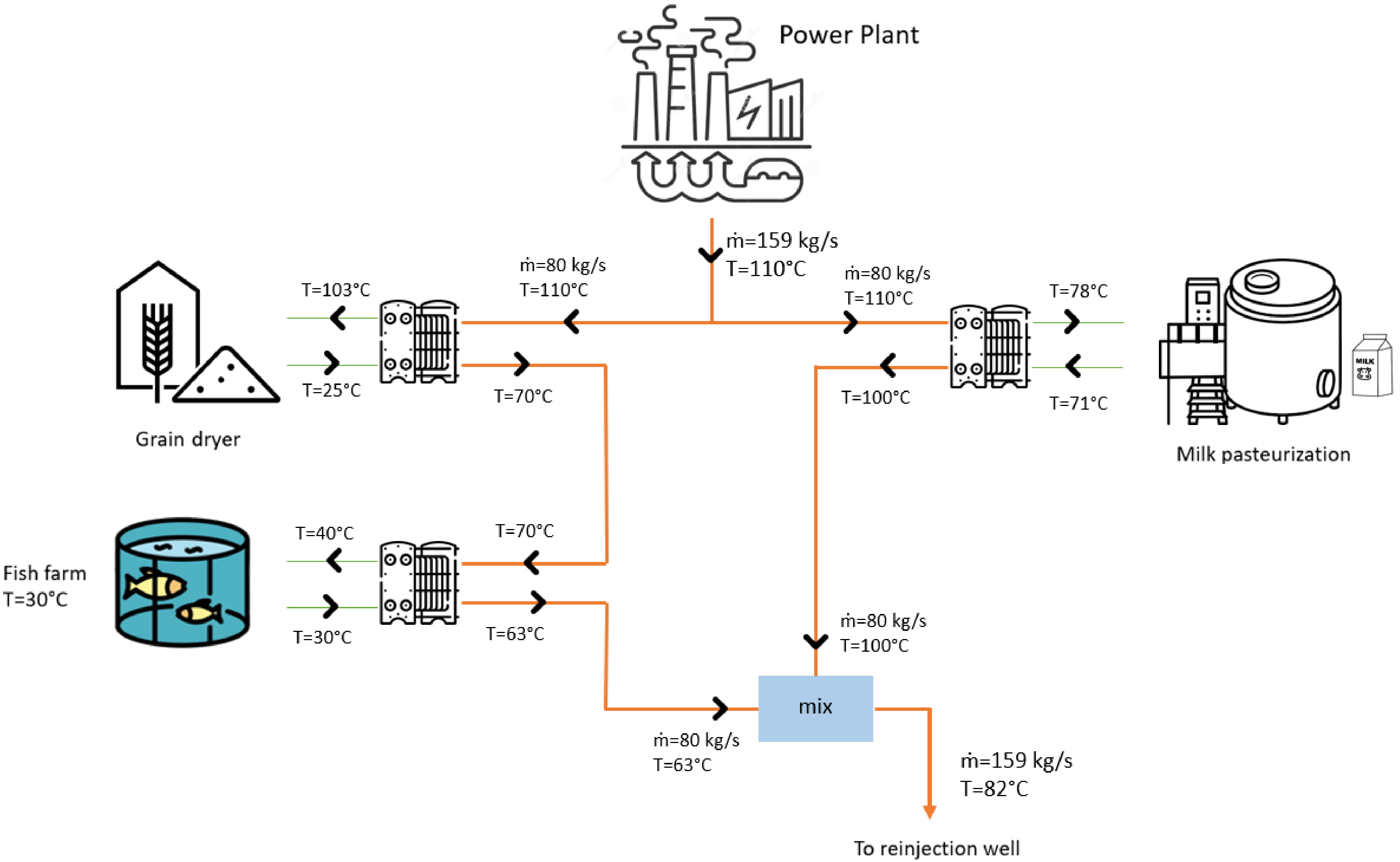
Balnealogy

EXAMPLE FROM STUDENT PROJECTS

*We have devised a cascading utilization system, where the water exiting the direct use system is fully utilized for **district heating**, and then half of the flow is used to supply a **swimming pool**, while the other half is used fo **aquaculture***



EXAMPLE FROM STUDENT PROJECTS



TYPES OF DIRECT USE OF GEOTHERMAL ENERGY

SPACE AIR CONDITIONING

Thermal load density or heat demand. **High heat density** is recommended.

Geothermal can usually meet **50%** of the load **80 to 90%** of the time, thus improving the efficiency and economics of the system. *Fossil fuel or alternatives* peaking usually applied.

Geothermal district heating systems are capital intensive. The typical **savings** to consumers range from approximately **30 to 50%** per year of the cost of natural gas.

Heating of individual rooms and buildings is achieved by passing geothermal water (or secondary fluid) through heat convectors (or emitters). The method is similar to the one used in conventional space heating systems.

