The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

Workshop on "Physics for Renewable Energy"
October 17 - 29, 2005

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"Geothermal Energy
Clean & Renewable Power from the Earth"

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THE ABDUS SALAM

INTERNATIONAL CENTRE FOR THEORETICAL PHYSISCS

WORKSHOP ON ***"Physics for Renewable Energy"***

GEOTHERMAL ENERGY

CLEAN AND RENEWABLE POWER FROM THE EARTH

Fausto Batini

Enel – International department

Roma – Italy

Trieste, October 27th 2005

Enel
L'ENERGIA CHE TI ASCOLTA.

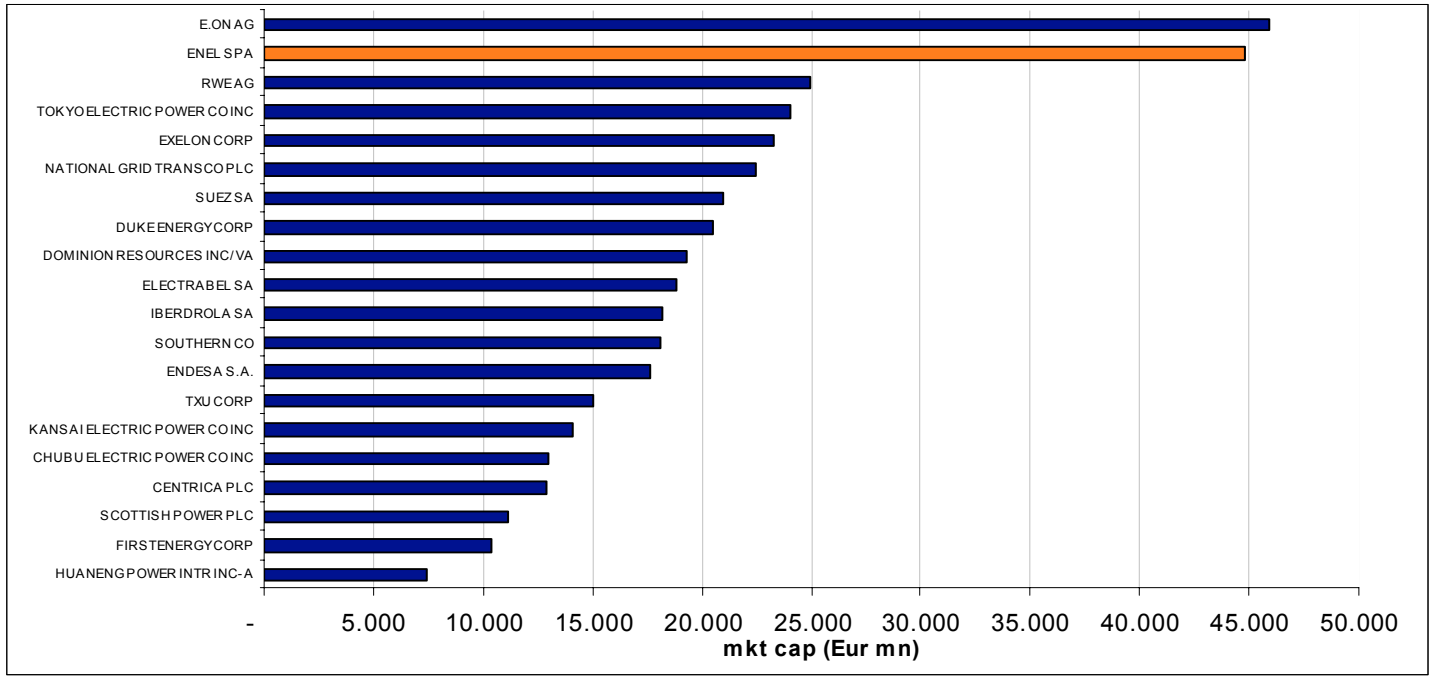
Content

Enel company profile

Enel s.p.a.

- The principal electricity operator in Italy with the leading position in the generation, transmission*, distribution and sale of electricity
- Strong presence in the gas market
- One of the world largest operators in the energy sector

Market capitalization as of April 18 th 2005



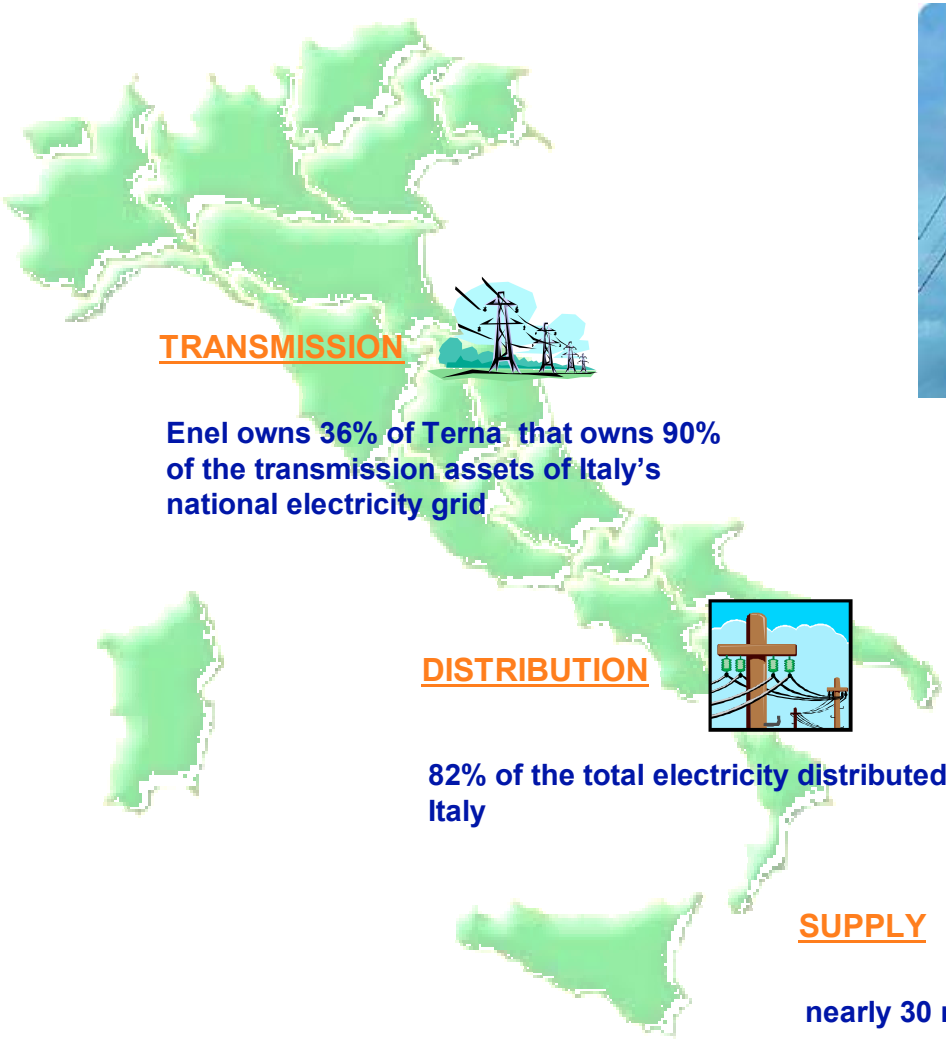
Source: Bloomberg

* **Enel owns 36,14% of the share capital of Terna and has already signed an agreement for the sale of up to 30% of the company**

Enel in the Italian Electricity Sector

GENERATION
42,047 MW

- 26,837 MW Thermal
- 14,318 MW Hydroelectric
- 642 MW Geothermal
- 250 MW Wind and other renewable



TRANSMISSION

Enel owns 36% of Terna, that owns 90% of the transmission assets of Italy's national electricity grid

DISTRIBUTION

82% of the total electricity distributed in Italy

SUPPLY

nearly 30 million customers.

Data as of December 31st 2004

Enel in the world

Europe: 4.005 MW and 2 million customers

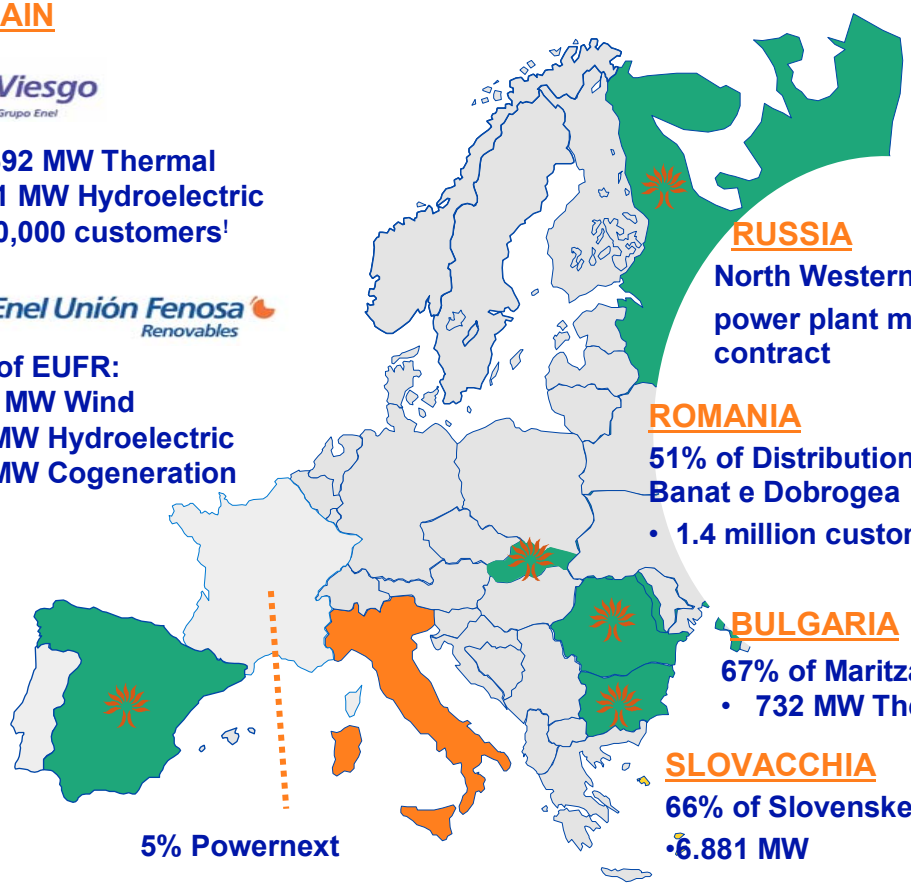
SPAIN

Viesgo Grupo Enel

- 1.592 MW Thermal
- 671 MW Hydroelectric
- 600,000 customers[1]

Enel Unión Fenosa Renovables

80% of EUFR:
- 294 MW Wind
- 89 MW Hydroelectric
- 62 MW Cogeneration



5% Powernext

RUSSIA

North Western thermal power plant management contract

ROMANIA

51% of Distribution companies Banat e Dobrogea
- 1.4 million customers

BULGARIA

67% of Maritza East III:
- 732 MW Thermal

SLOVACCHIA

66% of Slovenske Elektrarne
- 6.881 MW

Data as of Aprile 15 1th 2004
1 – On the regulated market

North and Latin America

565 MW

Enel North America

- 286 MW Hydroelectric
- 67 MW Wind
- 21 MW Biomass and Biogas

Enel Latin America

- 171 MW Hydroelectric
- 20 MW Wind

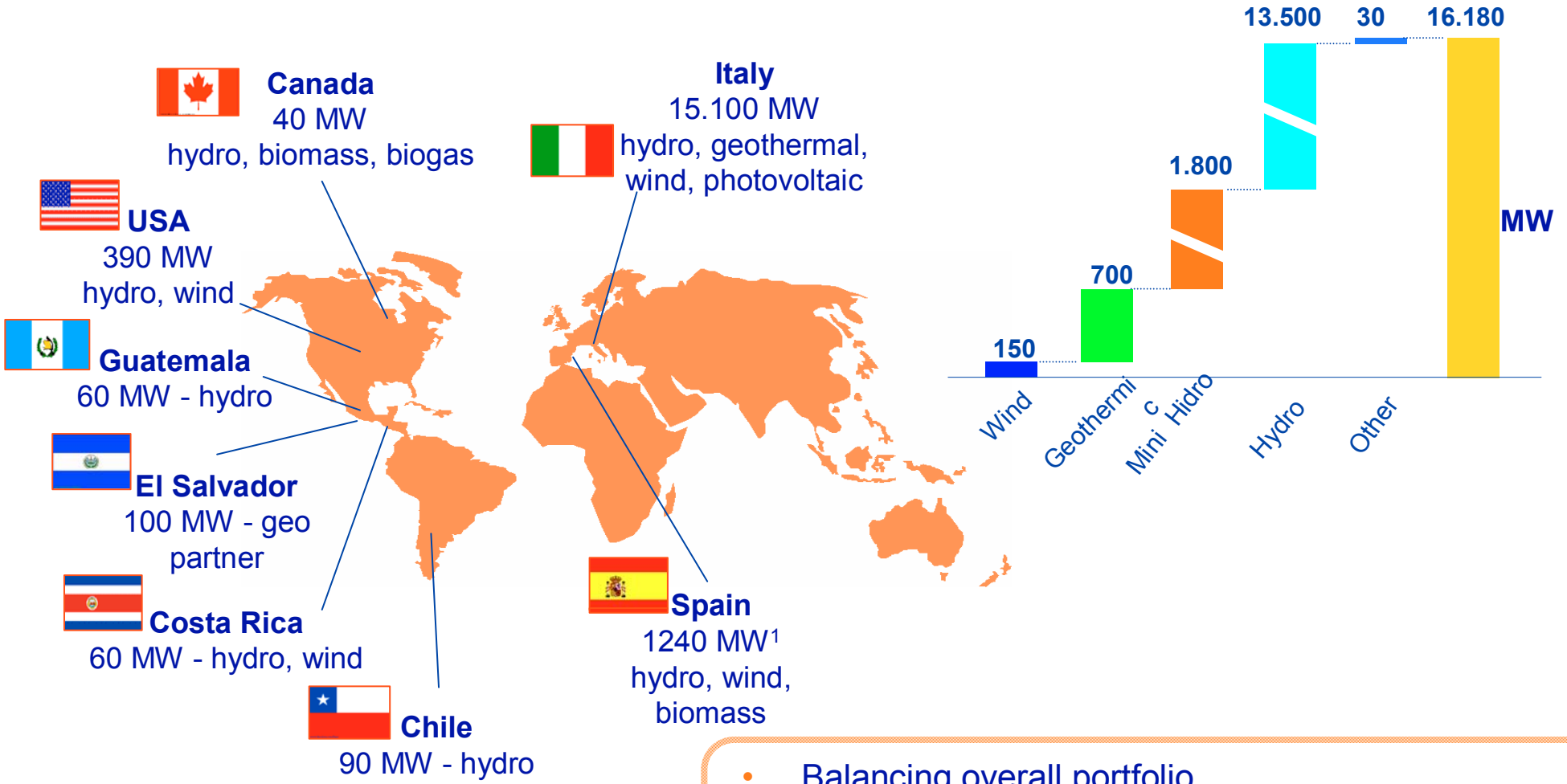
Economic and Financial results

Millions €

	2000	2001	2002	2003	2004
Revenues	25.109	28.781	29.977	31.317	36.489
EBIT	4.753	3.478	2.880	4.732	6.325
Net income	2.188	4.226	2.008	2.509	2.706
Current assets	9.456	11.902	14.464	14.520	16.902
Fixed Assets	35.744	35.004	37.533	37.155	36.459
Equity	18.312	20.966	20.772	21.124	19.847
Short-term Debt	6.406	7.107	8.371	8.643	6.419
Long-term Debt	7.984	16.072	17.172	18.005	20.241

