Associazione Termotecnica Italiana

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Lo sviluppo e l'evoluzione della tecnologia negli Impianti geotermici per la generazione elettrica

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Con il contributo di

KSB

MASOL Continental Biofuel

Geothermal power generation
a quick evolving context


First Geothermal Power Plant, 1904, Larderello, Italy

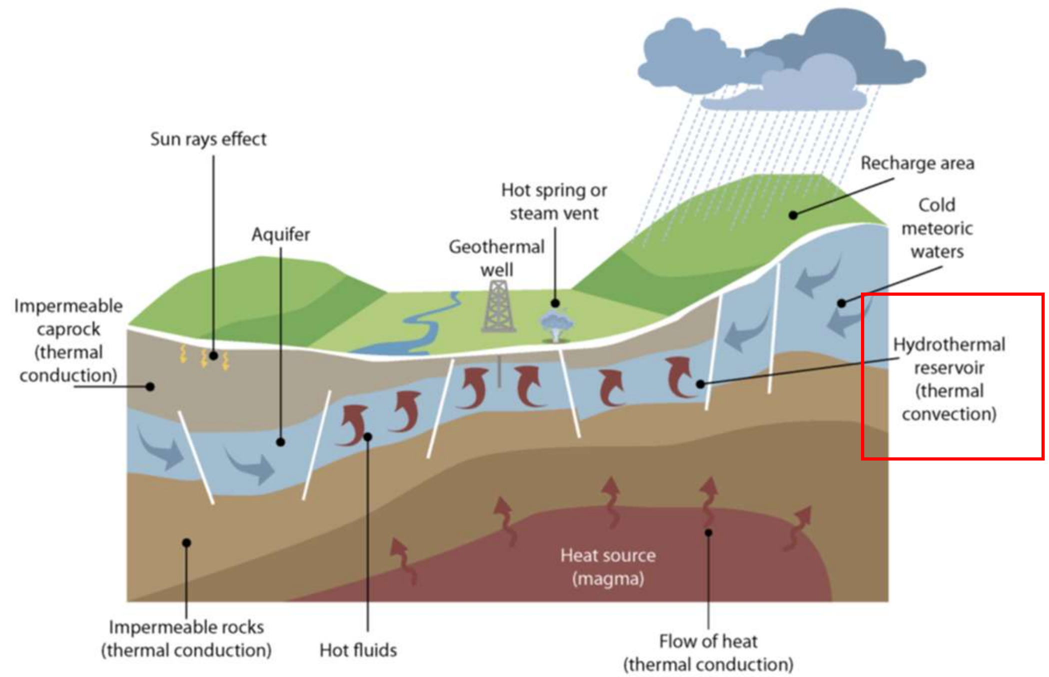
Slide 52 of 122, © 2000 Geothermal Education Office

- **New drilling technologies** are making geothermal viable almost anywhere and at competitive costs
- Rapid **AI and data-center** expansion requires continuous supply of electric power.
- **Economy of scale and standardization** allows higher return and efficiency increase
- Demand for **critical raw materials** pushes synergic technologies
- Availability of **abandoned O&G wells** calls for possible repurposing

Geothermal system

Extracting heat from underground involves circulating fluids that warm through heat exchange with hot rocks, transferring heat from a source—the hot subsoil—to a receiver, typically the earth's surface, forming a geothermal system.

Hydrothermal systems spontaneously form when meteoric water seeps in at the surface (recharge) and warms up as it exchanges heat with the hot rocks at depth



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The challenge: power plant design
Geothermal fluid temperature and properties are relevant

