ENEL research activities on low enthalpy geothermal resources

GeoThermExpo 2009

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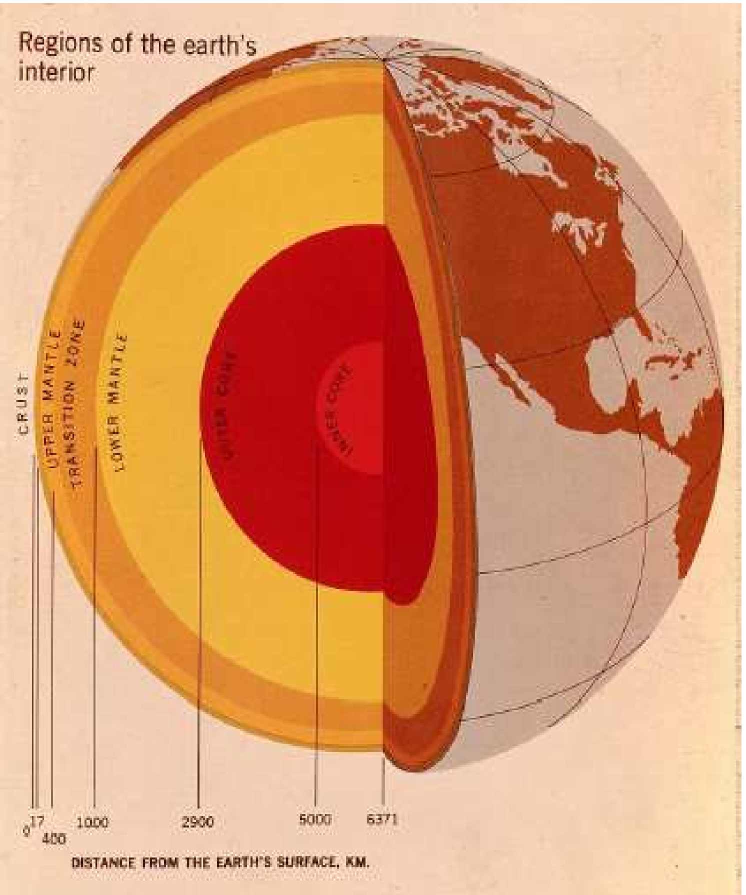
Geothermal energy: a big potential



- **Hydrothermal systems** – situated at a slight depth within the earth's surface.

  dry steam systems – steam is the continuous phase which controls the reservoir pressure.

  water dominant systems - water is the continuous phase and controls the reservoir pressure.

  hot water reservoirs - water reservoirs with temperature ranging from 30°C to 85°C.

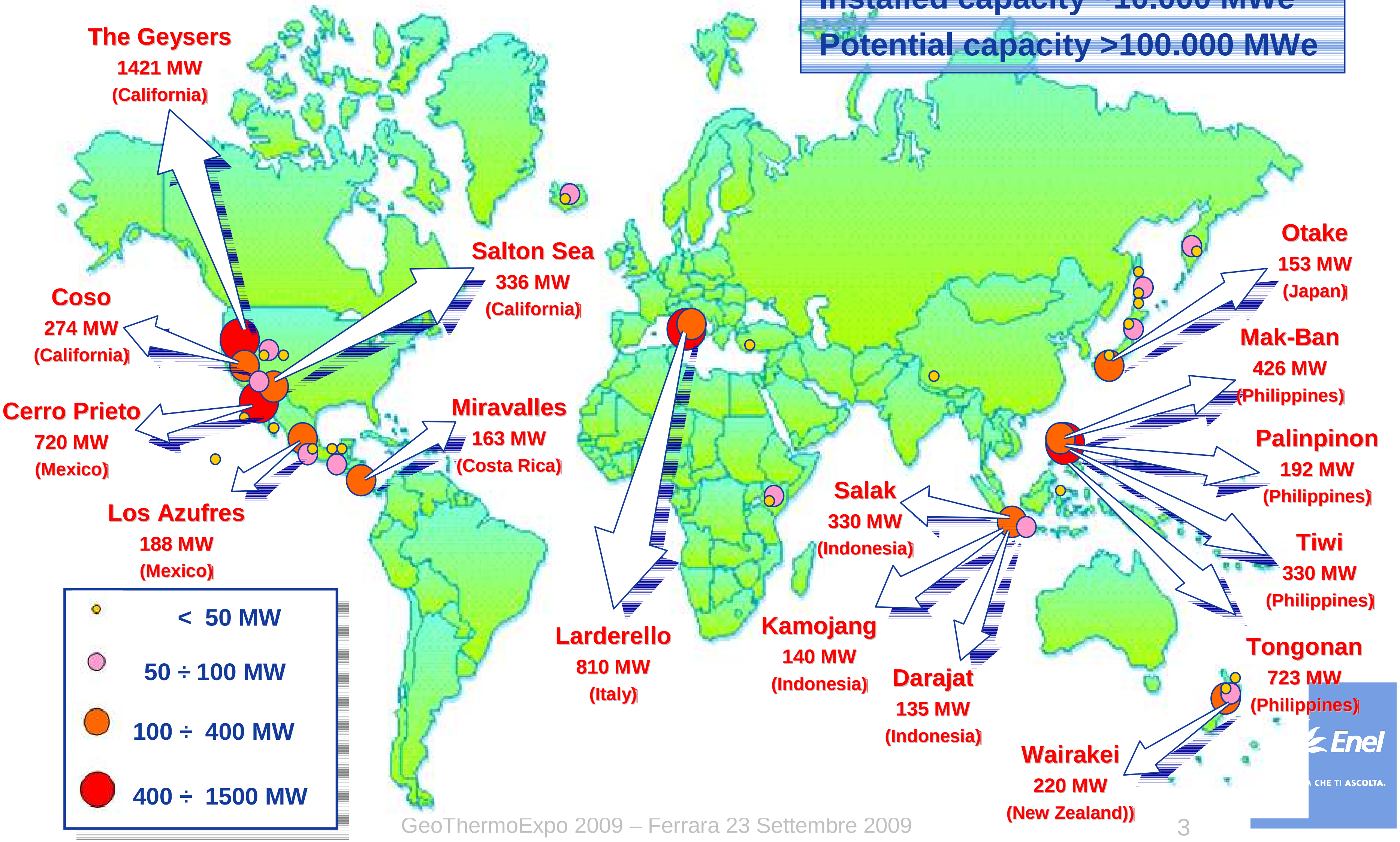
  wet steam reservoirs – this kind of reservoir erogates water, or a mixture of water and steam, and gases characterized by high temperature (100÷370°C) and pressure.
- **Hot dry rocks** – rocky masses situated at a considerable depth beneath the earth's crust and characterized by high temperature and total absence of circulation fluids.
- **Geo-pressurized reservoirs** – made up of water characterized by high temperature (200°C) and a level of pressure near to the litostatic one (depths>4000m).
- **Magmatic systems** – magma bodies relatively close to the earth's surface.