Headcount @ 31/12/2004 61.898

Enel's worldwide renewables portfolio



[1] including plants in partnership

- Balancing overall portfolio
- Enhancing technical leadership in geothermal
- Developing JI & CDM projects abroad to meet Kyoto targets in Italy

Content

1. Basic concepts
   - Heat sources
   - Geothermal systems and technologies
   - Exploration & production process
2. The geothermal industry worldwide
   - Electric energy generation
   - Direct use application
3. Drivers & barriers for the geothermal energy growth
   - Technological challenges
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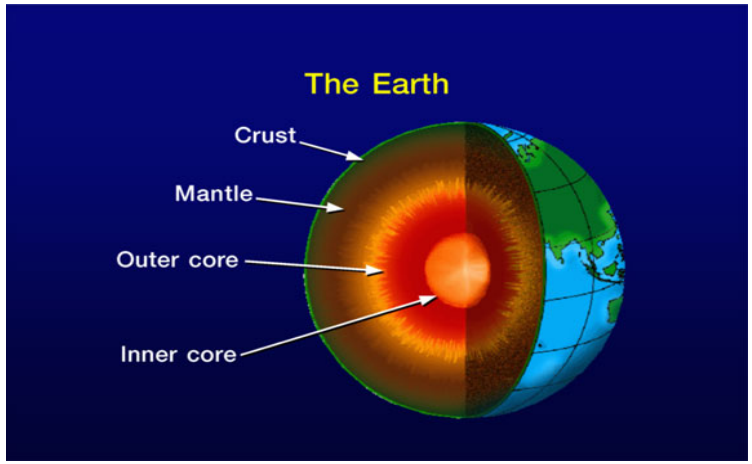
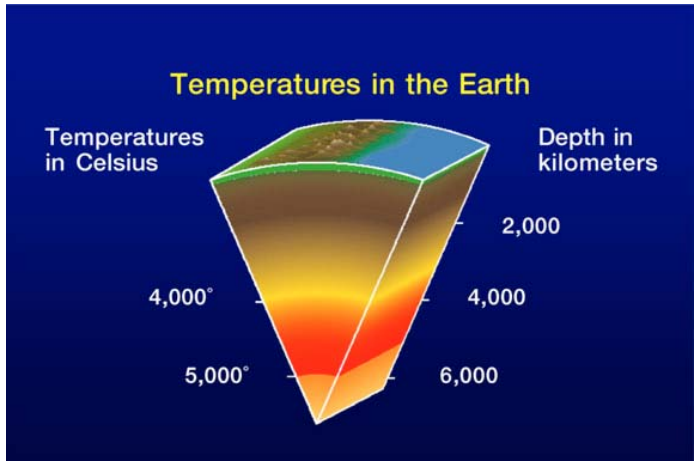
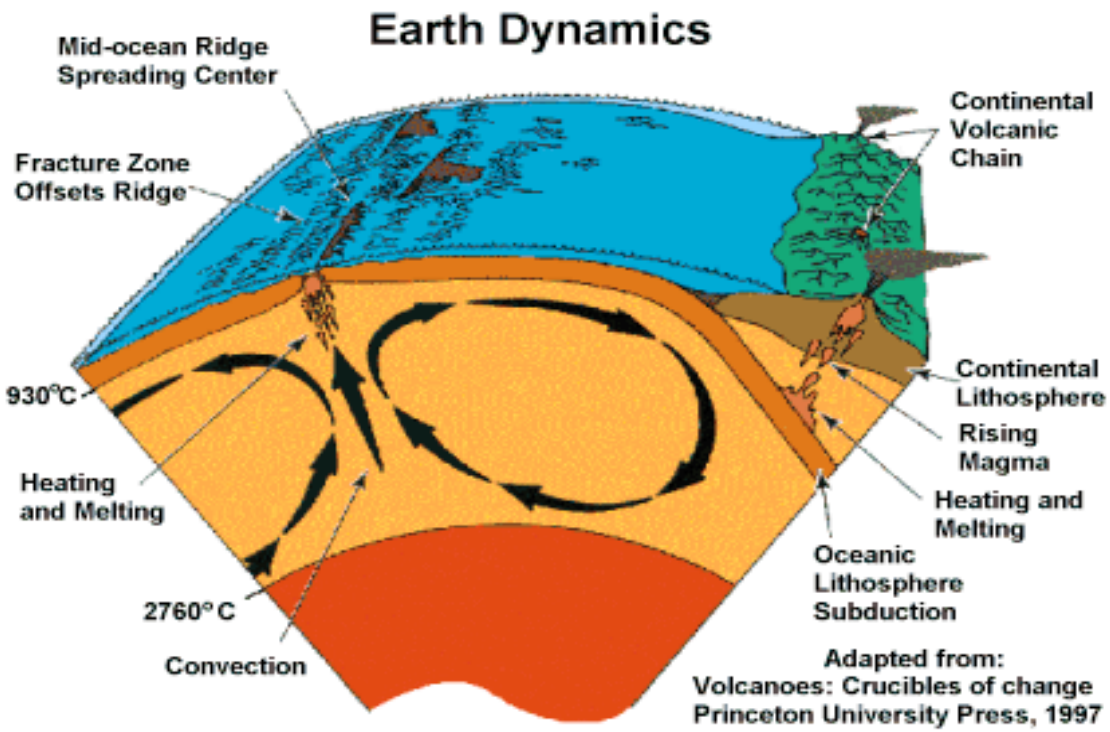
Heat sources



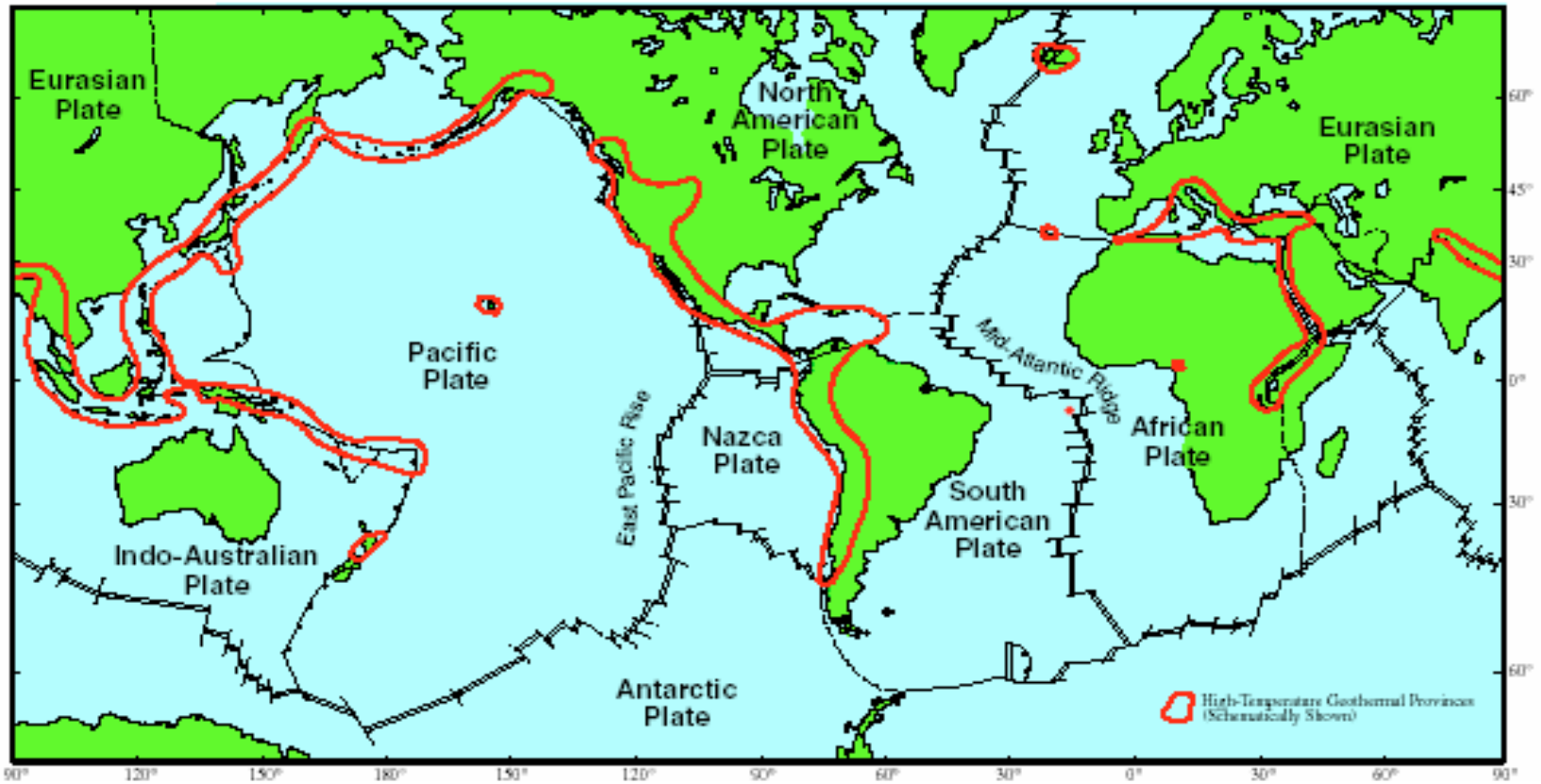




A mean heat flux at the earth's surface of around 16 kilowatts of heat energy per square kilometre which is dissipated to the atmosphere and space.

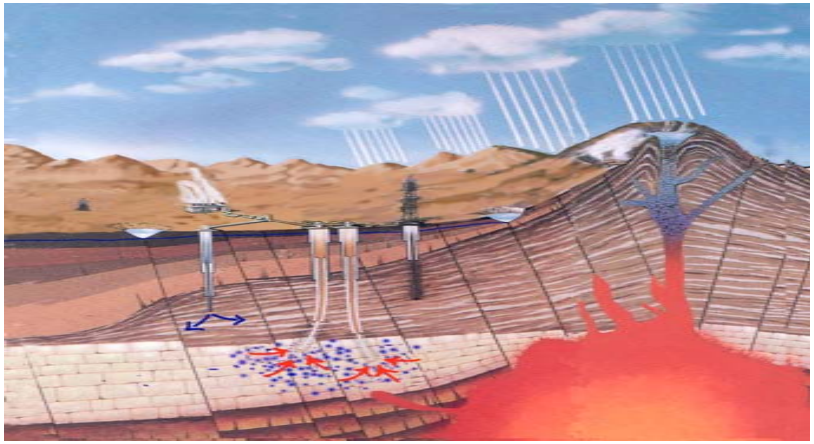
Geothermal areas worldwide

This heat flux tends to be strongest along tectonic plate boundaries where volcanic activity transports high temperature material to near the surface.



However, even in parts of the world far from plate boundaries, there can still exist areas of higher than average natural heat flow.

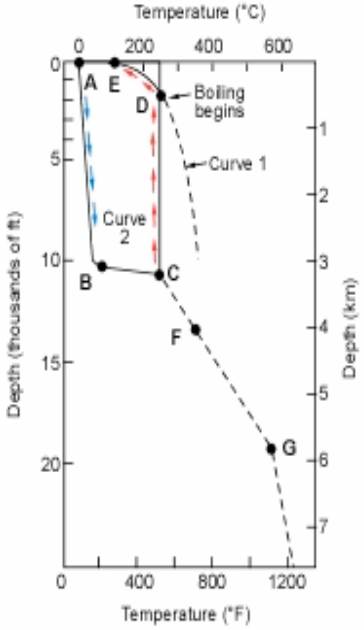
Geothermal systems

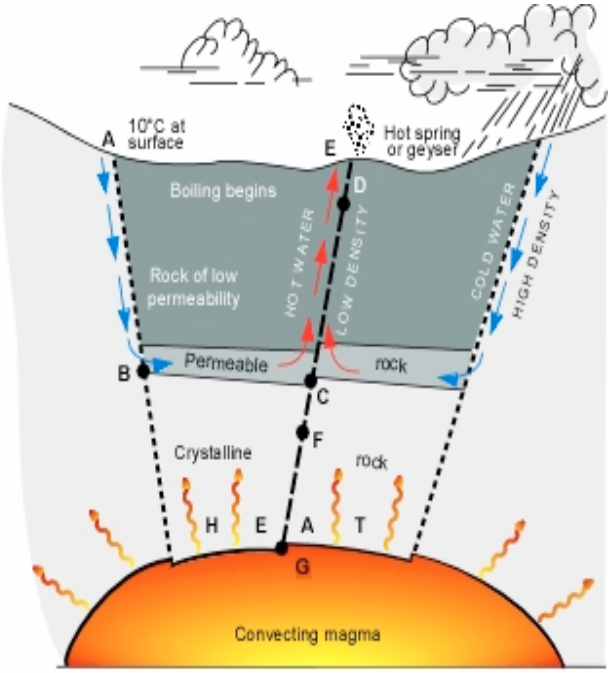


- **Heat source** : magmatic body molten or partially molten at depth < 8-10 km
- **Reservoir** : Porous& fractured rocks
- **Fluid:** meteoric and magmatic water
- **Sealing**: impervious rocks