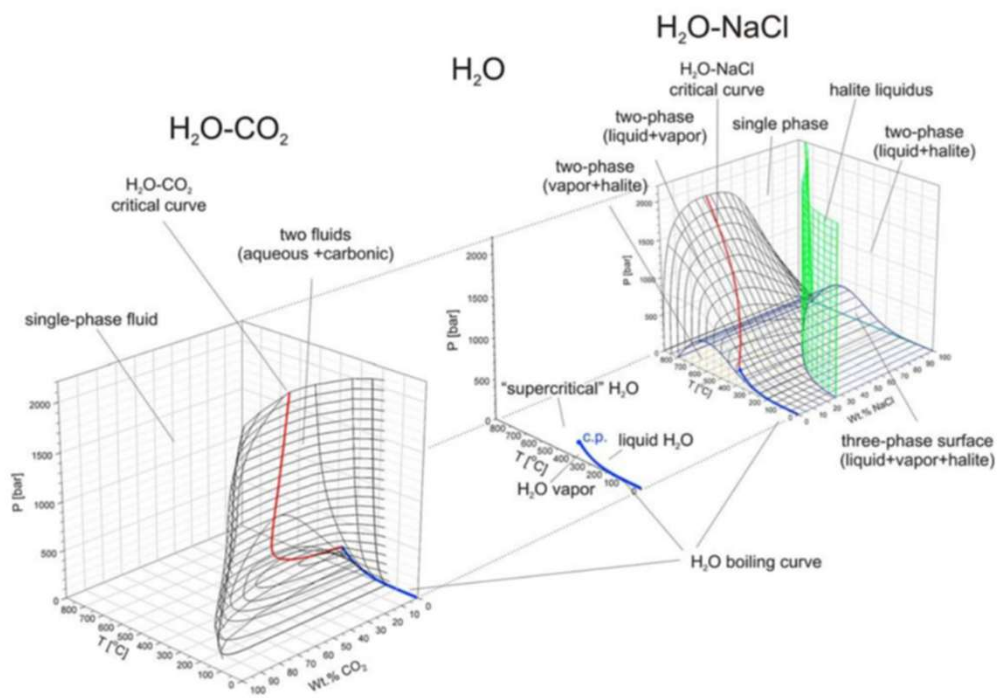
Geothermal fluid composition is site dependent!

- NCGs (mainly CO2, H2, CH4, H2S, NH3) are dissolved in geothermal brine or mixed with geothermal steam →CO2 typically more than 95%
- Dissolved solids are usually composed mainly of Na, Ca, K, Cl, SiO2, SO4, HC03. TDS values range from a few hundred to more than 300,000 mg/l. →NaCl waters are most common in geothermal systems.

Source: Marica Marcolini in Geothermal Energy: The Value Chain #3 –Reservoir Engineering & Modeling, https://mooc.uniurb.it/moodle/course/view.php?id=1360

Geothermal fluid issues in power plants:

- Mineral precipitation (scaling)
- Degassing
- Corrosion



Reviews of Geophysics, Volume: 48, Issue: 1, 2010, DOI: (10.1029/2009RG000287)

Direct steam technology evolution

Dry steam plants were developed at first, to exploiting dry steam from Larderello geothermal field

To exploit liquid Liquid dominated hydrothermal systems – the most common - the Flash technology was invented at Wairakei, New Zealand, 1958. Double flash and triple flash plants also introduced.

In both cases the geothermal fluids flows through the turbine: very simple and effective plant scheme. There are however some criticalities (scaling, droplet erosion, corrosion).

Flash plant examples:
Nga Awa Purua, NZ, 140 MW, triple flash;
Tauhara, NZ, 174 MW, the largest flash plant

Binary plant technology evolution

Main feature: two separate loops - one for geothermal fluid and one for the power conversion cycle (ORC).