Three major types of **heat convectors** are used for space heating:

1. forced convection systems
2. natural convection systems
3. radiant panels

Forced convection air systems are based on the use of a water/air heat exchanger through which the air is blown by a fan.

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SPACE AIR CONDITIONING

The supply temperatures required for a range of domestic heating distribution systems:

Distribution system	Delivery temp. °C
Under floor heating	30-45
Low temperature radiators	45-55
Conventional radiators	60-90
Air	30-50

Wet radiator system operates at 60°C to 80°C - drop in circulating temp. by 20°C ⇨ increase in emitter surface by 30% to 40%.

Air system - delivery temperature of 35°C ⇨ increase of the air change rate by up to three times to maintain the same output.

Under floor heating is the most efficient with a **GSHP** system.

Fan convectors are possible, but necessary flow temperatures of~50°C reduce the system efficiency.

SPACE COOLING IN DH PLANTS

Space cooling is a feasible option where **absorption plants** can be adapted to geothermal use. The technology is well known, and they are readily available on the market. The absorption cycle is a process that utilizes heat instead of electricity as energy source.

The refrigeration effect is obtained by utilizing two fluids: a **refrigerant**, which circulates, evaporates and condenses, and a secondary fluid or **absorbent**.

For applications *above* 0°C, the cycle uses **lithium bromide** as the absorbent and water as the refrigerant.
For applications *below* 0°C an **ammonia/water** cycle is adopted, with ammonia as the refrigerant and water as the absorbent.

Geothermal fluids provide the thermal energy to drive these machines. They may be either one- or two-stage units.

The two-stage units require higher temperatures (~160°C); but, they also have higher efficiency.
The single-stage units can be driven with hot water at temperatures as low as 77°C.

The **lower the temperature** of the geothermal water, the **higher the flow rate** required and the **lower the efficiency**.

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COOLING AND CHILLING WITH HEAT

An absorption cycle is a heat-activated thermal cycle. It exchanges only thermal energy with its surroundings; no appreciable mechanical energy is exchanged.

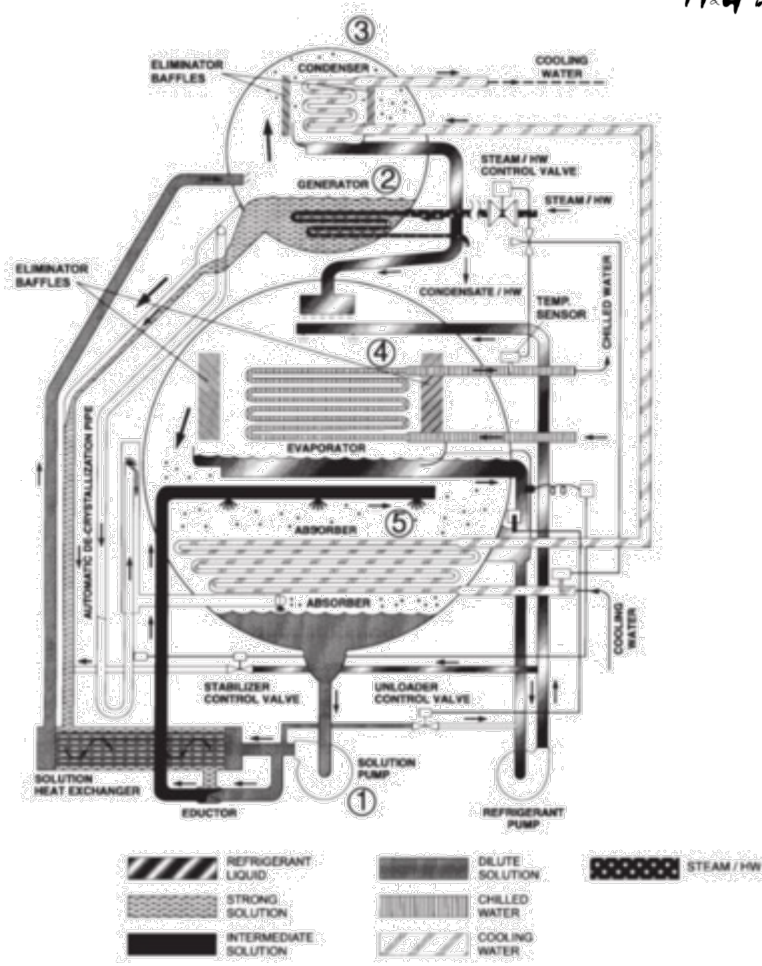
Furthermore, no appreciable conversion of heat to work or work to heat occurs in the cycle.

Absorption cycles are used in applications where one or more of the exchanges of heat with the surroundings is the useful product.