Temperature gradient in the earth 33°C/km

Temperature gradient in the geothermal areas > 100 °C/km



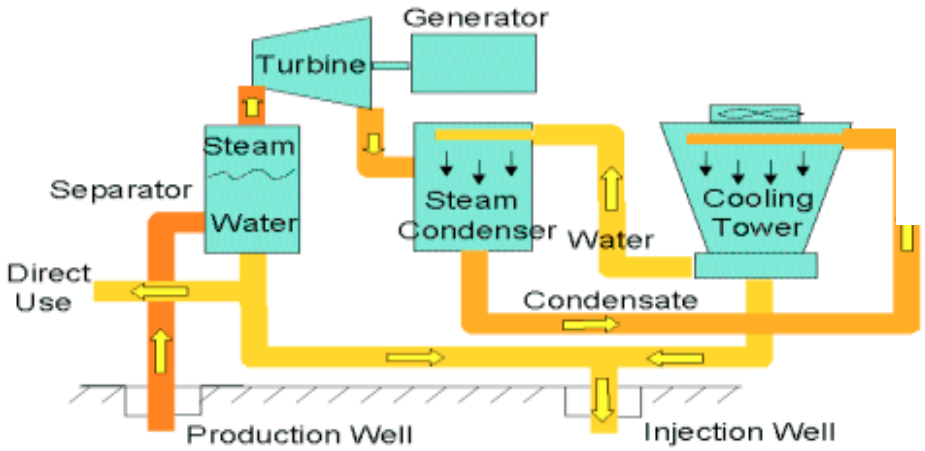


Geothermal systems and energy conversion

Reservoir Temperature	Reservoir Fluid	Common Use	Technology commonly chosen
High Temperature >220°C (>430°F).	Water or Steam	Power Generation Direct Use	▪ Flash Steam ▪ Combined (Flash and Binary) Cycle ▪ Heat Exchangers ▪ Heat Pumps
Intermediate Temperature 100-220°C (212 - 390°F).	Water	Power Generation Direct Use	▪ Binary Cycle ▪ Direct Fluid Use ▪ Heat Exchangers ▪ Heat Pumps
Low Temperature 50-150°C (120-300°F).	Water	Direct Use	▪ Direct Fluid Use ▪ Heat Exchangers ▪ Heat Pumps

Electric energy generation

Single Flash Power Plant

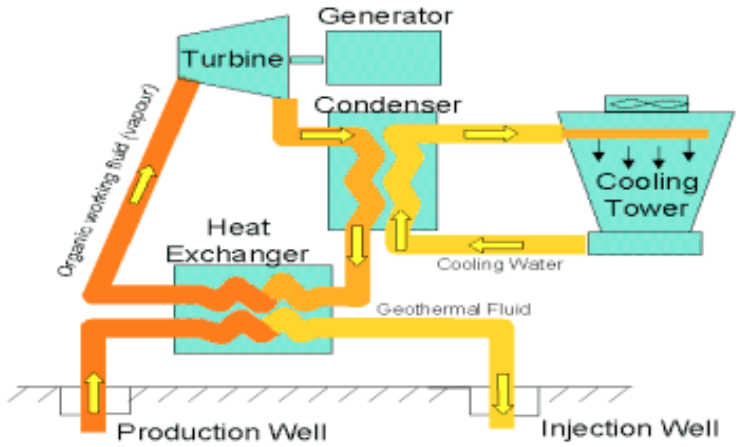


This is the most common type of geothermal power unit.

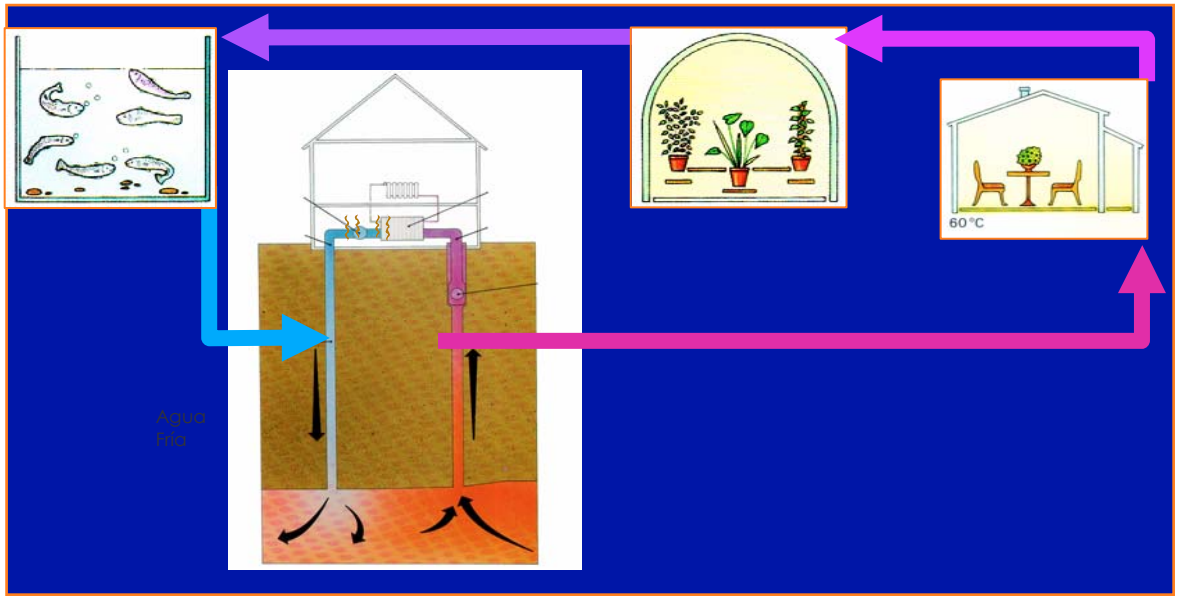
NAMEPLATE CAPACITY : 5 -60 MW

NAMEPLATE CAPACITY : 2 - 10 MW

Binary Cycle Power Plant



Direct use of geothermal heat

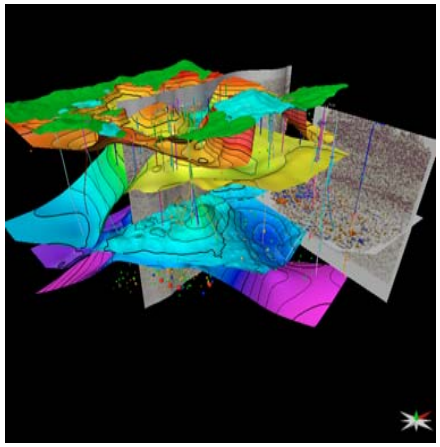


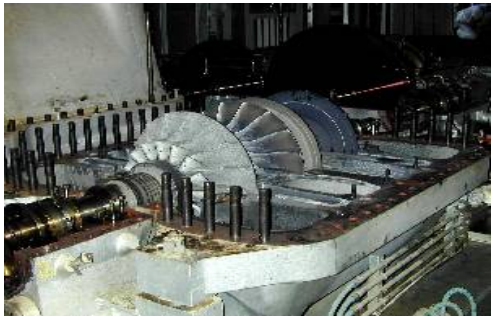
Principal uses (minimum temperature, °C):

- Heating buildings (50°)
- Greenhouse heating (35°)
- Processing agricultural/forest products (100°)
- Heating fishponds (35°)
- Spas and baths (35°)
- Mineral water (no requirement)
- Processing mineral/chemical products (120°)

Geothermal exploration & production process

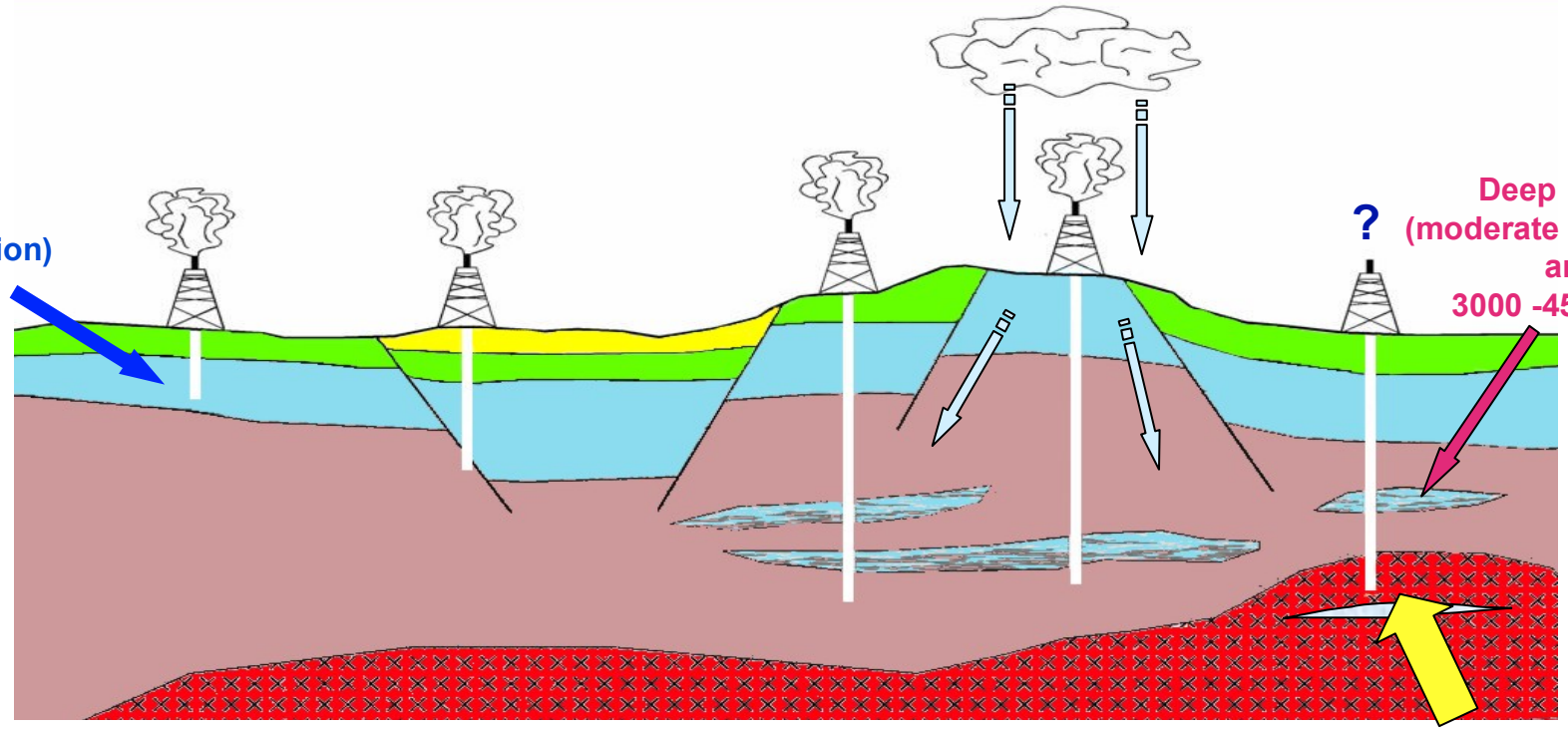
RESOURCE EXPLORATION & ASSESSMENT → **DRILLING** → **ENGINEERING & CONSTRUCTION** → **OPERATION & MAINTANANCE**