With wind and solar energy we look at the sky, but there is a lot of energy under our feet. *(J. Tester, MIT)*

Main geothermal fields worldwide

Installed capacity ~10.000 MWe

Potential capacity >100.000 MWe



The Geysers
1421 MW
(California)

Coso
274 MW
(California)

Cerro Prieto
720 MW
(Mexico)

Los Azufres
188 MW
(Mexico)

Salton Sea
336 MW
(California)

Miravalles
163 MW
(Costa Rica)

Larderello
810 MW
(Italy)

Salak
330 MW
(Indonesia)

Kamojang
140 MW
(Indonesia)

Darajat
135 MW
(Indonesia)

Otake
153 MW
(Japan)

Mak-Ban
426 MW
(Philippines)

Palinpinon
192 MW
(Philippines)

Tiwi
330 MW
(Philippines)

Tongonan
723 MW
(Philippines)

Wairakei
220 MW
(New Zealand)

● < 50 MW

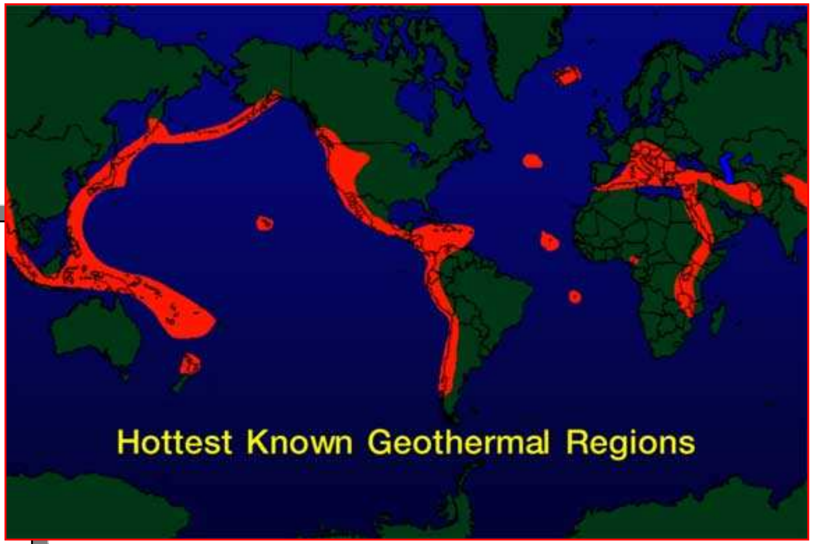
● 50 ÷ 100 MW

● 100 ÷ 400 MW

● 400 ÷ 1500 MW

Low enthalpy geothermal resources

High temperature geothermal resources naturally occur in geologically active areas



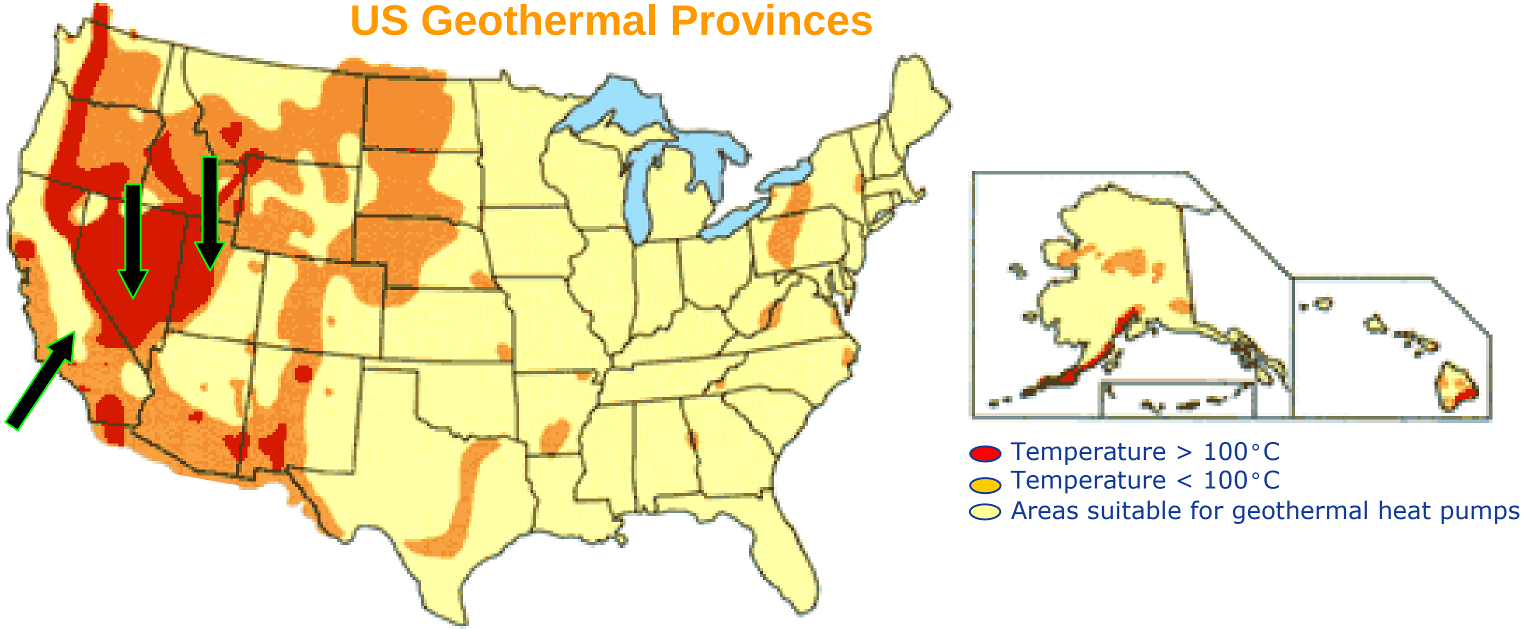
Medium/low temperature hydrothermal reservoirs are abundantly available and have by far the biggest electricity generation potential throughout Europe and worldwide

ORC technology represents best way to put into a productive way low-enthalpy geothermal resources