The two great advantages of this type of cycle in comparison to other cycles with similar product are:

No large, rotating mechanical equipment is required

Any source of heat can be used, including low-temperature sources



AGRIBUSINESS & INDUSTRIAL APPLICATIONS

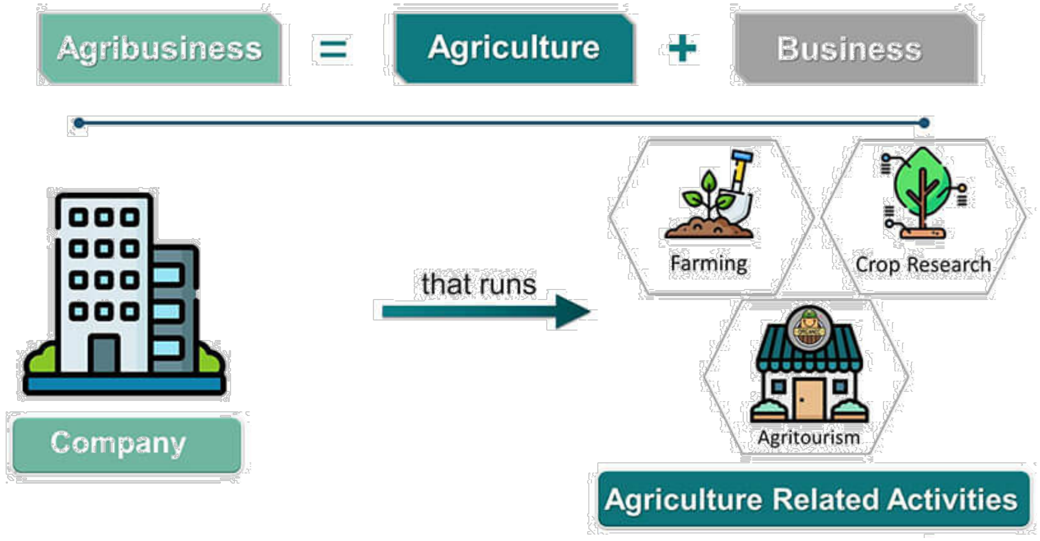
AGRIBUSINESS APPLICATIONS

Agribusiness applications (**agriculture** and **aquaculture**) are particularly attractive.

A number of agribusiness applications are considered:

- greenhouse heating,
- aquaculture and animal husbandry facilities heating,
- soil warming and irrigation,
- mushroom culture heating and cooling, and
- bio-gas generation.

The *agricultural applications* of geothermal fluids consist of open-field agriculture and greenhouse heating. Thermal water can be used in open-field agriculture to *irrigate* and/or **heat** the soil.



THE PRAWN PARK AT WAIRAKEI GEOTHERMAL FIELD

Near the Wairakei geothermal field in New Zealand, 400 tonnes of Giant Malaysian Freshwater Prawns per year are produced.

Originally, the management plan called for exporting the prawns; however, a restaurant was established on site, and now most of the harvest is consumed there.

It also became a **tourist attraction**, where visitors can fish the prawns for their own meal.

MICROALGAE CULTIVATION

Microalgae cultivation is based upon the logic of the photosynthetic process: solar energy is used for the synthesis of organic compounds out of non-organic substances.

Different methods of algal production technology optimization by geothermal energy consist of:

- use of geothermal CO_2 and energy for optimizing photosynthesis.
- use of geothermal water for nutrition algal media preparation.
- use of geothermal energy for algal biomass drying

THE SPIRULINA ALGAE

The project in Chiusdino (Italy) is a successful experimentation demonstrating the winning combination between geothermal and spirulina algae, a micro-algae with multiple industrial and food potentials – soon to be included in the menu of the NASA astronauts.

The microalgae produce about half of the atmospheric oxygen that we breathe, they represent a food source rich in protein (in spirulina they are 66%, when they average 43% in meat), they can also be grown in salt water and do not need pesticides; moreover 2 kg of CO_2 are fixed for every kg of biomass produced . All elements that make spirulina a formidable ally in the fight against climate change, and in a world where mouths to feed continue to increase.

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ALGAE PRODUCTION IN PHOTOBIOREACTORS

Innovations are ongoing in different countries to enhance the growth of algae using geothermal energy. The heat from geothermal provides a conducive environment for the optimal growth of the algae, while geothermal CO_2 is used to enhance photosynthesis, resulting in a negative carbon footprint.

Furthermore, growth of algae in these conditions results in low freshwater consumption and low land usage in comparison to conventional production methods. The algae so produced is used for animal and fish feeds, extraction of high-value micro-nutrients and manufacture of cosmetics.