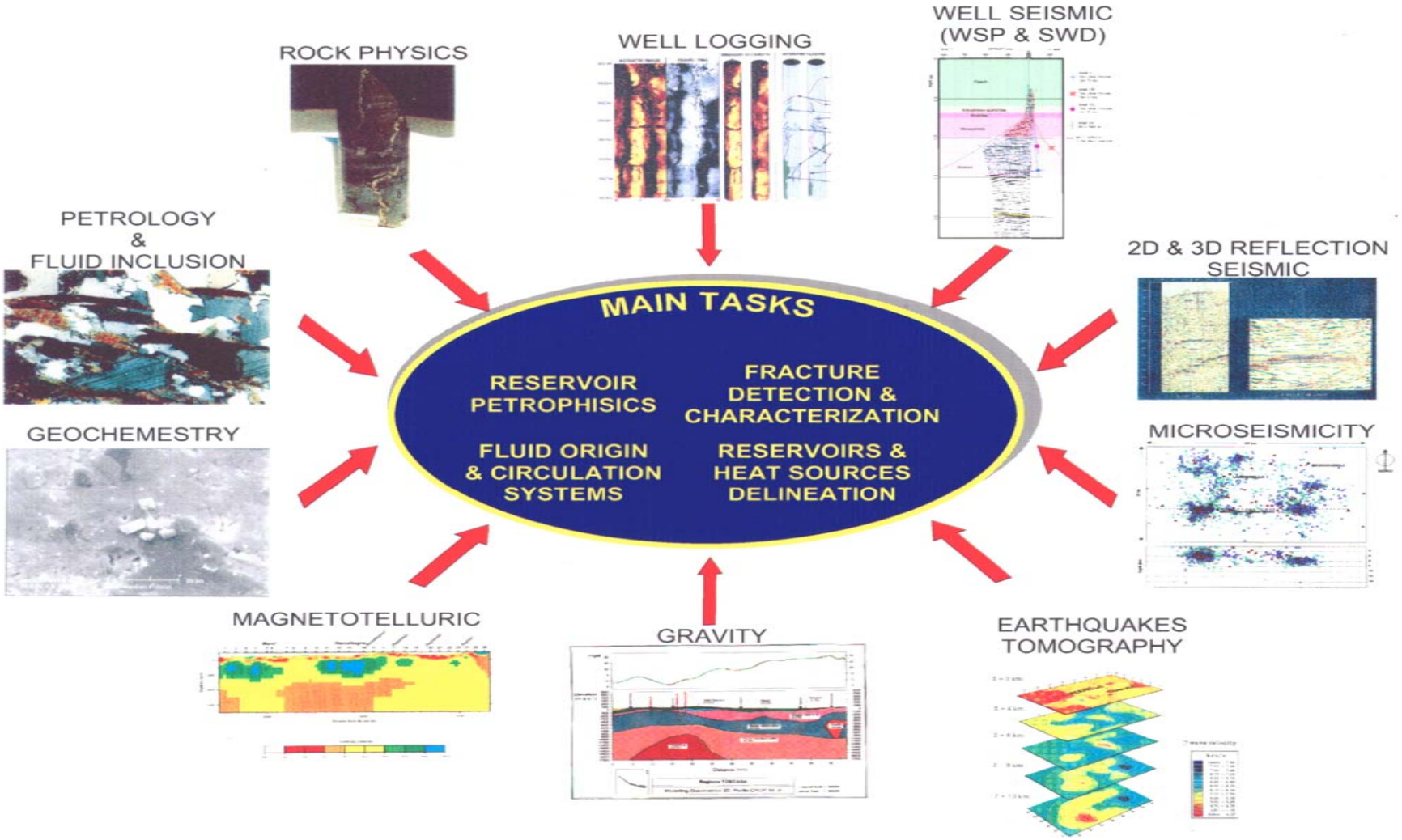
Geothermal exploration

Delineation of geothermal system and drilling target definition



Reservoir permeability controlled by fracture systems

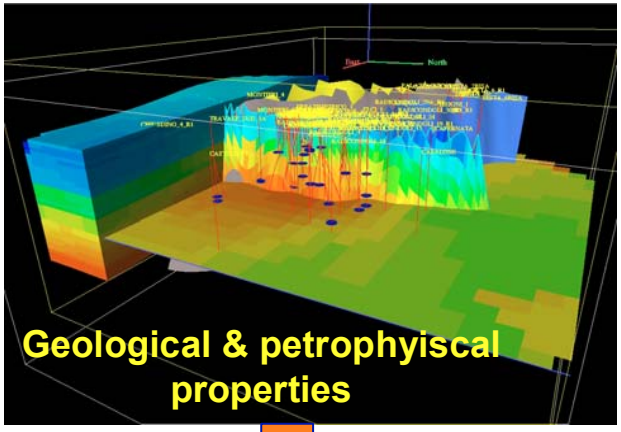
Exploration & resource assessment



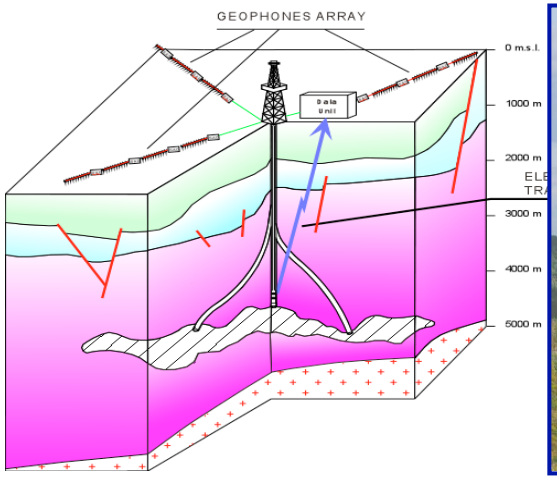
MULTIDISCIPLINARY APPROACH AND INTEGRATED INTERPRETATION

Exploration & resource assessment

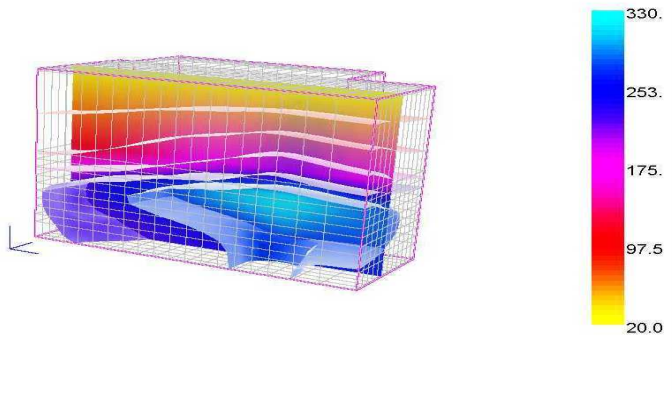
Predictive geothermal model ...



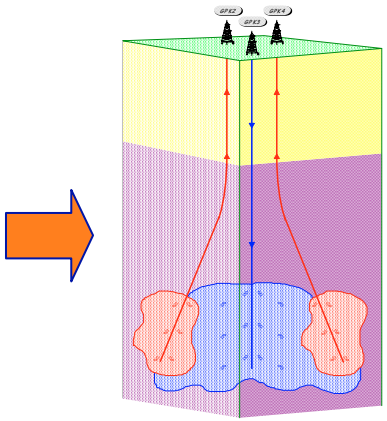
for better definition of drilling targets

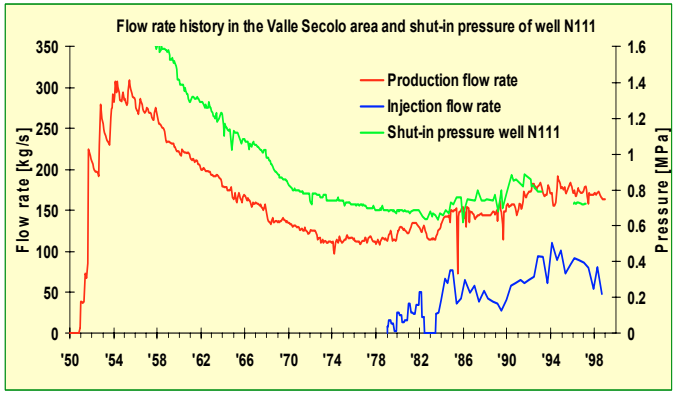


Fluido-dynamic model

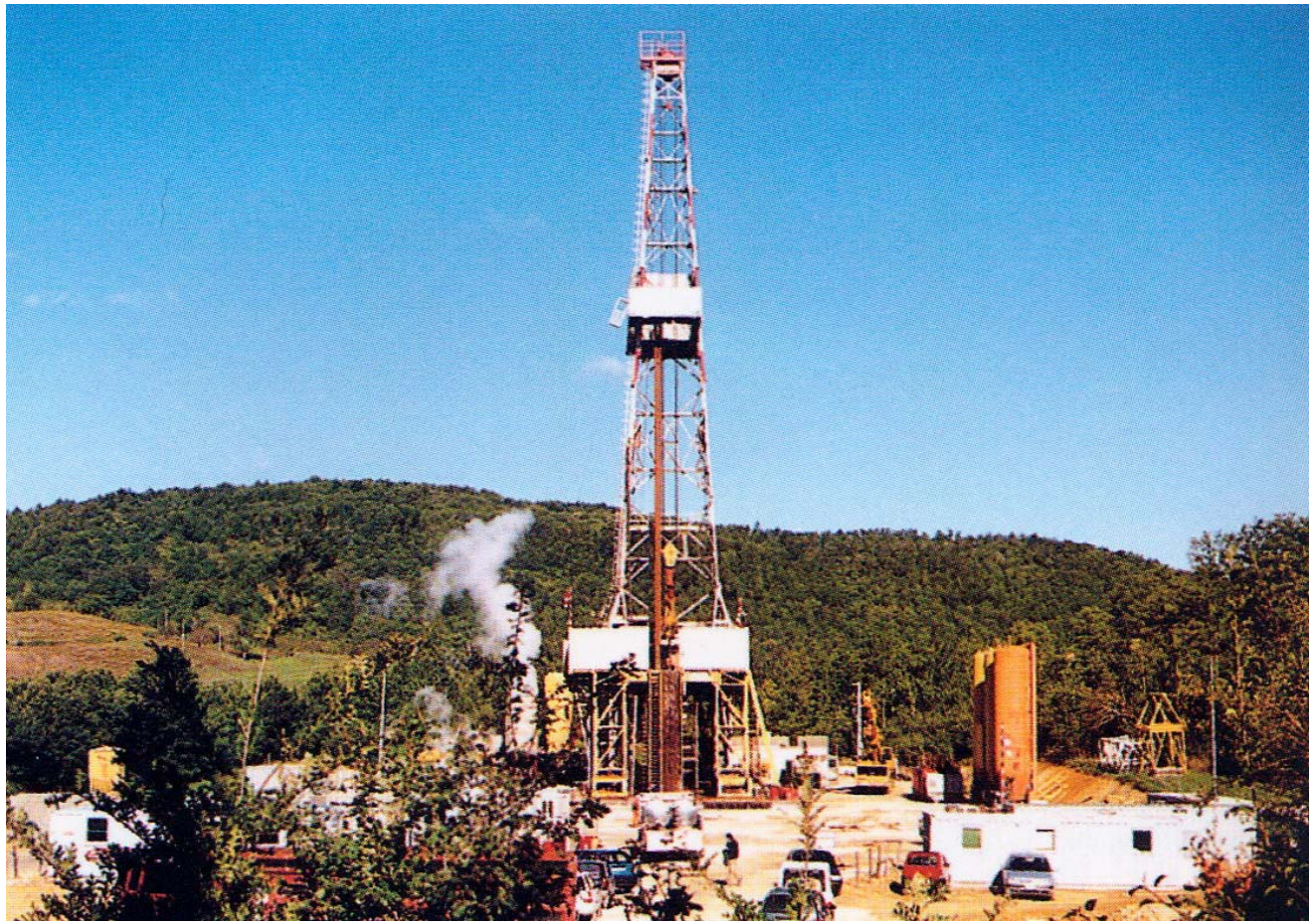


…for optimization of the reservoir management

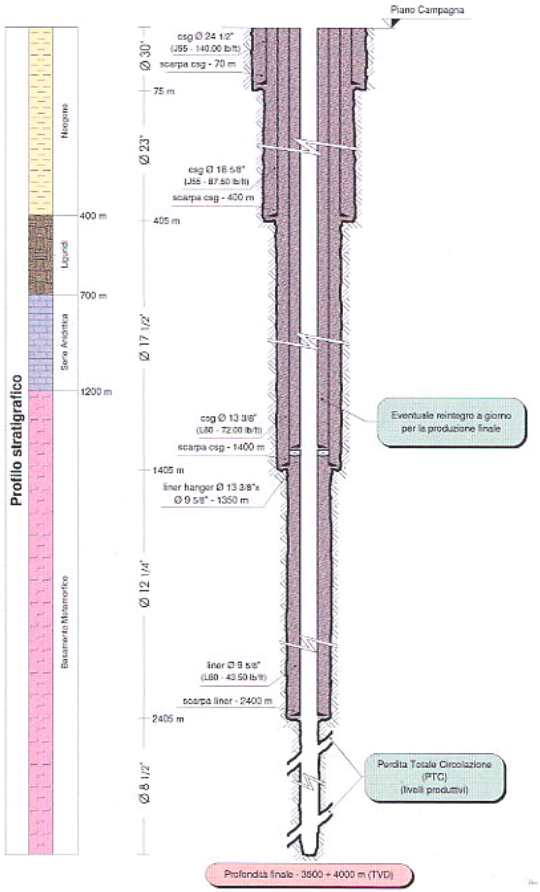




Drilling



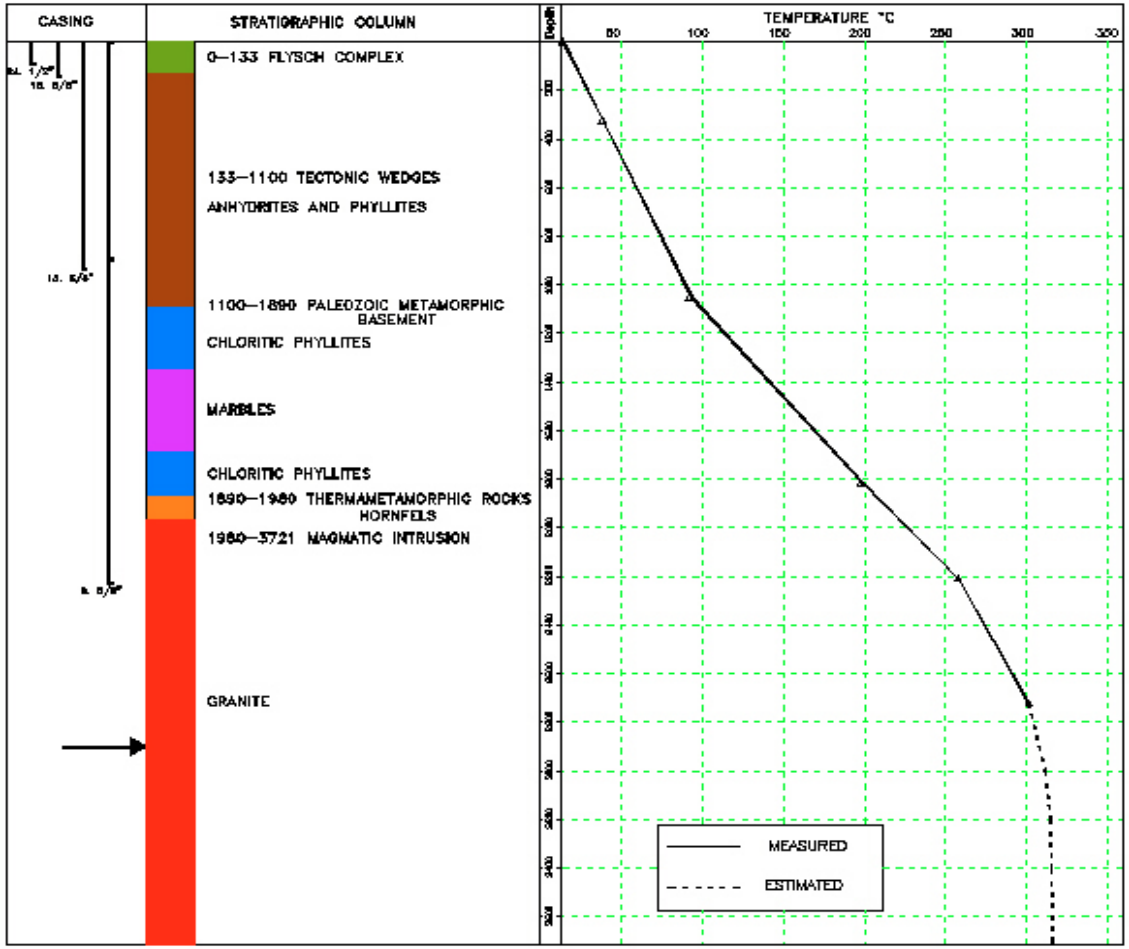
Well design



Depth: up to 5200m

Drilling

Montieri 1 well (Tuscany – Italy)