ENEL's interest in low enthalpy geothermal resources

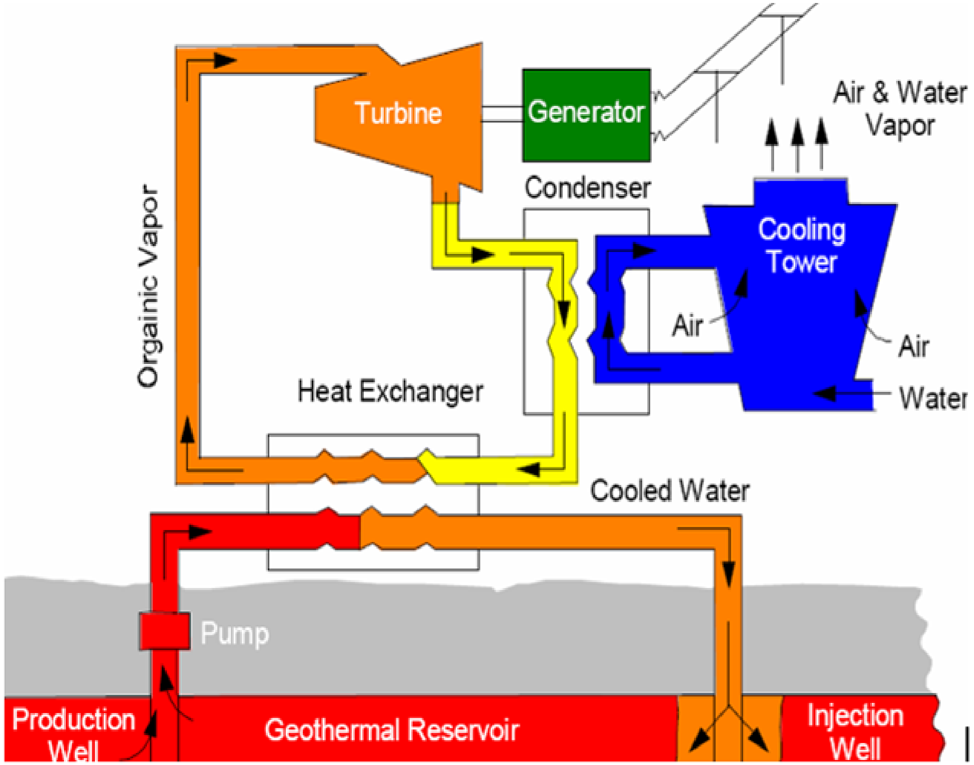
- In early 2007 Enel North America acquired the rights to develop 4 geothermal fields in, California, Nevada and Utah.
- Approximately 65MWe from low enthalpy geo-resources are now in operation (Stillwater and Salt Wells Plants).

US Geothermal Provinces



	Salt Wells	Stillwater	Cove Fort	Surprise Valley	Cove Fort II
Brine mass flow [kg/s]	504 ÷ 560	877	378 ÷ 416	756	756
Brine Temperature [℃]	135	154	152	165	152

Binary cycles for low enthalpy geo-resources



- For water dominant resources with temperature lower than 180°C, the binary cycle technology is the most efficient.
- The geo-fluid energy is transferred through a heat exchanger to a secondary fluid that works in a closed ORC cycle.
- The binary power plants have the least environmental impact due to the “confinement” of the geo-fluid.

ORC technology’s roadmap

Geo-solar hybrid plants

- Subcritical → supercritical ORC
- High operating flexibility

Advanced new technologies

- Supercritical ORC
- Net specific work > 44 kJ/kg brine
- Medium-high operating flexibility

Presently available technology

- 1-5 MWe subcritical binary ORC
- Net specific work 35÷ 40 kJ/kg brine
- Low-medium operating flexibility

Wabuska (NV), Latera (ITA)

- 0,5 – 1 MWe units
- Sub-critical ORC

Efficiency

18%

15%

12%

8%

ENA – Stillwater plant (NV, USA)

Time

2008

2010

2012

2014

Innovation in binary cycle technology

STATE OF THE ART

ORC CYCLE EFFECTIVENESS

7% ÷ 12%

ORC power production from low temperature resources has a low thermal efficiency

BYNARY PLANT CAPITAL COST

1200 ÷1500 €/KW
(1 ÷ 5 MWe unit)

2300 €/kW
(400 ÷ 500 kWe unit)

Low efficiency requires increased power plant equipment size that can become cost prohibitive

INNOVATION MAINSTAYS

ENHANCED PERFORMANCES & OPERATIONAL FLEXIBILITY

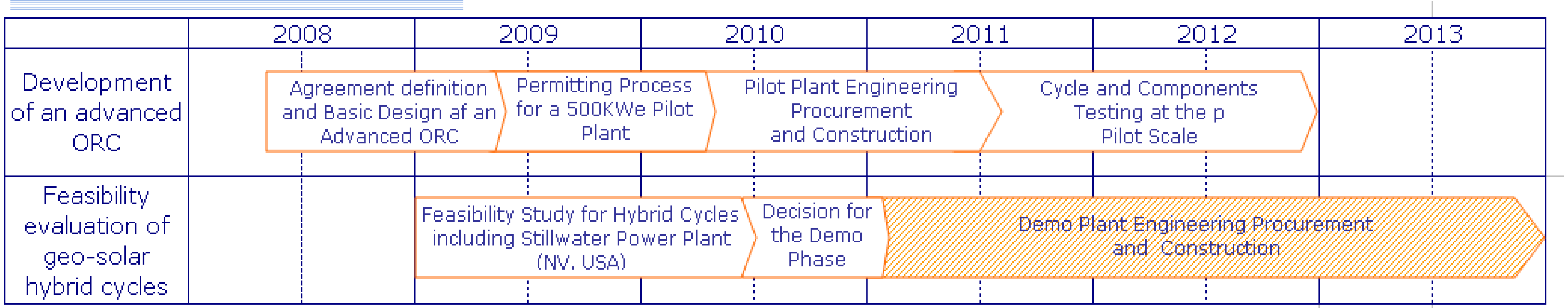
- To upgrade geothermal resources exploitation (electric generation more profitable)
- To better match the intrinsic characteristics of geothermal reservoirs
- To avoid performance decline due to the natural resources depletion and temperature drop

Project "Geotermia Innovativa" - Objectives

- To develop an advanced, supercritical, ORC technology in order to improve ENEL's geothermal production from low enthalpy geothermal resources worldwide (with a specific focus to USA).
  - Net specific work > 44 kJ/kg brine (~ +30% respect to actual technology).
  - High operation flexibility (capability to work with high performances in a wide range of brine temperatures).
  - Contained costs of investment.
- To demonstrate an advanced ORC at the pilot scale (500kWe).
  - Cycle thermodynamic performance.
  - Operating flexibility.
  - Component design and scale-up criteria (with a particular focus on turbo - expander).
  - Component reliability during long term operation (some thousands hours).
- To evaluate the feasibility to increase the productivity of ENEL's ORC geothermal plants in the USA thorough integration with solar energy.