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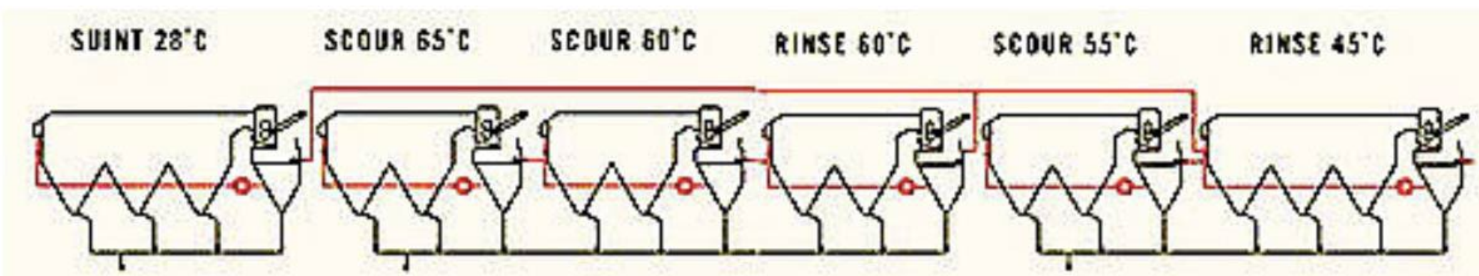
WOOL PROCESSING CYCLE

Treatment proposal

The outgoing flow rate from the District Heating plant is divided into 2 and sent to two industrial plants to clean merino wool; so, the flow rate that feeds each plant is equal to 31.05 kg/s.

The wool treatment plant is made up of 6 bowls at different temperatures, we have designed a system with 5 heat exchangers:



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INDUSTRIAL APPLICATIONS OF GEOTHERMAL ENERGY

The oldest industrial use is at Larderello, Italy, where boric acid and other borate compounds have been extracted from geothermal brines since XIX century.

There are various potential applications in the industrial sector especially in the hot processes like:

- Evaporation – salt extraction
- Drying
- Distillation – liquor and hydrocarbon industry
- Sterilization
- Washing-food industry
- De-freezing – de-icing
- Chemical extraction
- Refrigeration-absorption freezing
- Milk pasteurization
- Process heating–preheating of boiler water
- Wood drying