Well production : over 240 tonnes/h of steam

Design & construction of the power systems

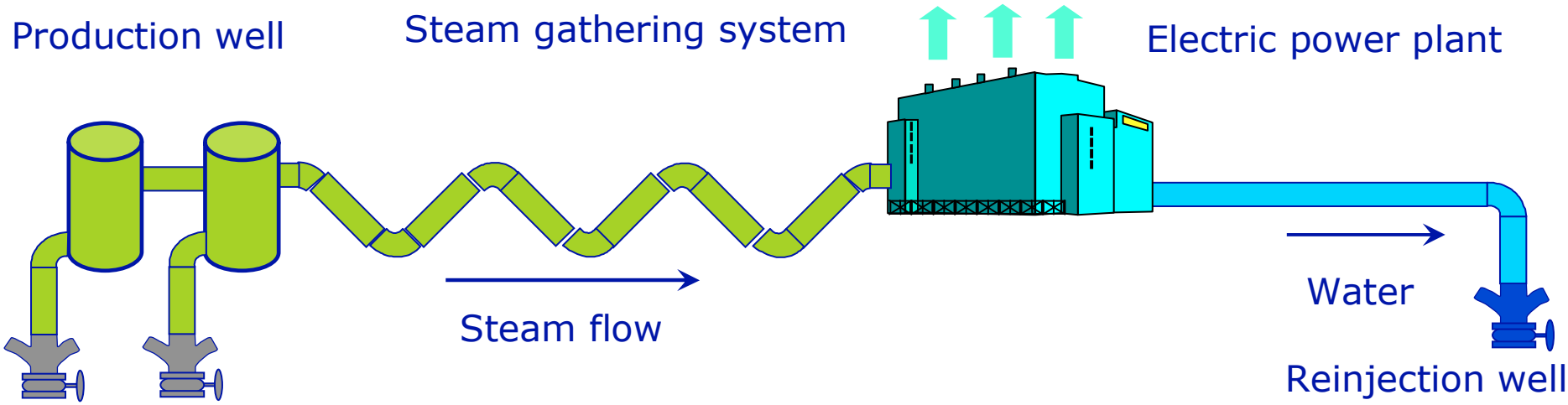
Steam pipeline

(lenght range :1-10 km)

2 Power plants

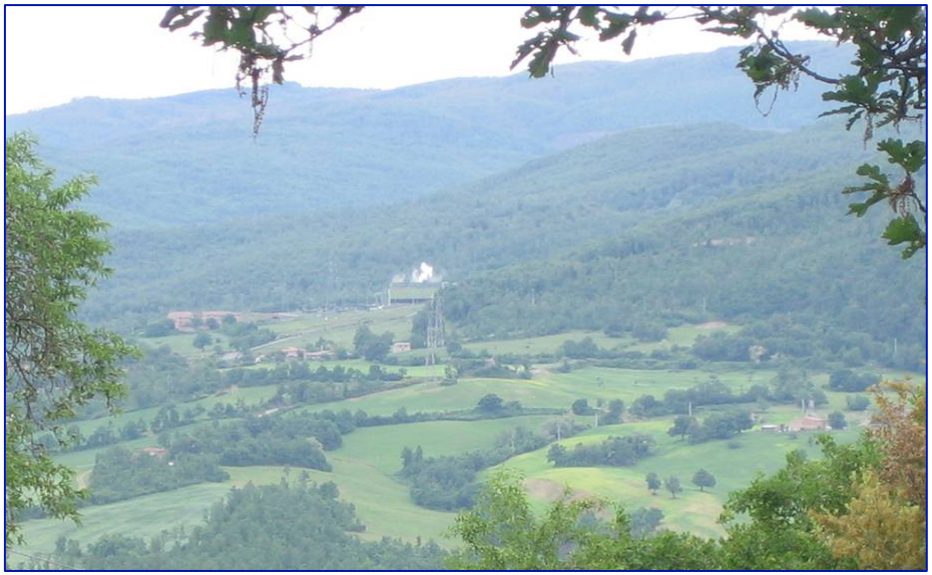
20 MW each one

Field and power plant O & M



Integrated management of geothermal resources for production optimization

Environmental sustainability



Architectural solutions to minimize the visual impact

Reduction of gas emission

AMIS (process for H2S and Hg removal)

Abatement

✓ Hg	>90%
✓ H_2S	70-80%

Geo-heat supply in Italy

DISTRICT HEATING

GREEN HOUSES

Geo-heat supply -

Getz, Warren

A fish farm in Colorado.

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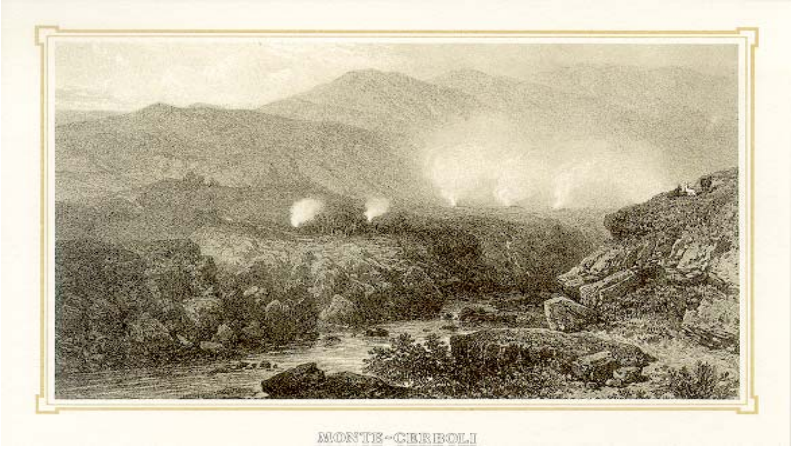
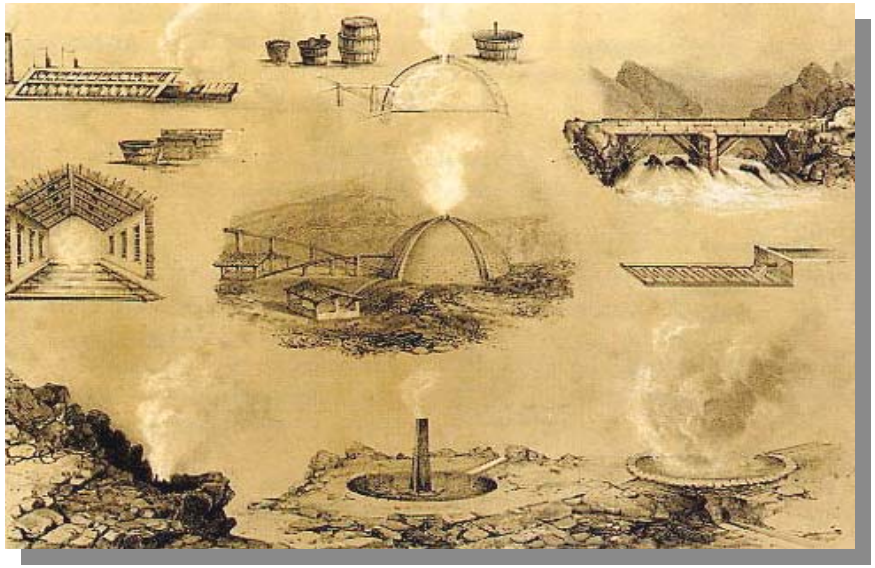
The dawn of geothermal industry in Italy

Once upon a time at Larderello (Italy)…

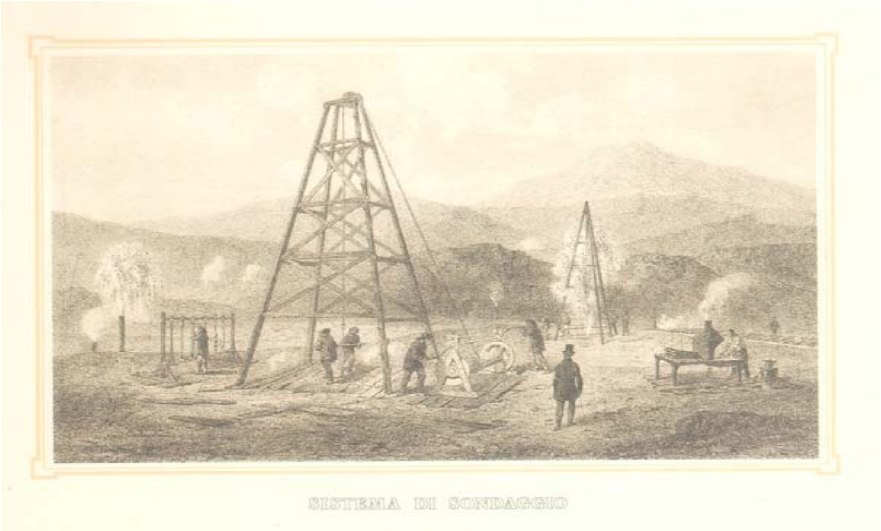


…at the underworld watchdog site...

… in the early 1800 with boric salts production and direct uses of steam



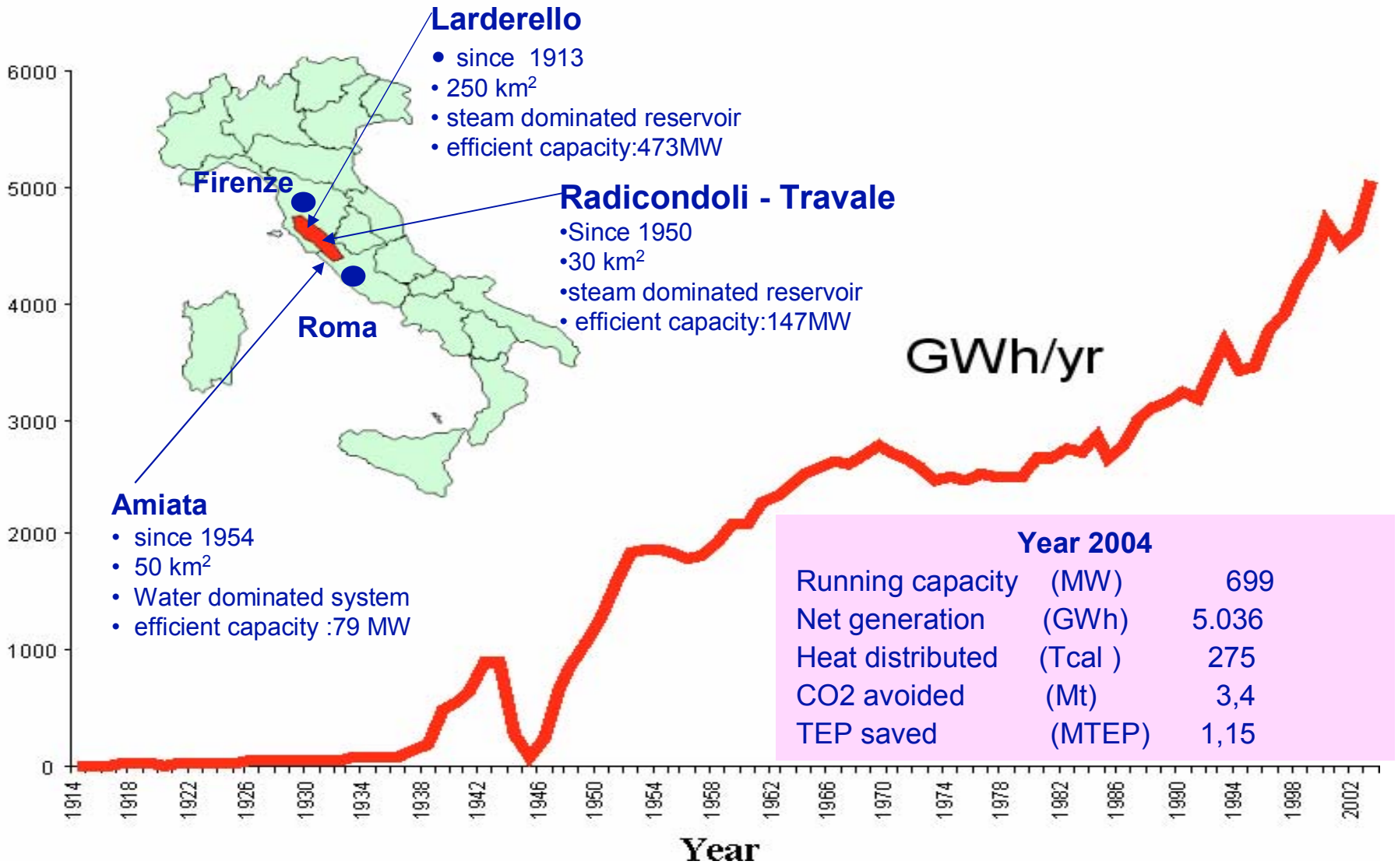
The dawn of geothermal industry in Italy



… in 1827 the first approach
to explore the hell …

… in 1904 the first experiment of
electric energy generation

Geothermal highlights in Italy



Year 2004

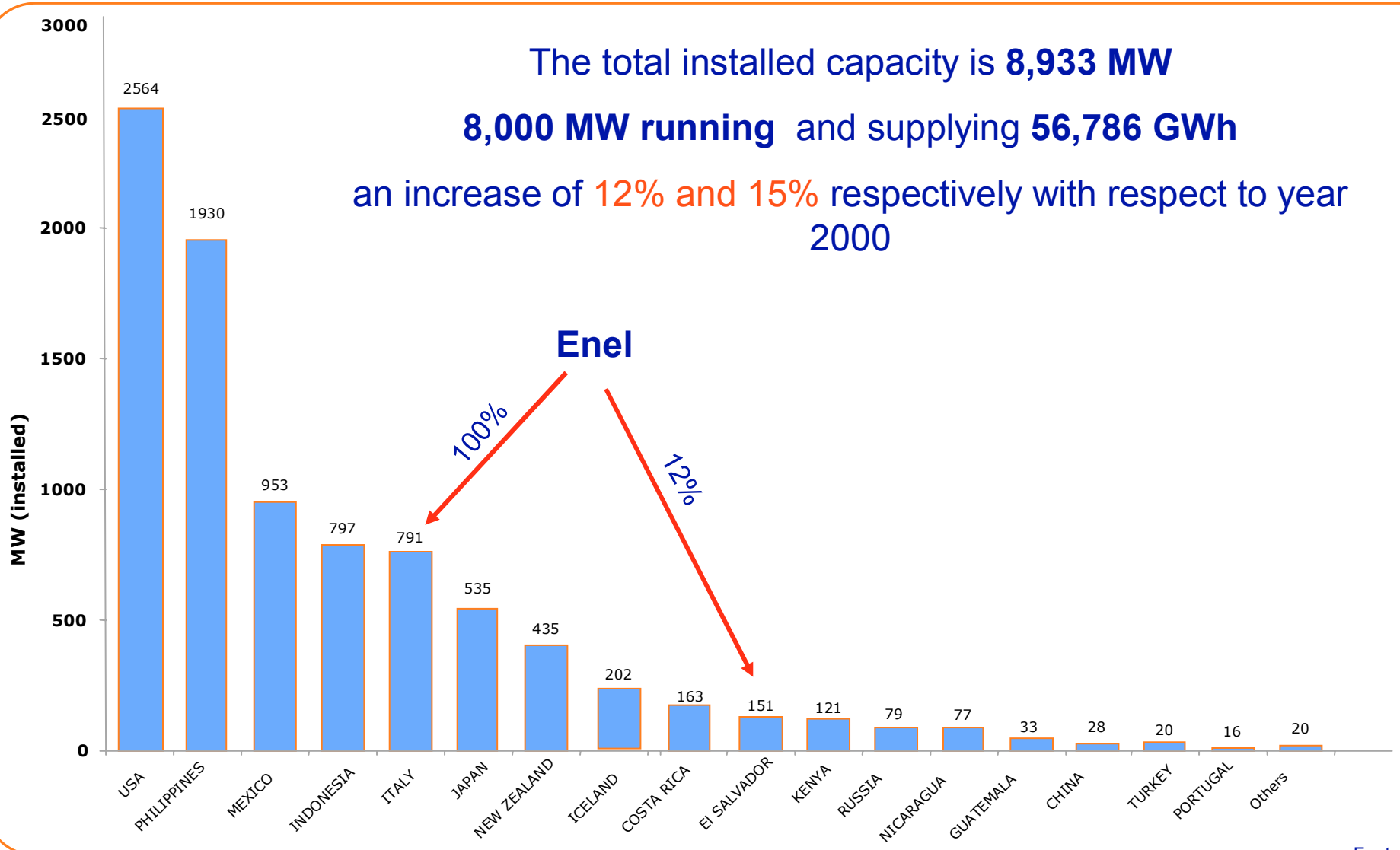
Running capacity	(MW)	699
Net generation	(GWh)	5.036
Heat distributed	(Tcal)	275
CO2 avoided	(Mt)	3,4
TEP saved	(MTEP)	1,15