Binary plants were developed to economically exploit geothermal resources characterized by a "too low" geothermal fluid temperature or when the chemical composition of the geothermal fluid make direct expansion impractical. The binary plant concept involves some intrinsic advantages: confinement of the possibly corrosive and chemical aggressive geothermal fluid in a sealed loop, feasibility of full reinjection, near-zero environmental impact, support of reservoir management)

The first plants date back to the first half of the 1900s:

- Larderello 1, Italy (1913), Citara, Italy (1940)

Binary plant technology is suitable for the exploitation of a wide variety of geothermal resources (e.g., hydrothermal systems, sedimentary basins, EGS, closed loop power generation...) in an extended range of temperatures

Recent plants:

Cerro Pabellon, Liquid brine + steam, at 160-170°C

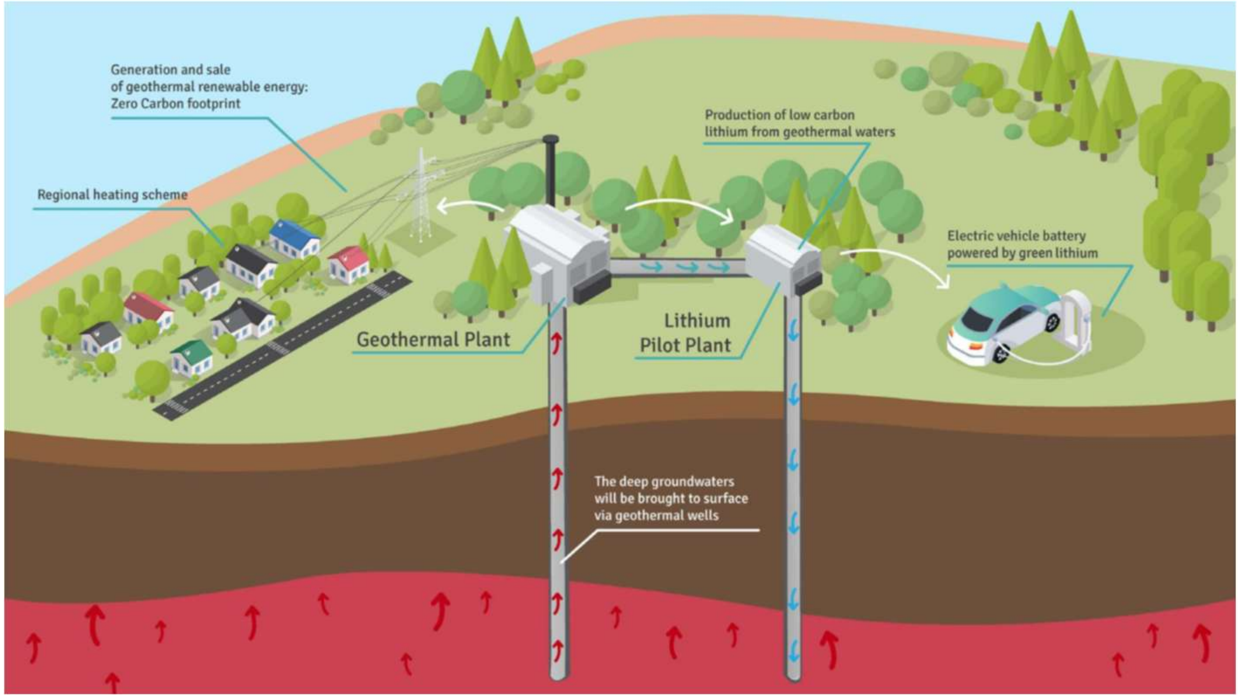
Cape Station 1 and 2 (under construction)