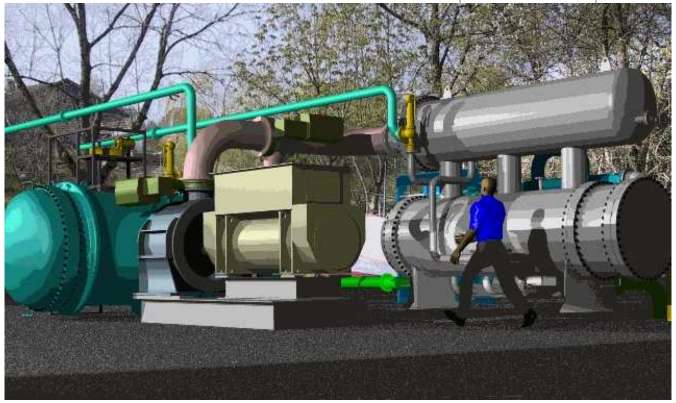
Project “Geotermia Innovativa” - Overview

Project time schedule



Short - Middle Term Activities

- TD cycle and working fluid have been selected
- Basic design of pilot plant SC ORC (Oct. ’09).
- Permitting procedure start-up (Nov. '09).
- Construction works at ENEL’s Livorno experimental area (Dec. '09).
- Pre-feasibility study completion for geo-solar hybrid cycles (Dec. ,09).



- **An agreement has been signed with Turboden and Polytechnic of Milan for advanced ORC development, pilot plant EPC and ORC testing (Phase 1) on April the 24th.**
- **A cooperation has been activated with MIT in order to evaluate the feasibility of geo-solar integration in USA geothermal fields.**

Cycle optimization and working fluid selection

- **Cycle modelling**

  - Sub-critical cycles (saturated, superheated)

  - Super-critical cycles

  - Two-pressure level sub-critical cycles

- **Working fluid screening criteria**

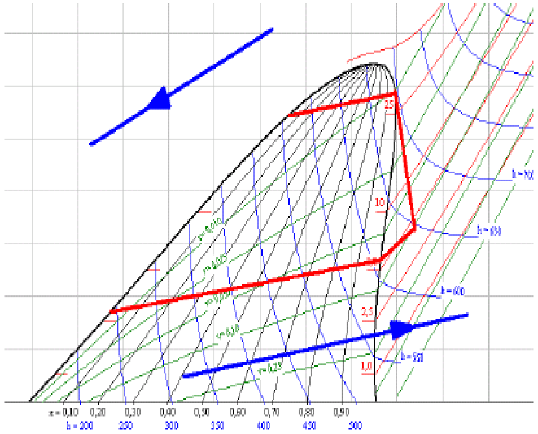
  - Low boiling point and high vapor pressure fluids related to operating T and P

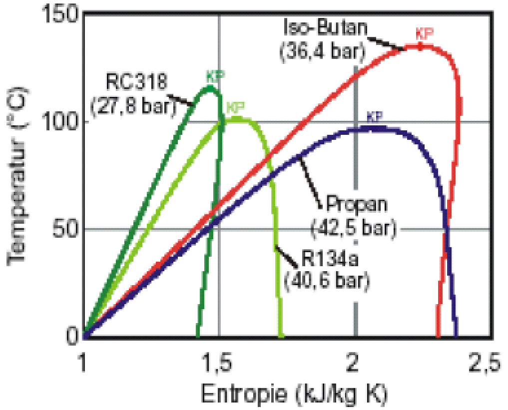
  - Heavy fluid, characterized by little enthalpy drop, therefore the turbo-machinery is little mechanically stressed

  - Not toxic, not flammable

  - **6** Hydrocarbons tested

  - **4** Refrigerants tested





- **Cycle optimization**

  Evaluation of system net specific energy production referring to different operative conditions and basic design of main components

Cycle optimization criteria

OPTIMIZATION VARIABLES

- Working fluid mass flow rate
- Working fluid turbine inlet pressure
- Working fluid condensing pressure

PERFORMANCE INDICATORS

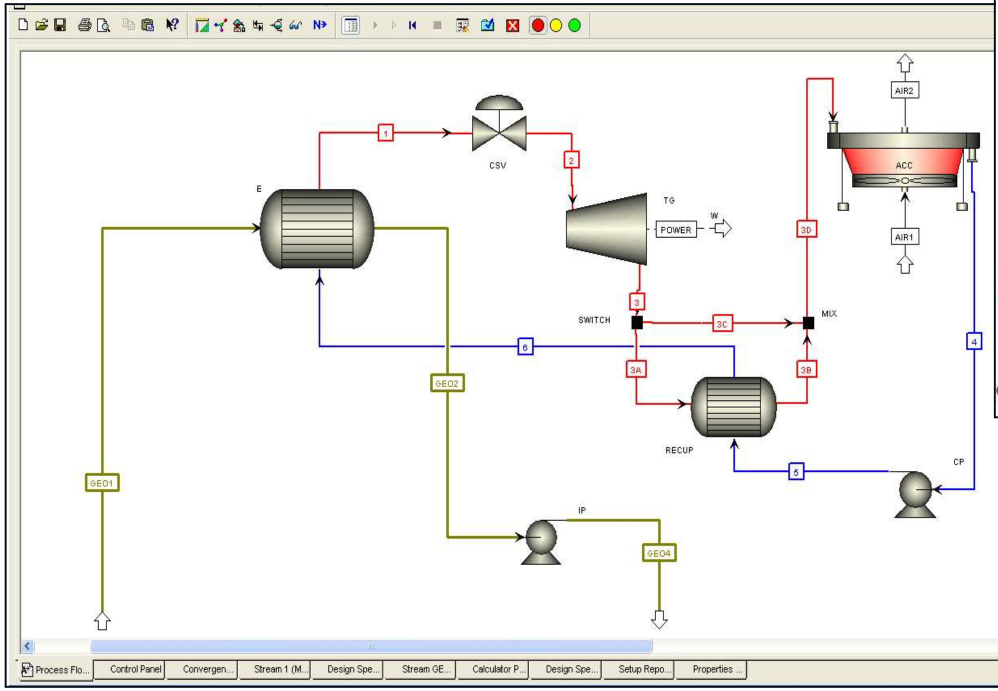
- Utilization efficiency → $\eta_u = \frac{W_{net}}{E_{in}}$
- Thermal efficiency → $\eta_{th} = \frac{W_{net}}{Q_{in}}$