Geothermal Energy Worldwide – Ytd 2004

The total installed capacity is **8,933 MW**

8,000 MW running and supplying **56,786 GWh**

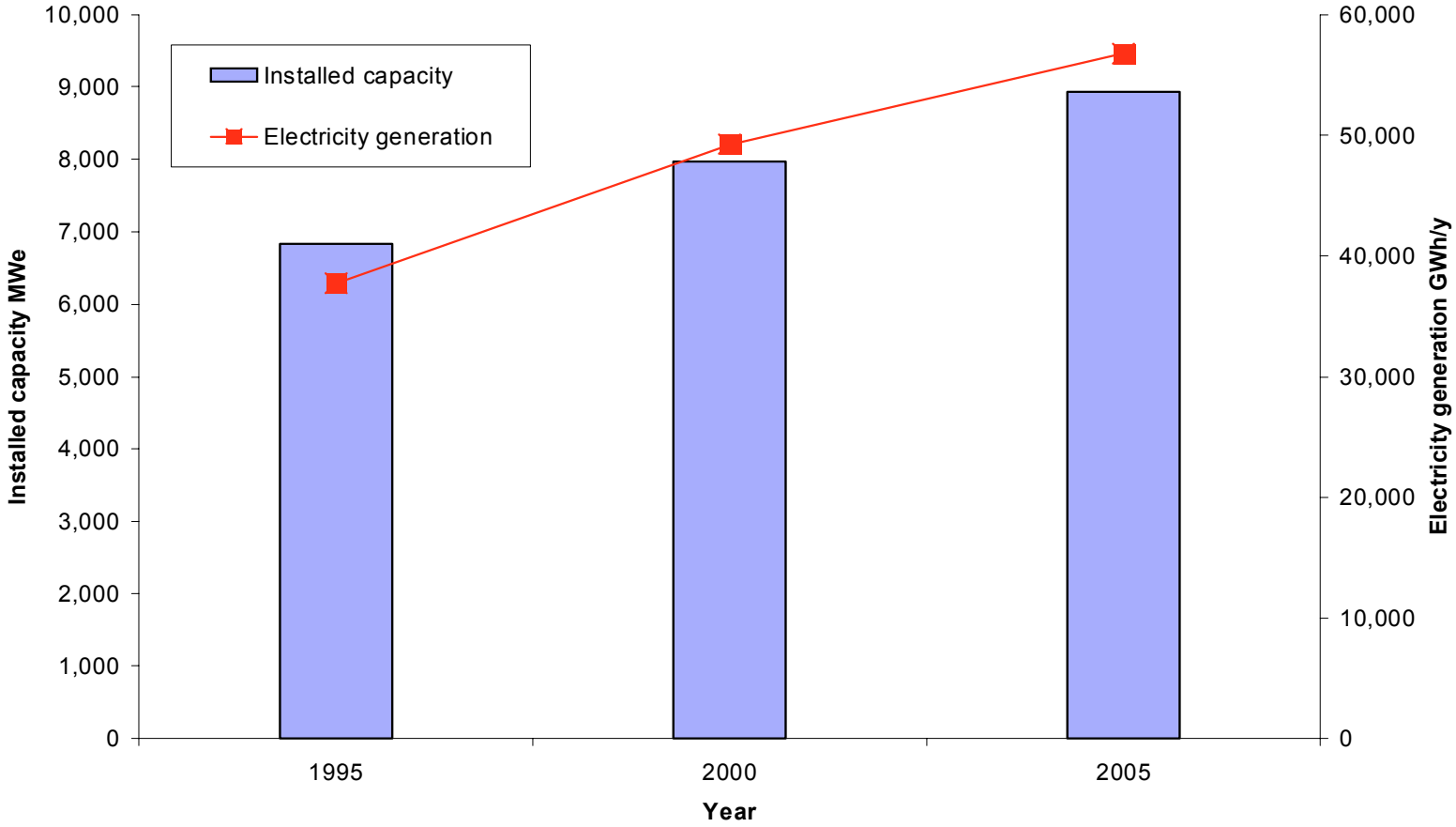
an increase of 12% and 15% respectively with respect to year 2000



Fonte: IGA 2005

Enel
L'ENERGIA CHE TI ASCOLTA.

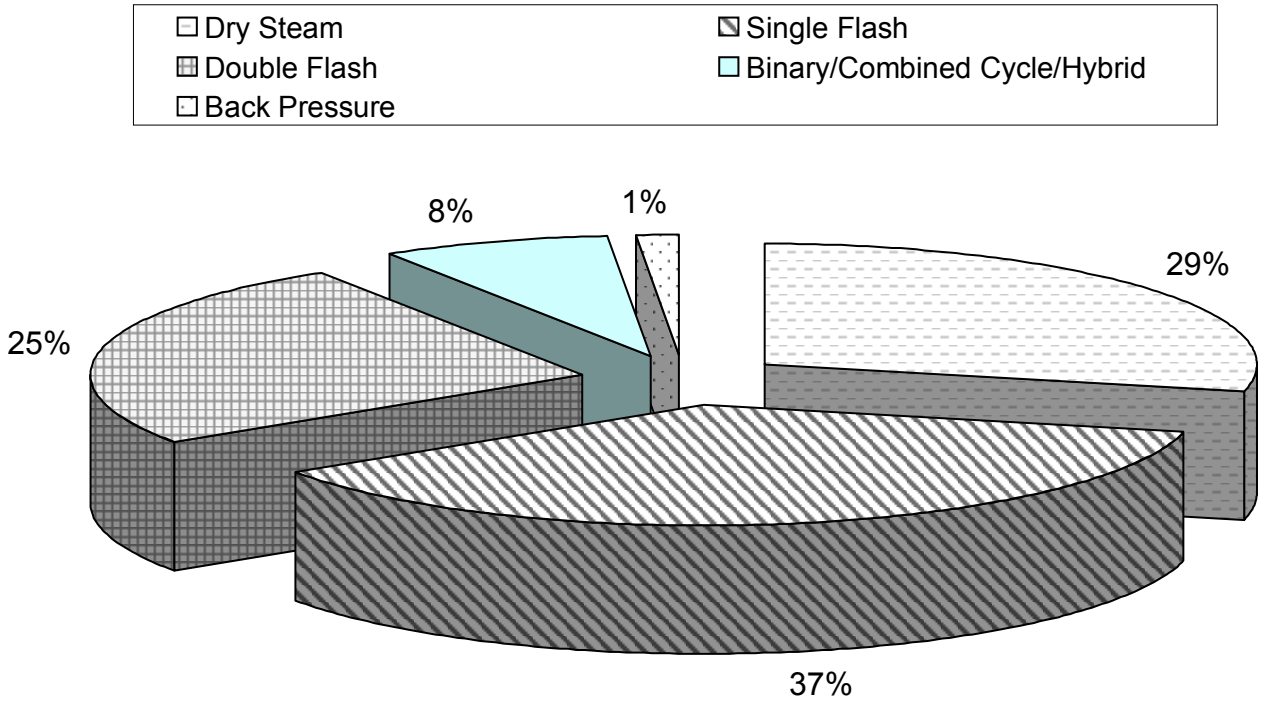
Geothermal growth



- The trend has not improved since 2000, increasing by 960 MW, **only 190 MW per year**.
- **The geothermal contributes for 0,4% on world electricity as in year 2000**

Fonte: IGA 2005

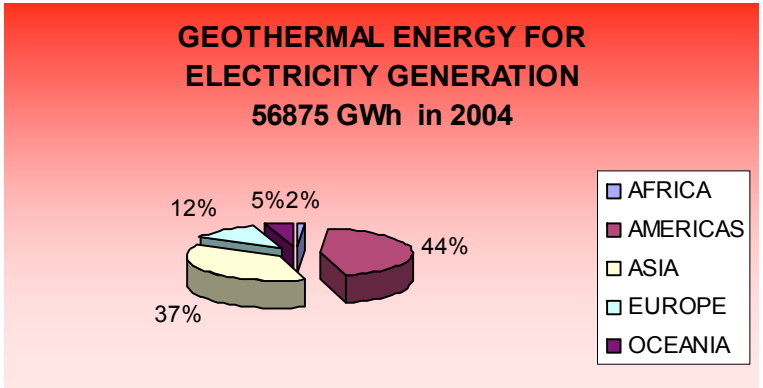
Installed capacity



- **2/3 of the total installed capacity are for dry steam and single flash units**
- **Binary units are increasing, but with a lower value of capacity per unit.**

Fonte: IGA 2005

Energy saving & pollution avoided

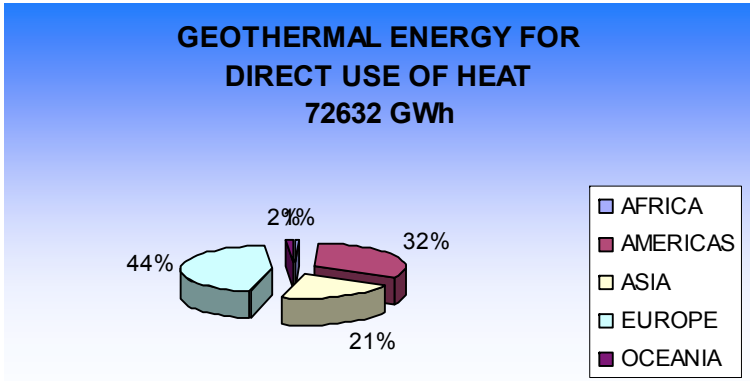


Electric use

- **Energy saving** (*) of fuel oil per year 96,6 million barrels or 14, 5 millions tonnes
- **Carbon pollution avoided** (millions tonnes year) 3 (natural gas) or 13 (oil) or 15 (coal)

Direct uses

- **Energy saving** (*) of fuel oil per year 123,4 million barrels or 18,5 millions tonnes
- **Carbon pollution avoided** (millions tonnes year) 4 (natural gas) or 16 (oil) or 18 (coal)



(*) generating electricity with 0,35 efficiency factor

Total energy saving of fuel oil per year over 220 million barrels

Total carbon pollution avoided per year over 39 (oil) million tonnes

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Drivers & barriers for geothermal growth

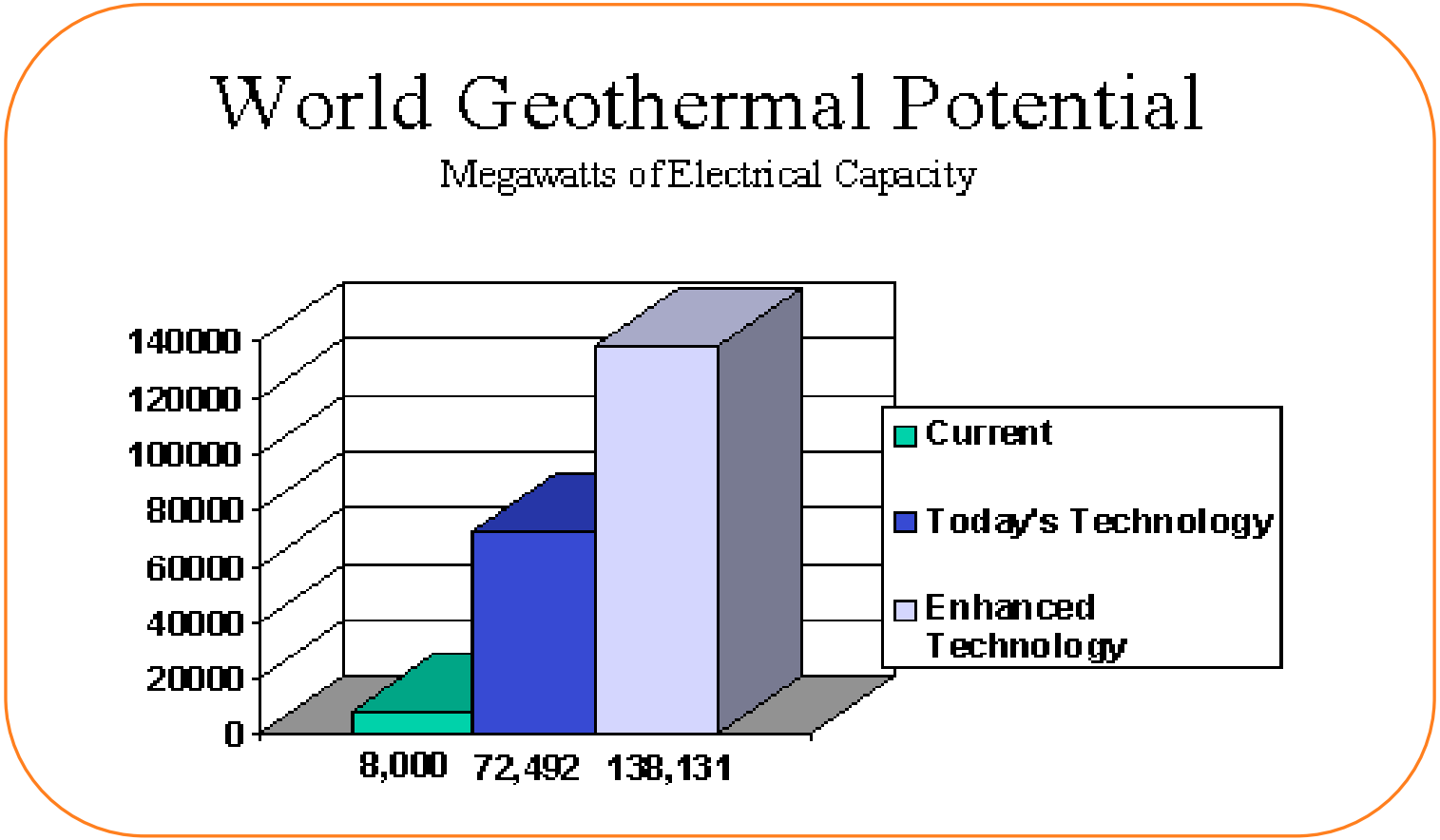
Drivers

- ✓ Great number of areas with an interesting geothermal potential
- ✓ Electrical energy demand growing within the next years
- ✓ Base load capacity, renewable and domestic energy
- ✓ Employment opportunity