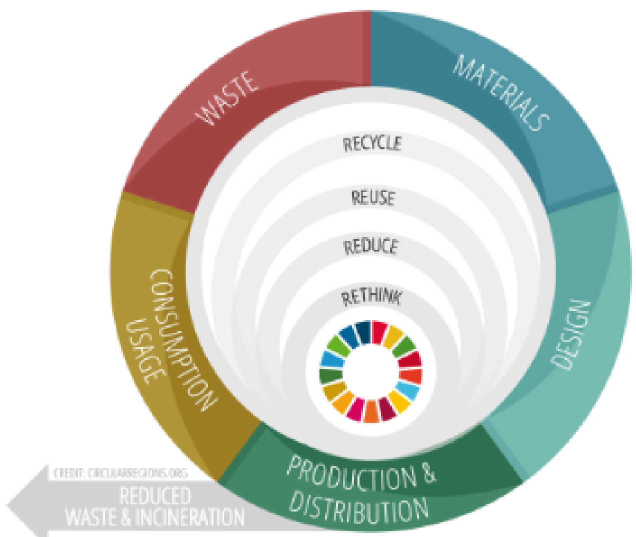
WASTES AND BIOMETHANE

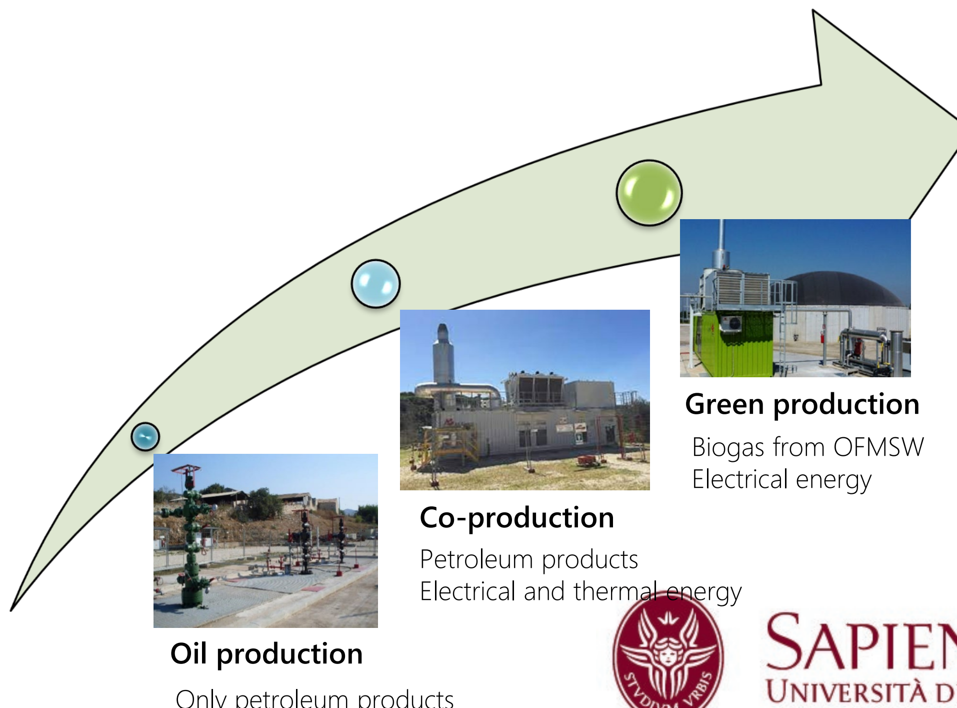
GEOTHERMAL AND CIRCULAR ECONOMY

The evolution of the **Irminio** field from a fossil energy to a green energy producer based on the **OFMSW** and **geothermal** energy

MAIN TARGETS

- **Reuse** existing infrastructures
- Maintain and improve up to 100% the **cogenerator** production
- Link the infrastructure to the territory virtuous cycles (**MSW**)





EXISTING PLANT: CO-PRODUCTION STEP

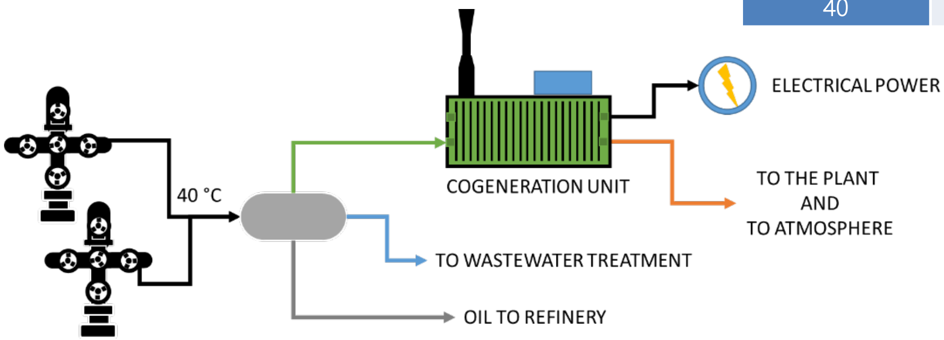
Cogeneration unit

Thermal energy: 765 kW

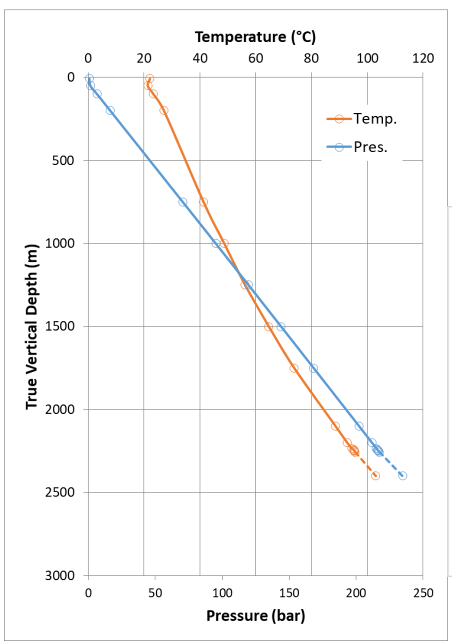
Load [%]	Electrical Power [kWe]	Gas Consumption [Nm^3/h]
100	981	239
75	846	208
50	560	158
40	392	138

Irminio depleted well operating condition

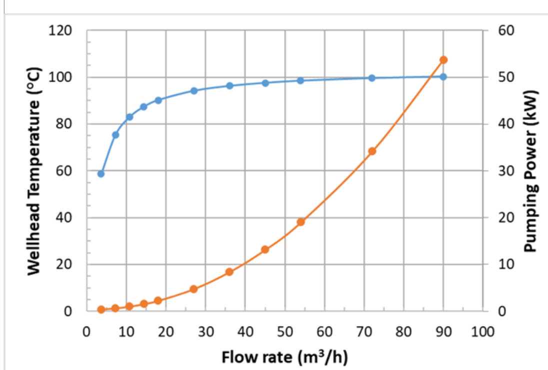
- Bottomhole temperature 95.6 °C @2255m TVD
- Open hole 2279-2400 m
- Flowing data: 40 °C @ 122 m^3/d



WELL SURVEY



WELL FLOW SIMULATION



- **Self-consumption** accounts for **40%** of the electricity produced by the cogenerator, while the remainder is fed into the grid and sold.
  About **35%** of **thermal energy** recovered in cogeneration is used to maintain the plant at the temperature required by the processes. The surplus heat is currently not exploited, and it is dissipated into the atmosphere.
  The cogenerator is working only at 40% of its maximum load