Synergic innovation driven by mineral extraction - mainly Lithium, Silica

Lithium occurrence in geothermal fluids: up to 400-500 mg/l

- Rhein Graben,
- Alto Lazio

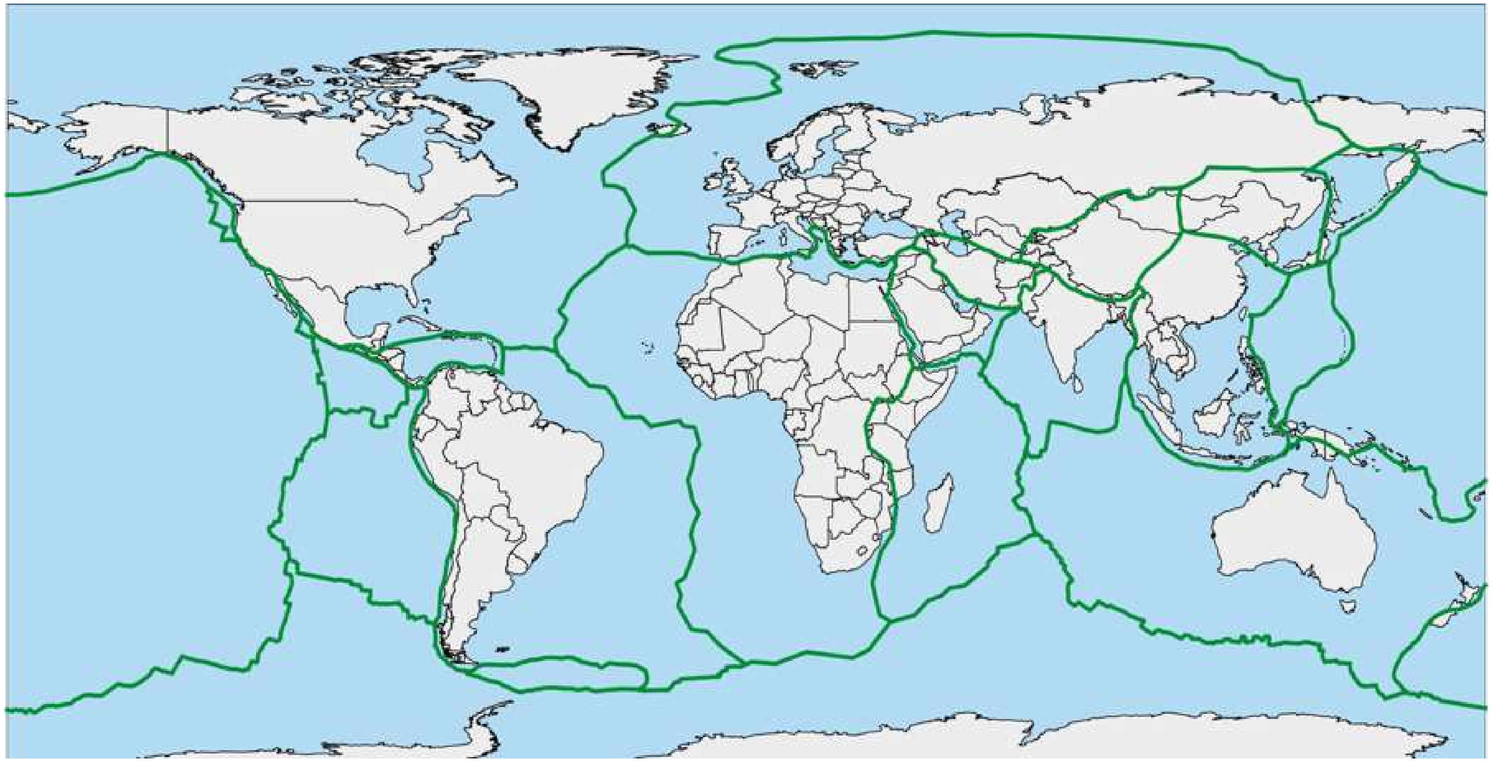
Project Lionheart by Vulcan Energy, 30 MW + 24,000 tonnes of lithium hydroxide monohydrate (LHM) per annum – under construction
https://v-er.eu/



Source: A. Dini, Geothermal Energy: The Value Chain #6-Mineralsfrom Geothermal Brines, https://mooc.uniurb.it/moodle/course/view.php?id=1360