Barriers

- ➢ Technological challanges for deep seated resourses
- ➢ Economic . High development cost (logistics, transmission, exploration risk in "green field" project
- ➢ Environmental - adverse impacts in some areas
- ➢ Regulatory / market / political risks

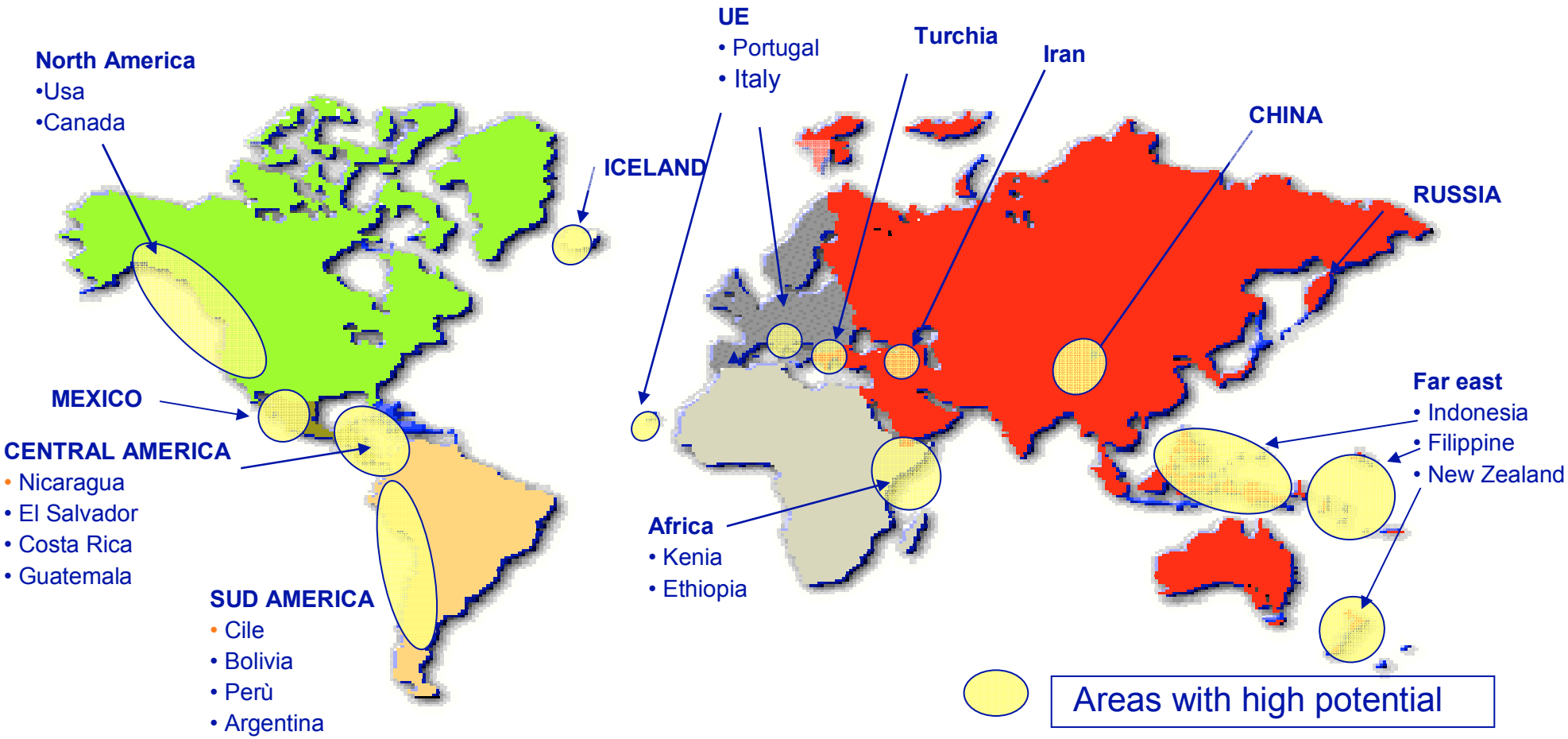
Geothermal energy



… up to 72.500 MW exploitable with existing technologies while future technologies will allow the exploitation of up to 140.000 MW …

Source: World Bank

Geothermal energy worldwide development



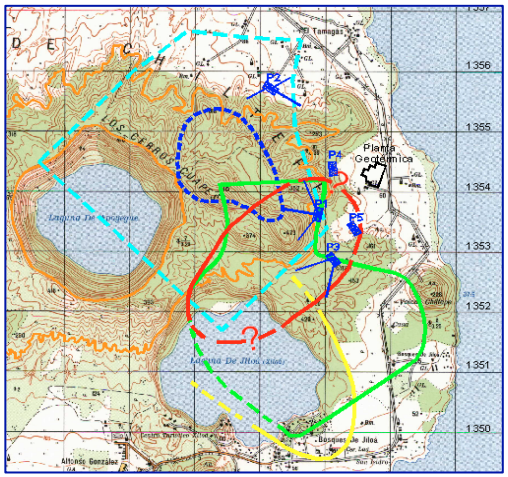
8900 MW (running) forecast to year 2010

Technological challenges

Current efforts are focused on:

- **Identifying Resources development and opportunities**
  - Resources Assessment
  - Exploration and Drilling
- **Optimizing Resource Utilization and Management**
  - Resource Management
  - Generation Technologies
- **Investigating Applications that Increase**
  - system reliability
  - environmental compatibility

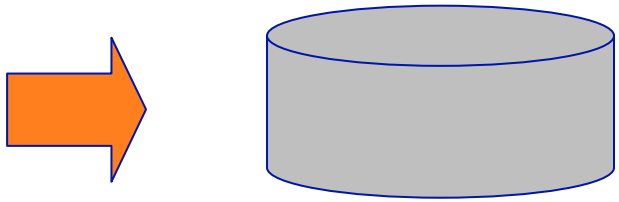
Resources assessment



Volumetric Estimation

Input parameters

- Reservoir extension
- Reservoir thickness
- Fluids temperature
- Rocks porosity (Φ)



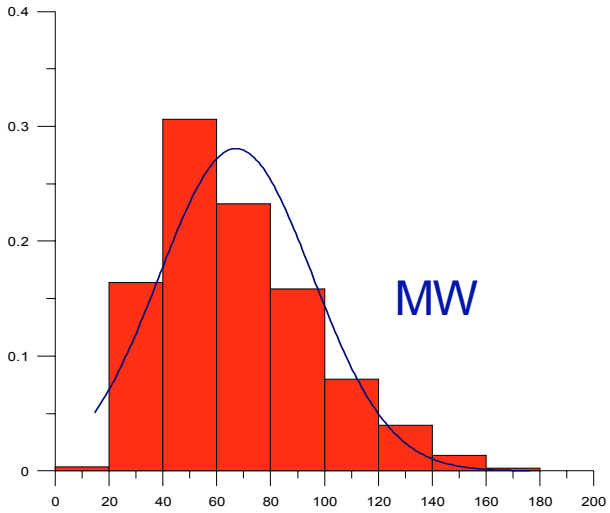
Thermal energy within a specific volume (single block)

Recovery Factor = 1.25 Φ
(literature)