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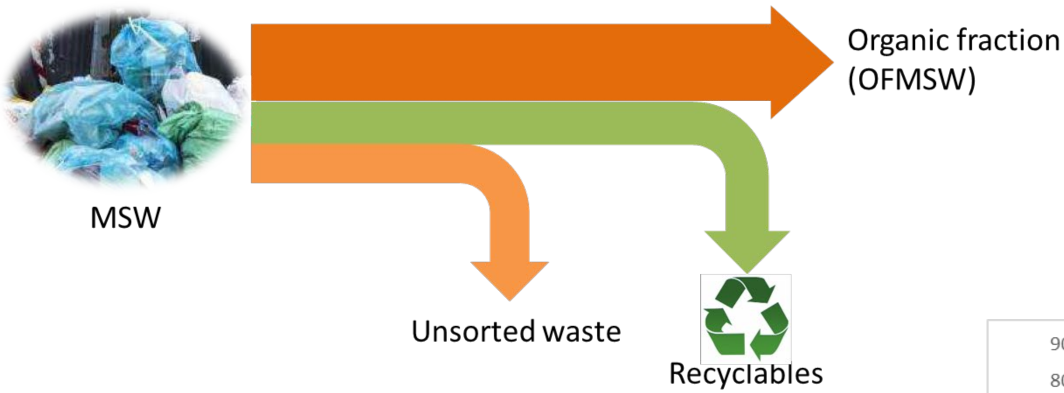
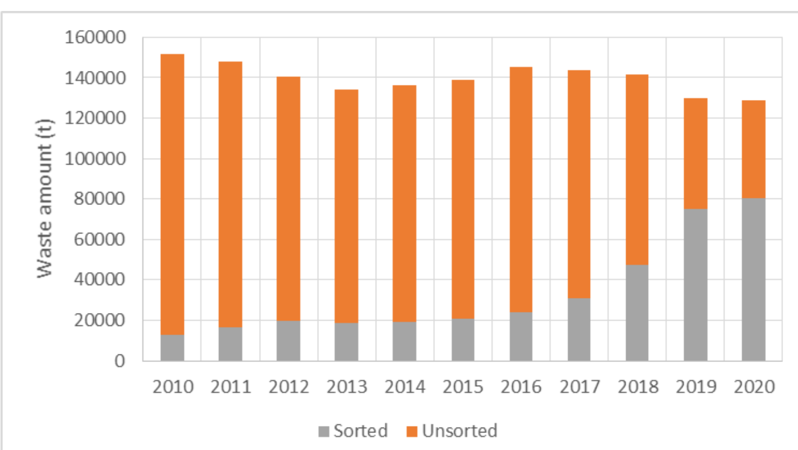
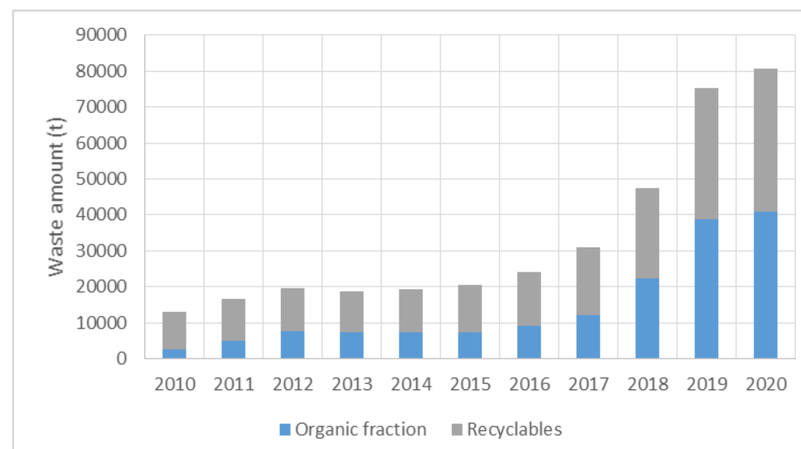
MUNICIPAL SOLID WASTE – RAGUSA PROVINCE

Organic Fraction **grows** from 5 to 30% of MSW and up to 50% of differentiated waste collection in last 3-4 years