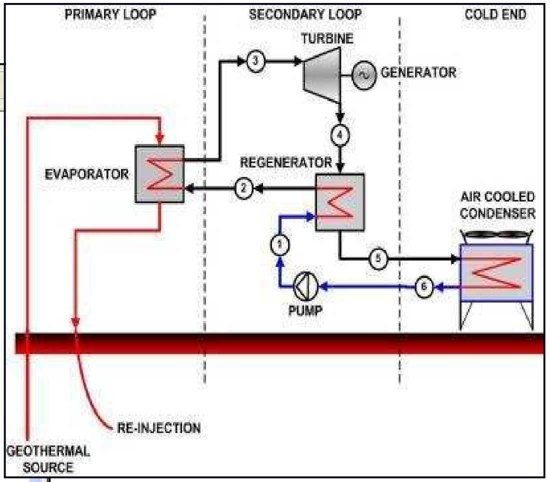
Optimization variables were varied in order to reach the optimum in terms of cycle net conversion efficiency

Cycle optimization

- Extended simulations with ASPEN Plus process simulation tool
- Conventional ORC Cycles efficiency ~ 35÷ 40 kJ/kg
- Innovative Supercritical Cycle efficiency ~ 44.5 kJ/kg

OPTIMIZED CYCLE

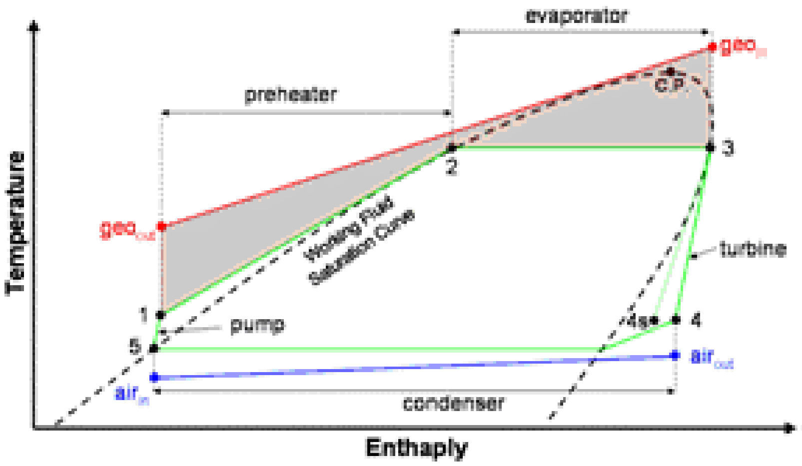




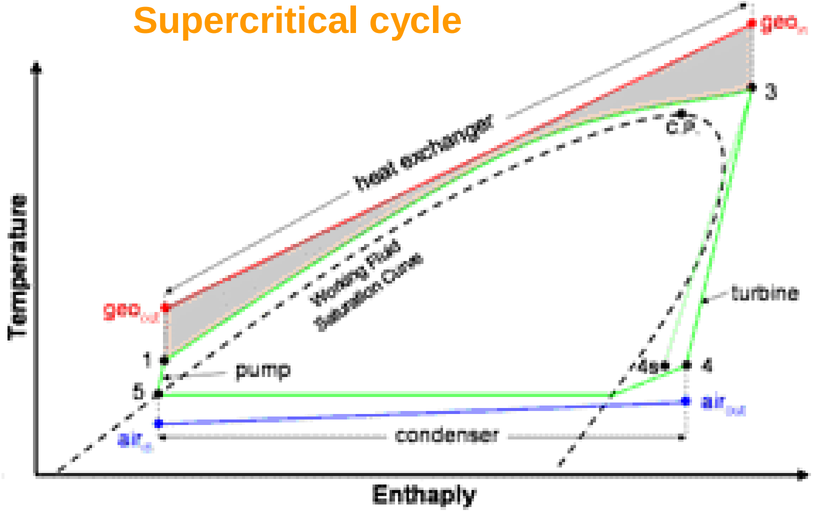
BASIC IDEA

Subcritical vs. Supercritical Cycles

Subcritical cycle

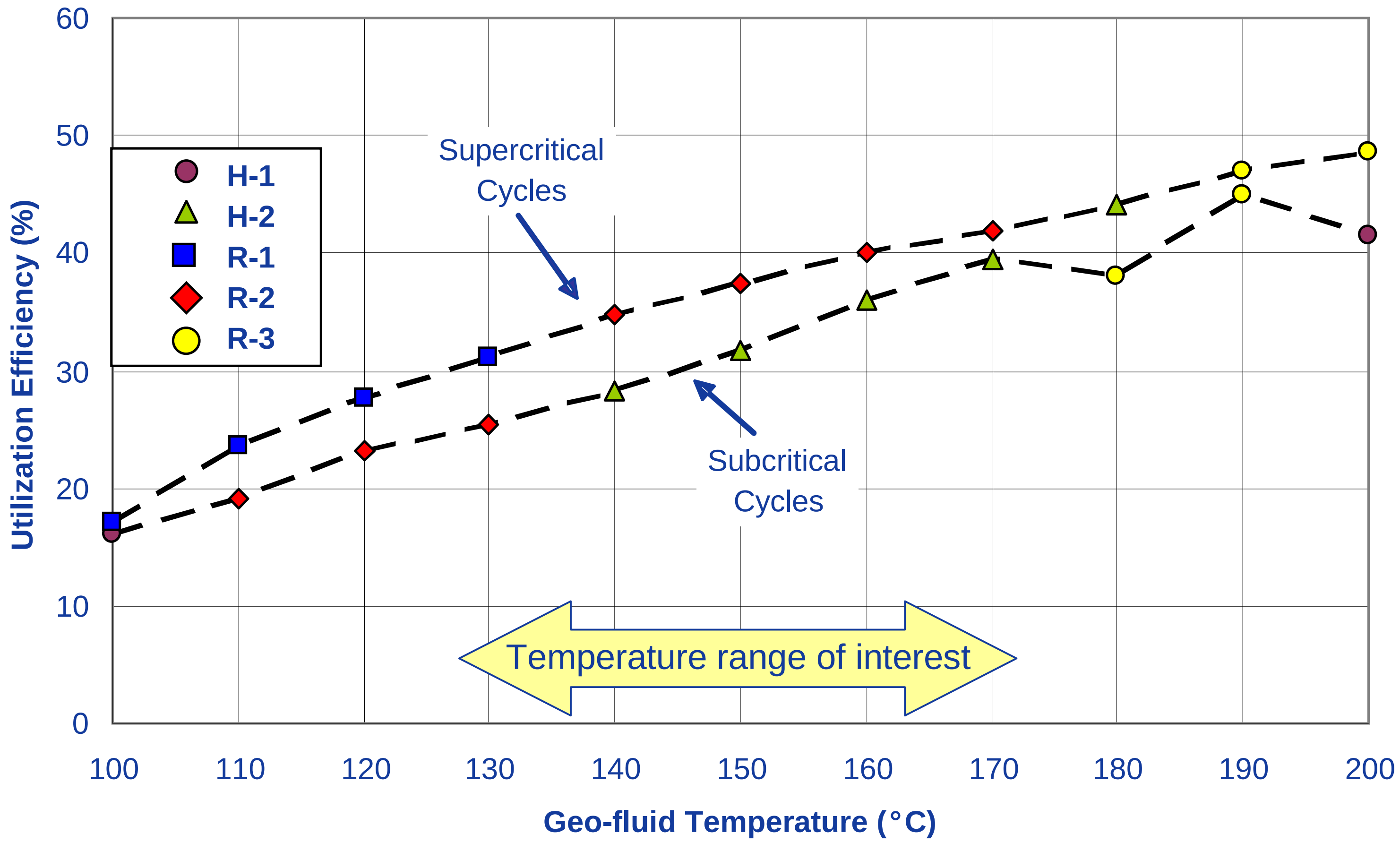


Supercritical cycle



- Supercritical cycles guarantee higher cycle efficiency due to higher cycles T and P
- Supercritical cycles guarantee a better match between hot and cold fluid temperature profile with a consequent enhanced second law efficiency