Monte Carlo Simulation

Input parameters
randomly sampled
between min – max

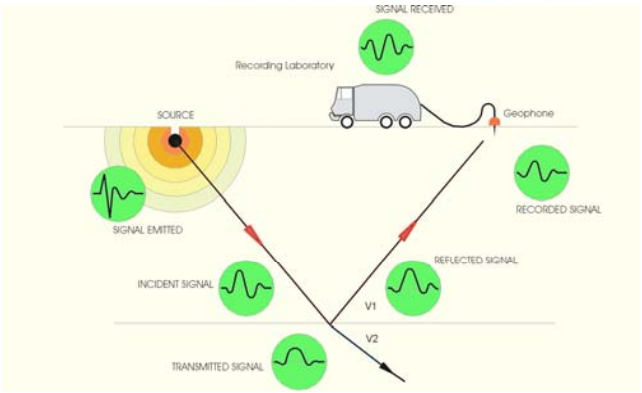
"n" years project life

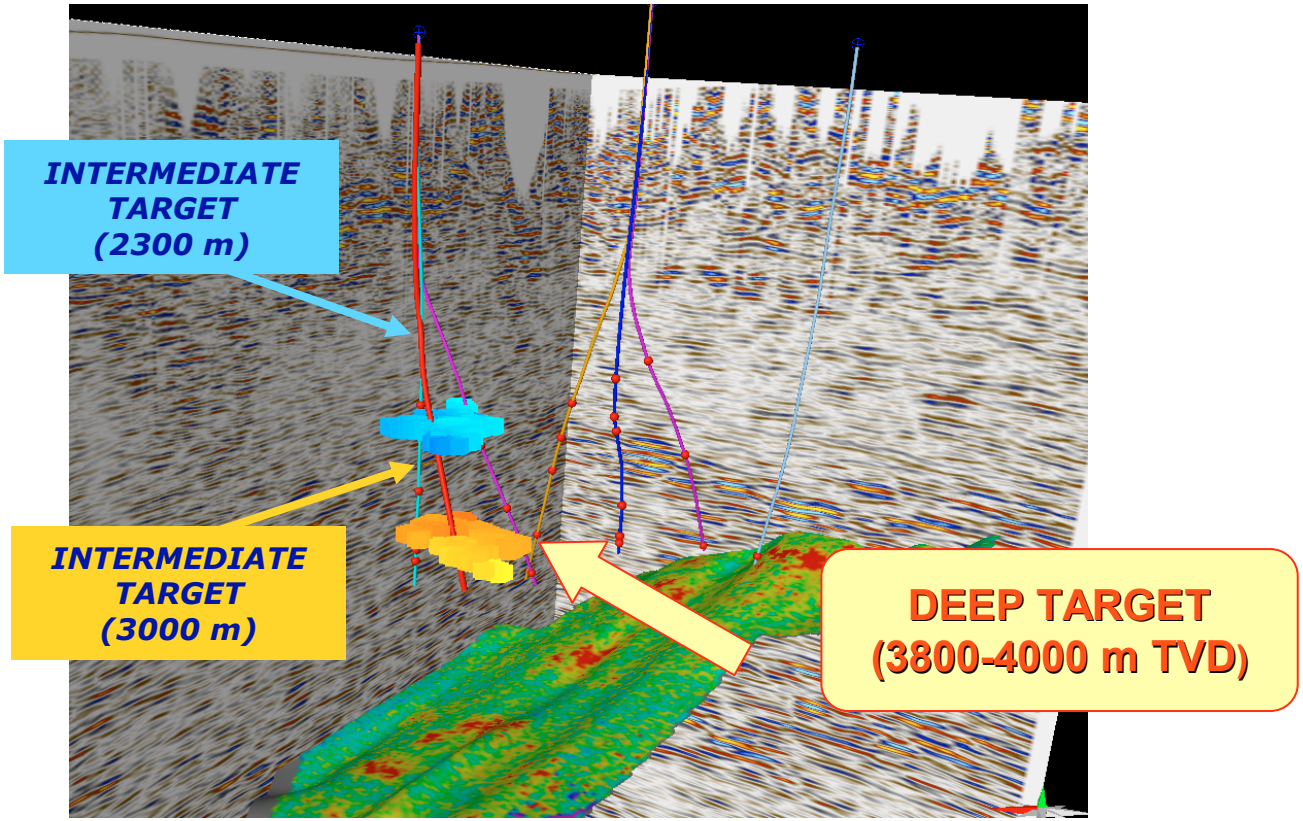


More accuracy is requested for investment valuation

Exploration & drilling technology

3D seismic is applied for target location of deep wells





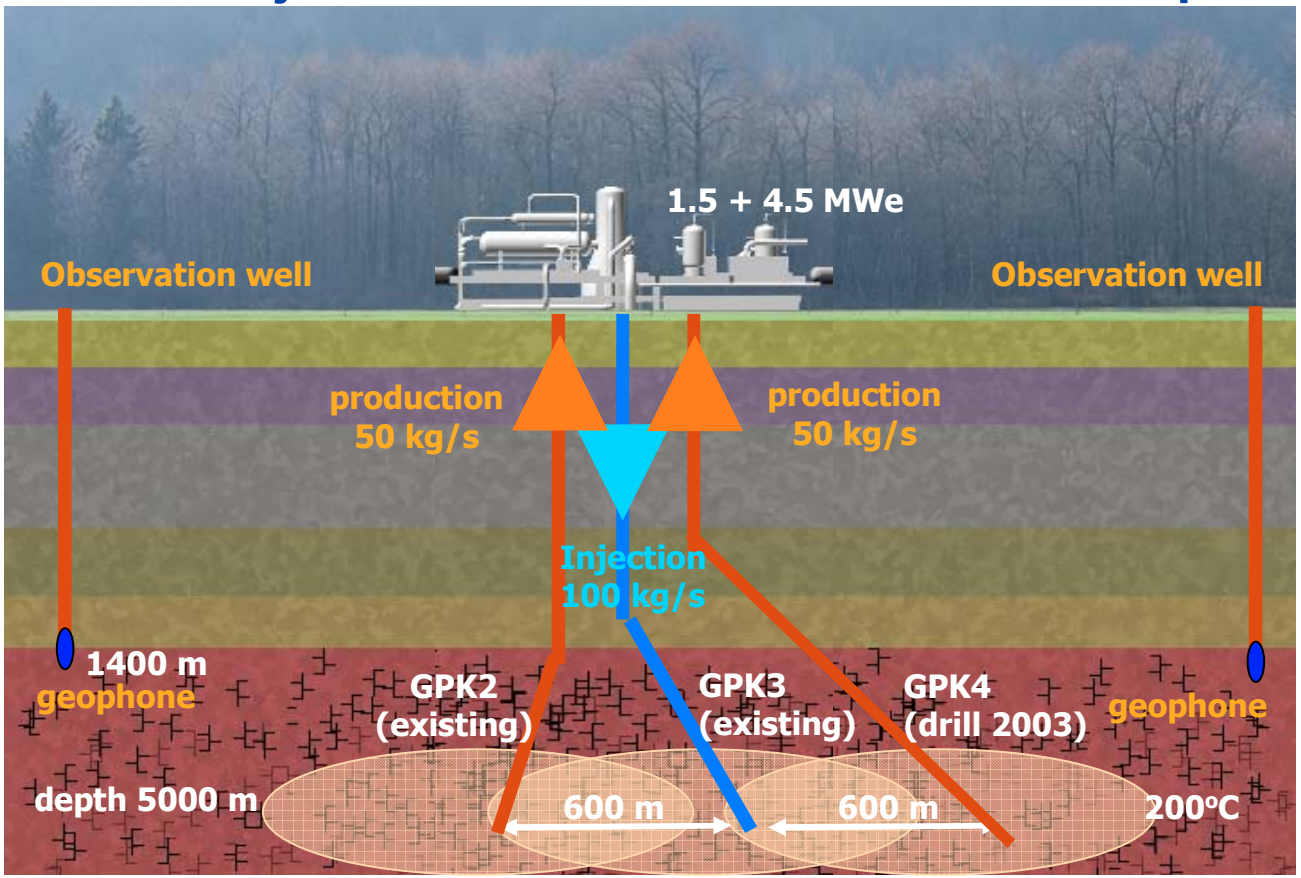
OIL & GAS TECHNOLOGICAL KNOW-HOW TO BE APPLIED

Optimizing Resource Management

SUBJECT	ANALYSIS	MITIGATION	CHECK
Permeability	Hydrogeology, Reservoir modeling	Well acidification, stimulation, etc.	Well production tests
Temperature	Geological/geophysical model, geochemistry	Nothing	Temperature log, Well production tests
High gas content	Geochemistry	Abatement for some gases, reinjection	Fluid geochemistry, O&M
Cold water ingress	Hydrogeology, Reservoir modeling	- Reinjection management, - Nothing (natural recharge)	O&M
Scaling	Geochemistry	P-T operation management, inhibitor, pipe cleaning, etc	O&M
Corrosion	Geochemistry	Inhibitor	O&M
Self sealing	Geochemistry	Well acidification	Production monitoring, Geochemical monitor.
Volcanic hazard	Volcanology	-Nothing -Civil works	O&M
Seismic hazard	Seismology	Civil works Reinjection management	O&M
Subsidence	Geophysical model, Reservoir modeling,	Nothing	Topographic monitoring

Heat mining

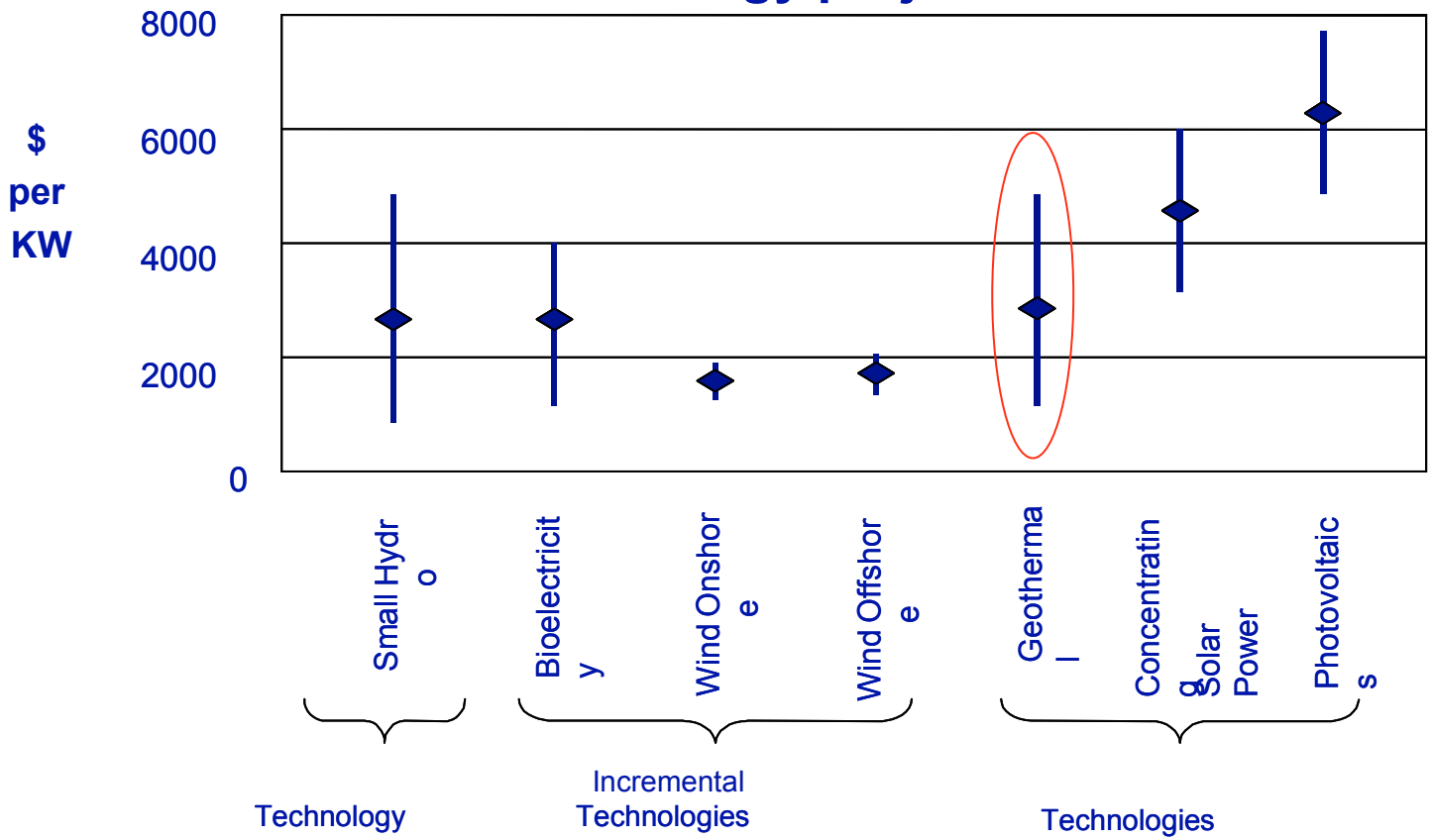
HDR Project at Soultz : the Pilot Plant concept



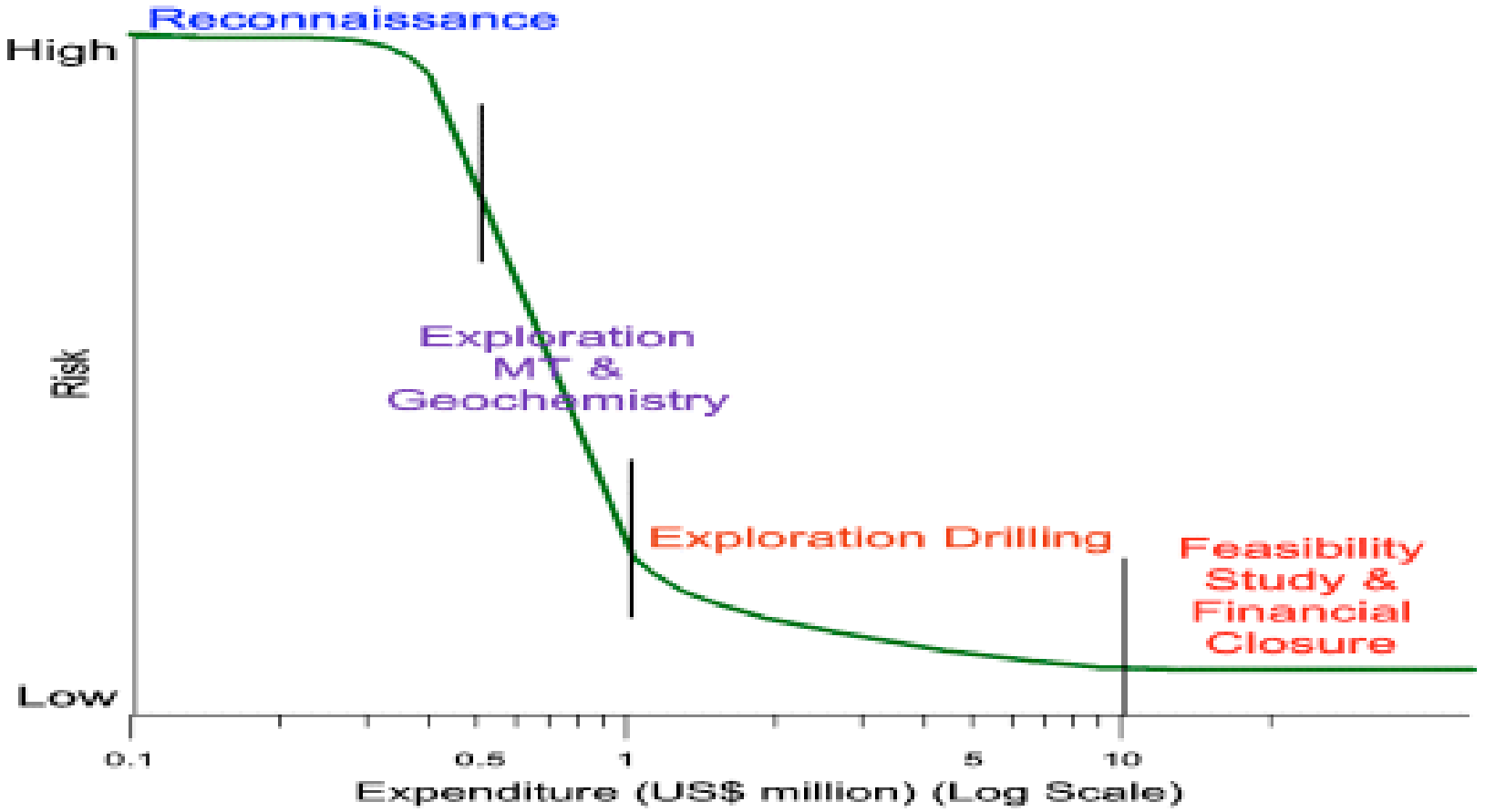
Develop advanced technology to use the huge thermal energy amount contained in the earth crust

Economic challenges

Comparison of investment expenditures for different renewable energy project



Expenditures & risks of a geothermal project



Content

1. Basic concepts
   - Heat sources
   - Geothermal systems and applied technology
   - Exploration & production process
2. The geothermal industry worldwide
   - Electric energy generation
   - Direct use application
3. Drivers & barriers for the geothermal energy growth
   - Technological challenges
   - Economic and enveronmental sustainability
4. Conclusions

Conclusions

Geothermal energy, like other renewable energy sources (RES), plays an important role to:

- ✓ **complement existing energy production systems**
- ✓ **tackle climate change**
- ✓ **contribute to an overall strategy of sustainable development**
- ✓ **reduce dependence on energy imports, thereby ensuring sustainable security of energy supply**
- ✓ **have a positive impact on regional development and employment**

Tanks for your attention

For any further information please contact me

at the following e-mail address:

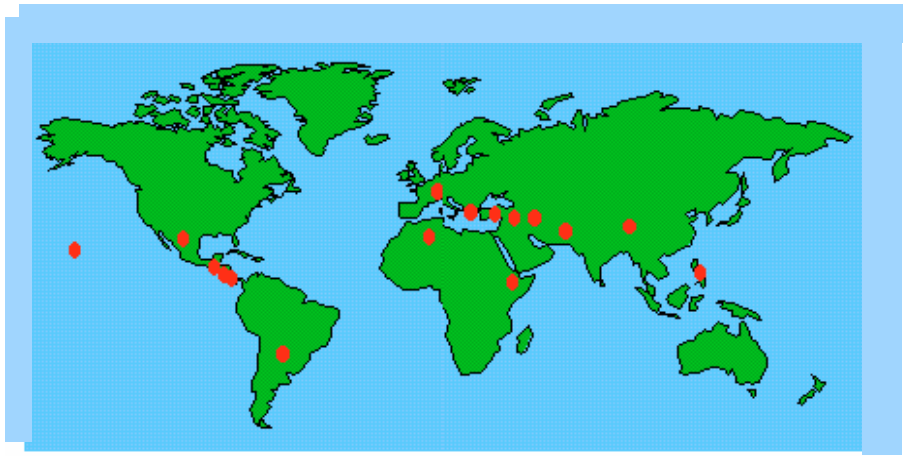
fausto.batini@enel.it

Enel's worldwide geothermal development

Enel was the first geothermal operator worldwide…

.... in 1921 at EL Tatio in the North of Chile Mr.Tocchi of the Larderello S.p.A. performed the first geothermal exploration including the drilling of two shallow wells.

Enel carried out geothermal exploration in more than 15 countries, mostly in the framework of co-operation and know-how transfer programs



Enel's worldwide geothermal development

El Salvador ➡ Strategic partnership with LaGeo

achieved through international bid

(114 MW geothermal in operation)

New project under development (50 MW)

- Geo - scientific studies to define the integrated model of the geothermal system
- Drilling of 12 wells at 1500 - 2500 meters
- Steam gathering system
- 2 new units for electric energy generation
  - •Berlin 40 MW (operation in 2006)
  - •Cuyanausul 10 MW (operation in 2007)

Enel's worldwide geothermal development

Chile ➡ Strategic partnership with ENAP

EMPRESA NACIONALE GEOTERMICA S.A.
(51% ENEL and 49% ENAP)
has been established for the exploration and development of Calabozo and Chillan geothermal concessions