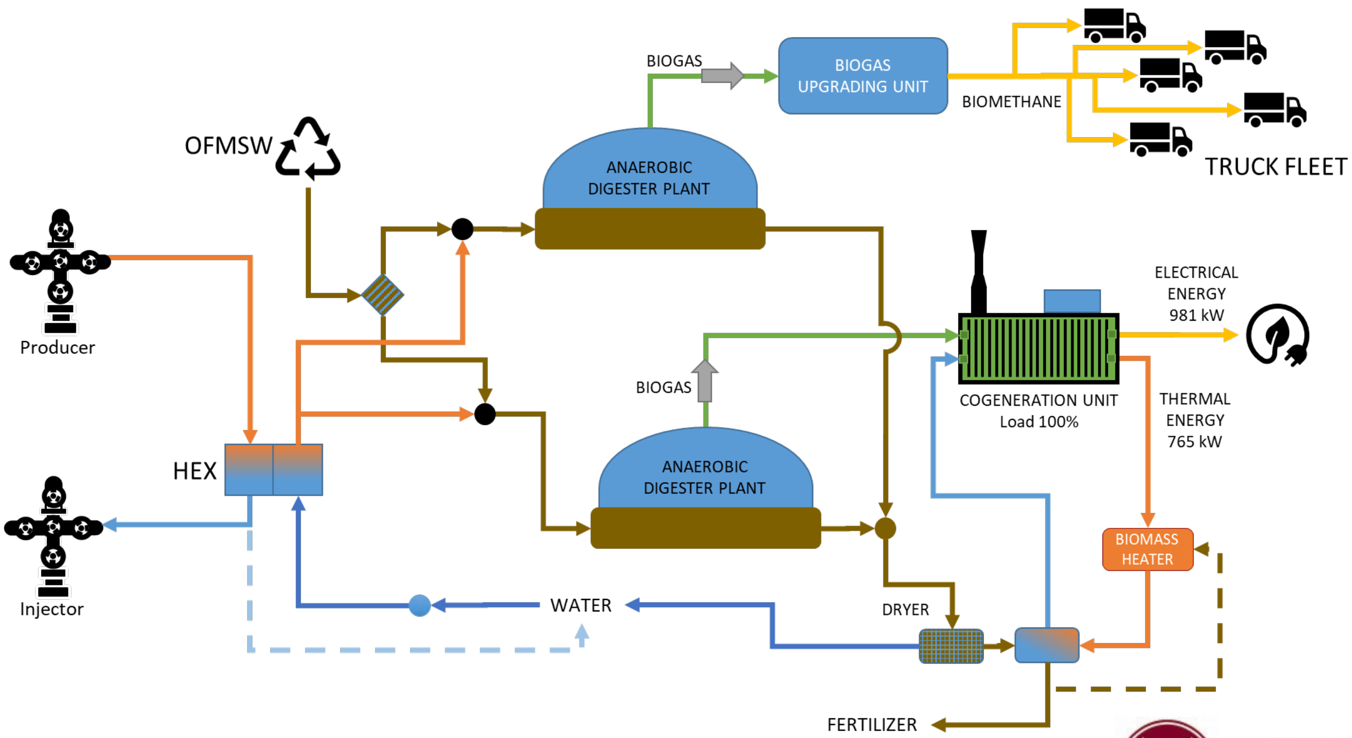


Data from ISPRA National Section Waste Cadastre

TOWARD THE GREEN PRODUCTION SCENARIO

TARGETS of the project:

- Co-Generator working at **full load**
- **Less impact** on existing well, no workover required (*possible co-production*)
- **Maximum recovery** of the OFMSW in Ragusa province
- **Reuse** of the digestate as biomass as well as fertilizer
- Anaerobic Digester with a semi-dry **mesophilic** process (T=30 °C)
- Improvements of **water cycle**, controlling stress on the local water resources



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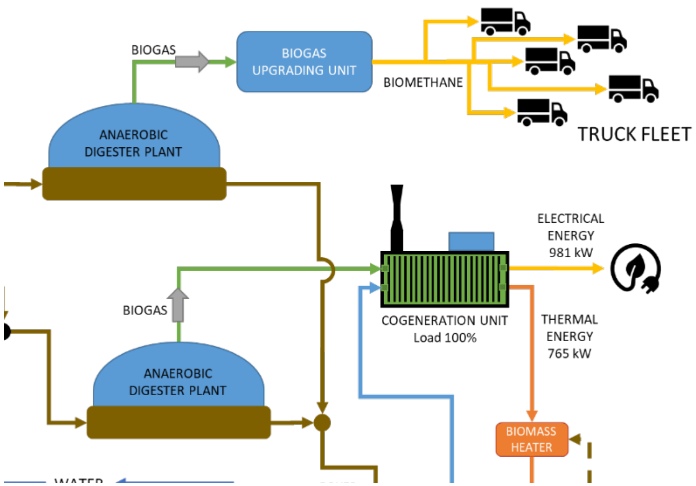
CAPABILITY OF THE PLANT



Sizing of AD reactor and main parameter obtained

	Mesophilic	Thermophilic
Digester volume (m³)	1456 (3x21.8) x 2	1165 (3x19.5) x 2
Biogas (m³/h)	596	556
OFMSW (t/y)	35000	
Water supply (kg/d)	112180	112200
Digestate mass (kg/d)	207195	208350
Thermal energy (kWh/d)	4788	9953
Flow rate (m³/d)	210	312
Pump power (kW)	0.77	1.29
Wellhead Temperature (°C)	79.6	87.4