- Supercritical cycles guarantee availability of contemporaneous cycle pressure/temperature regulations thanks to once-through heat exchanger with a consequent improvement in adaptability to geo-fluid conditions
- Supercritical cycles guarantee greater operative flexibility to reduce problems due to geo-fluid temperature depletion

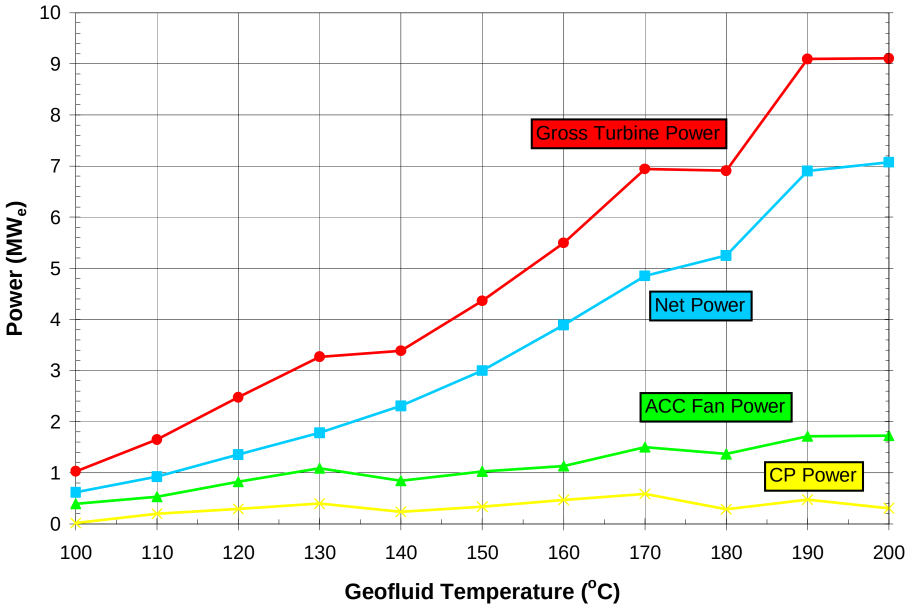
Simulation results



Supercritical cycles provide higher utilization efficiency for all geo-fluid temperature range, resulting in max 23% increase in net power.

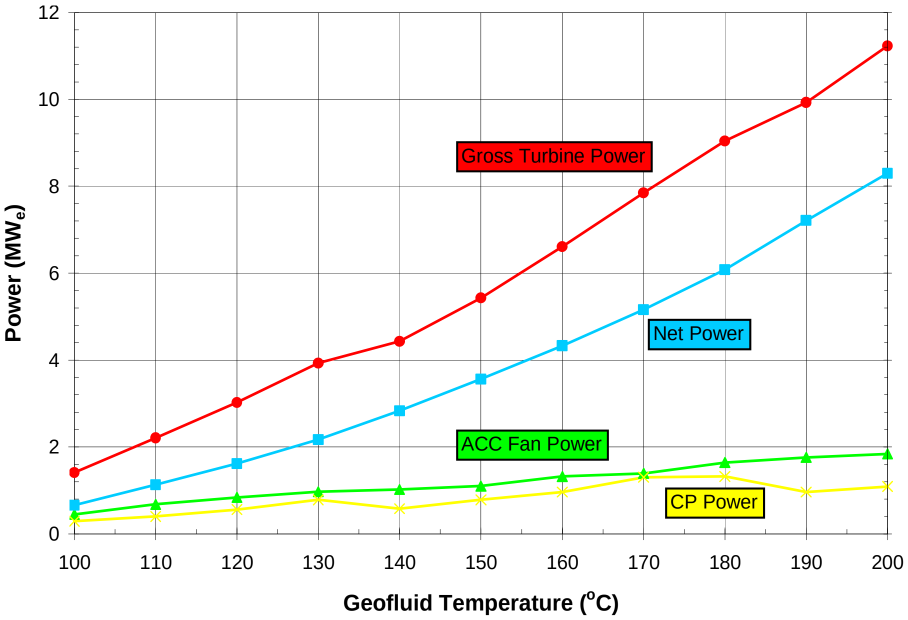
Simulation results

Subcritical cycle



Power, MW	H-1 @ 100°C	H-2 @ 150°C	H-1 @ 200°C
Gross	1.03	4.37	9.12
Parasitic losses	40%	31%	22%
Net	0.62	3.00	7.07

Supercritical cycle

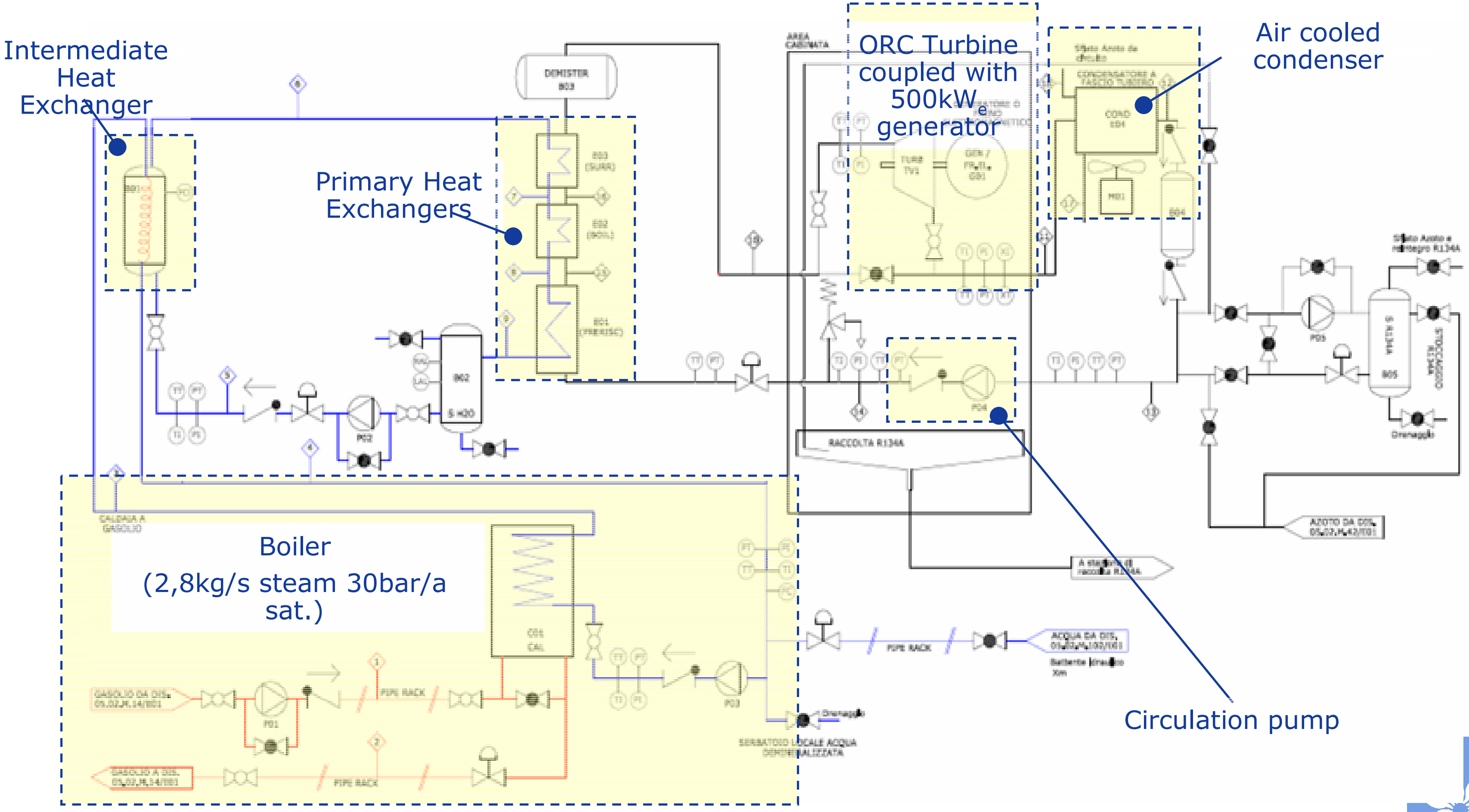


Power, MW	R-1 @ 100°C	R-2 @ 150°C	R-3 @ 200°C
Gross	1.41	5.43	11.23
Parasitic losses	53%	34%	26%
Net	0.66	3.56	8.30

Geo-fluid flow rate = 100 kg/s

Enel
L'ENERGIA CHE TI ASCOLTA.

Advanced 500 KW$_e$ ORC pilot plant PFD



Intermediate Heat Exchanger

Primary Heat Exchangers

ORC Turbine coupled with 500kW$_e$ generator

Air cooled condenser

Boiler

(2,8kg/s steam 30bar/a sat.)

Circulation pump

Advanced 500 KW_e ORC pilot plant

Auxiliary boiler already available 5,6 MW (8,5 t/h, 250°C)

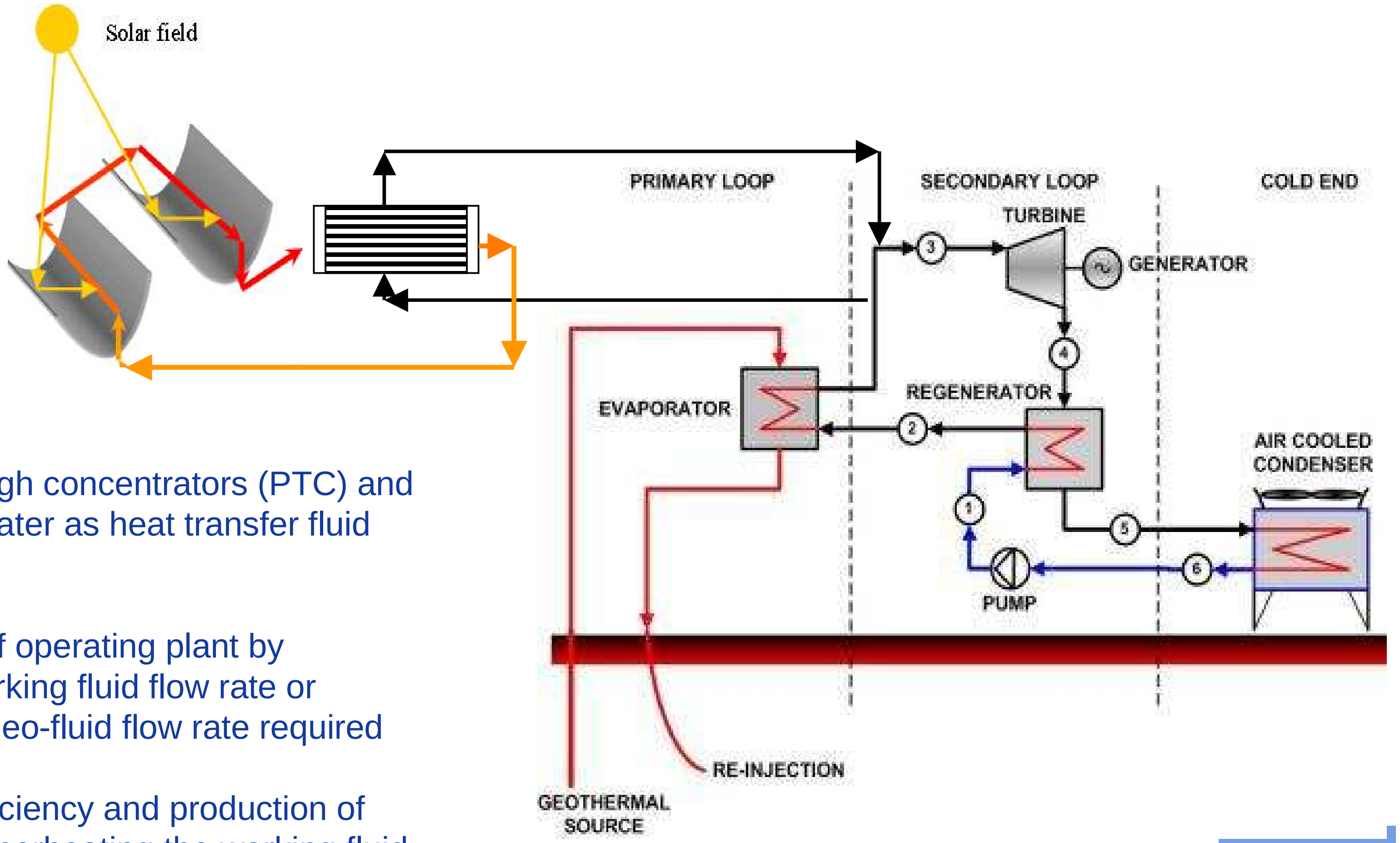
200 m² foundation platform for pilot plant installation

Solar geothermal hybrid-cycles - Advantages

- Minimize geothermal technology problems and produce more electricity without expanding the use of the geo-resource.
- Improve performance over a pure geothermal system.
- More cost-effective than standalone solar facilities, also thanks to medium temperature and low-cost solar collectors. No storage needed.
- To offset the risk of premature resource depletion.
- To hedge risk associated with geothermal production (predictability of resource's temperature and flow rate).