Sizing of the second AD reactor and main parameter in the two stages approach

First reactor process	Mesophilic		Thermophilic	
Second reactor process	Mesophilic	Thermophilic	Mesophilic	Thermophilic
Digester volume (m³)	1402 (3x23.9)	1403 (3x21.4)	1663 (3x23.3)	1338 (3x20.9)
Biogas (m³/h)	358	334	341	318
OFMSW (t/y)	21000		20000	
Water supply (kg/d)	67308	67308	64102	64102
Digestate mass (kg/d)	124317	125004	119051	119051

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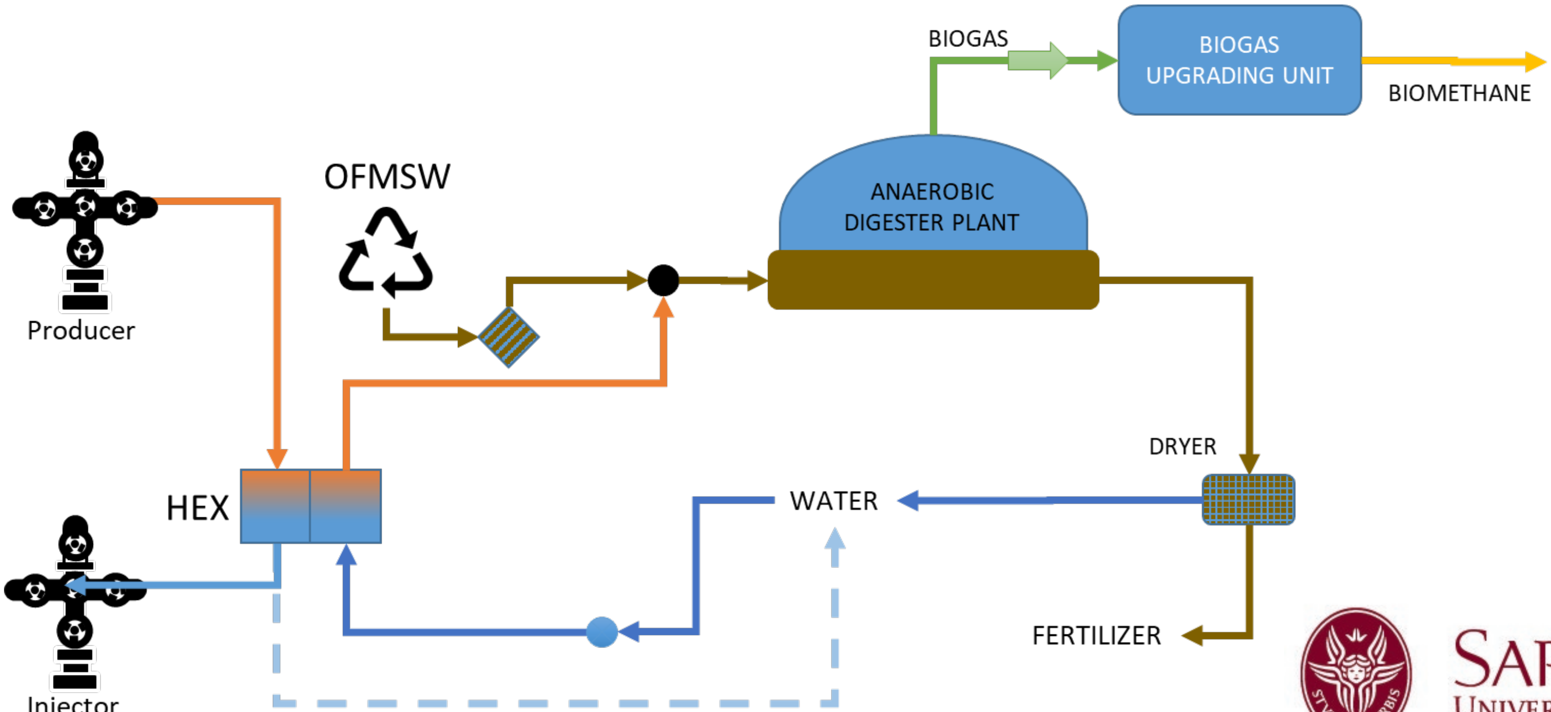
BIOMETHANE & GEOTHERMAL

Using the results obtained from the Irminio case study, the heat required to produce **one cubic metre of biomethane** in the mesophilic process is **0.56 kWh/m³**. Assuming the flow rate through a conventional production tubing is equal to 5 l/s and considering a temperature difference through the heat exchanger of 20 °C, the harnessed heat is about **10,000 kWh/d per well**. The number of available productive and potentially productive wells on the Italian territory is 846.

In conclusion, the amount of biomethane produced with the proposed approach would be in the **3-6 billions of m³/y** range, considering only the productive well or the potentially productive ones.



Thank You