Hybrid-cycles concept B

Boosting liquid geo-fluid

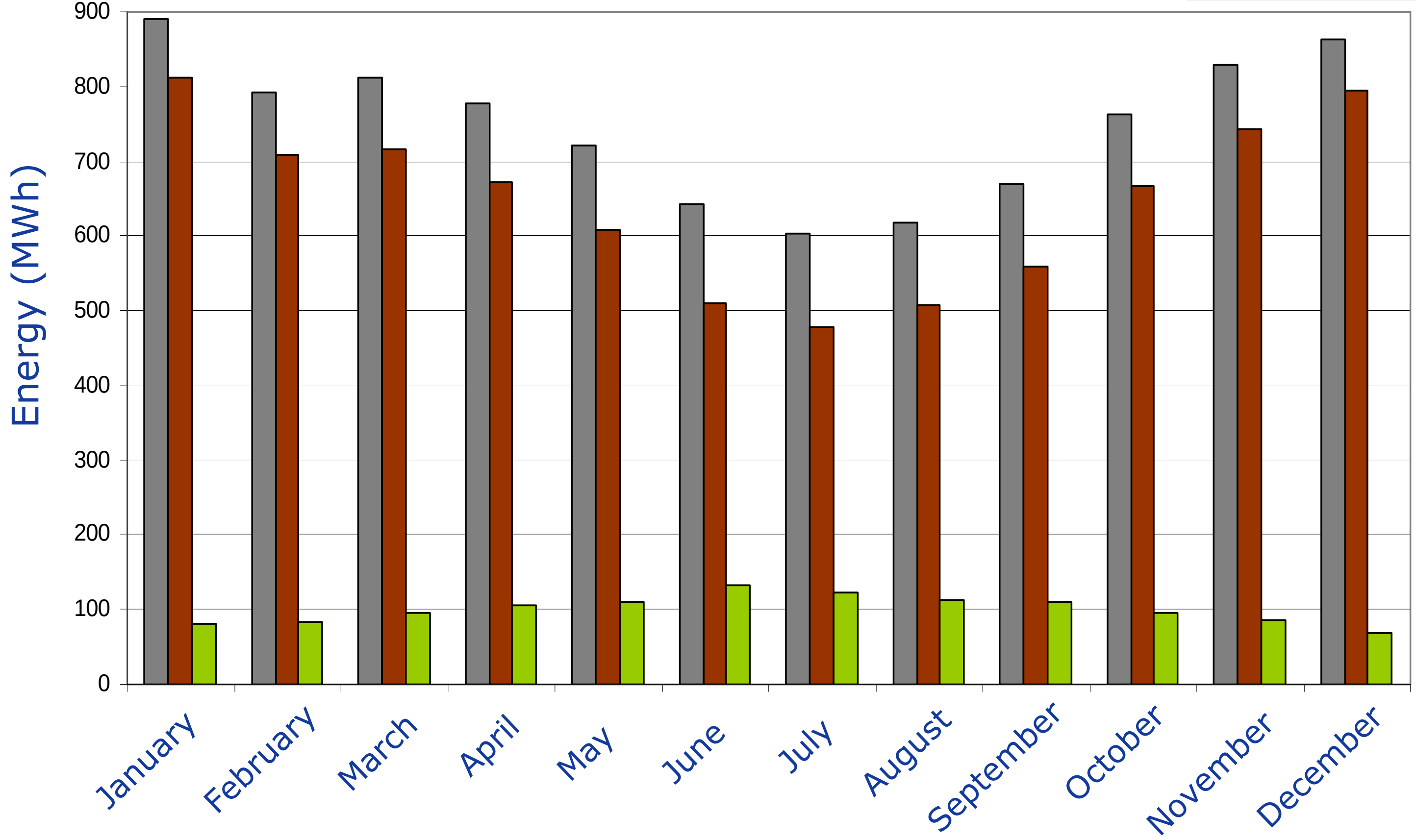


- Parabolic trough concentrators (PTC) and pressurized water as heat transfer fluid (HTF)
- Repowering of operating plant by increasing working fluid flow rate or reducing the geo-fluid flow rate required
- Increasing efficiency and production of new plants superheating the working fluid by solar energy

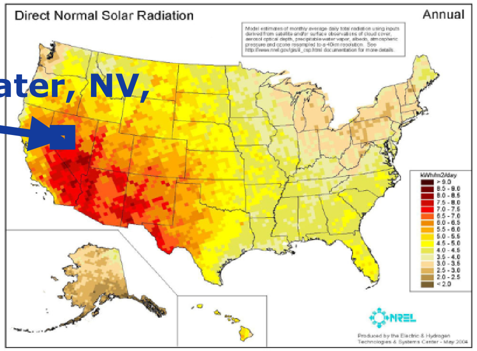
Hybrid-cycles – First results

Old Stillwater Plant

- ⬛ Hybrid
- 🟥 Only geothermal
- 🟩 Incremental energy



Stillwater, NV, USA



Concluding remarks

- Over the temperature range studied and for the design specifications assumed, supercritical binary cycles are more efficient than subcritical cycles, producing up to **23% more net power**, despite parasitic pumping losses in the supercritical cases are 2-3 times higher than subcritical ones.

- Refrigerants performed very well as working fluids, especially for supercritical cycles.

- In a supercritical cycle the possibility of operating outside the fluid saturation diagram during the heat adduction phase guarantees a greater operational flexibility with respect to subcritical cycles.

- Based on the positive results of the undertaken work, ENEL has signed a cooperation agreement with Turboden and Milan Polytechnic aimed at designing and constructing a 500KWe pilot plant in its experimental area in Livorno in order to assess TD performance, component reliability and costs of the new technology.

- In the mean time the techno-economic feasibility of geo-solar integration for ENEL’s binary plant in the USA is under evaluation in cooperation with Massachusetts Institute of Technology aimed at increasing production, reducing risks and increasing flexibility.

Thank you for your attention

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