Geothermal production in a global perspective

Plate boundaries

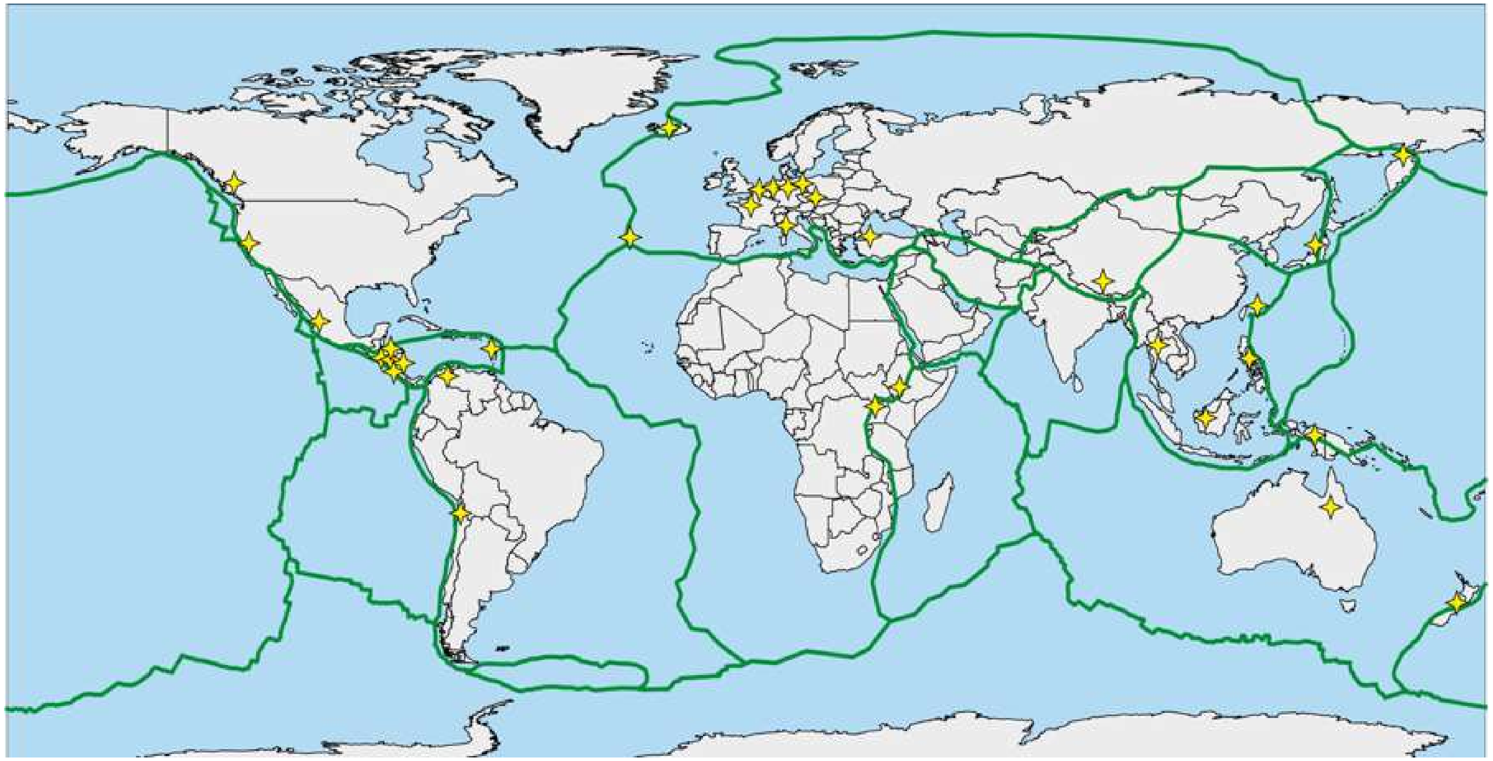


Geothermal production in a global perspective

Plate boundaries

Geothermal power plants

When geothermal energy was first used for large-scale electricity, the hottest areas were targeted. Even now, the distribution of production plants mostly resembles tectonic maps of plate boundaries.



Geothermal power generation growth

Source: ***Worldwide Geothermal Power 2020-2023 Update Report*** *Luis C.A. Gutiérrez-Negrín, Proceedings World Geothermal Congress 2023 Beijing, China, September 15-17, 2023*

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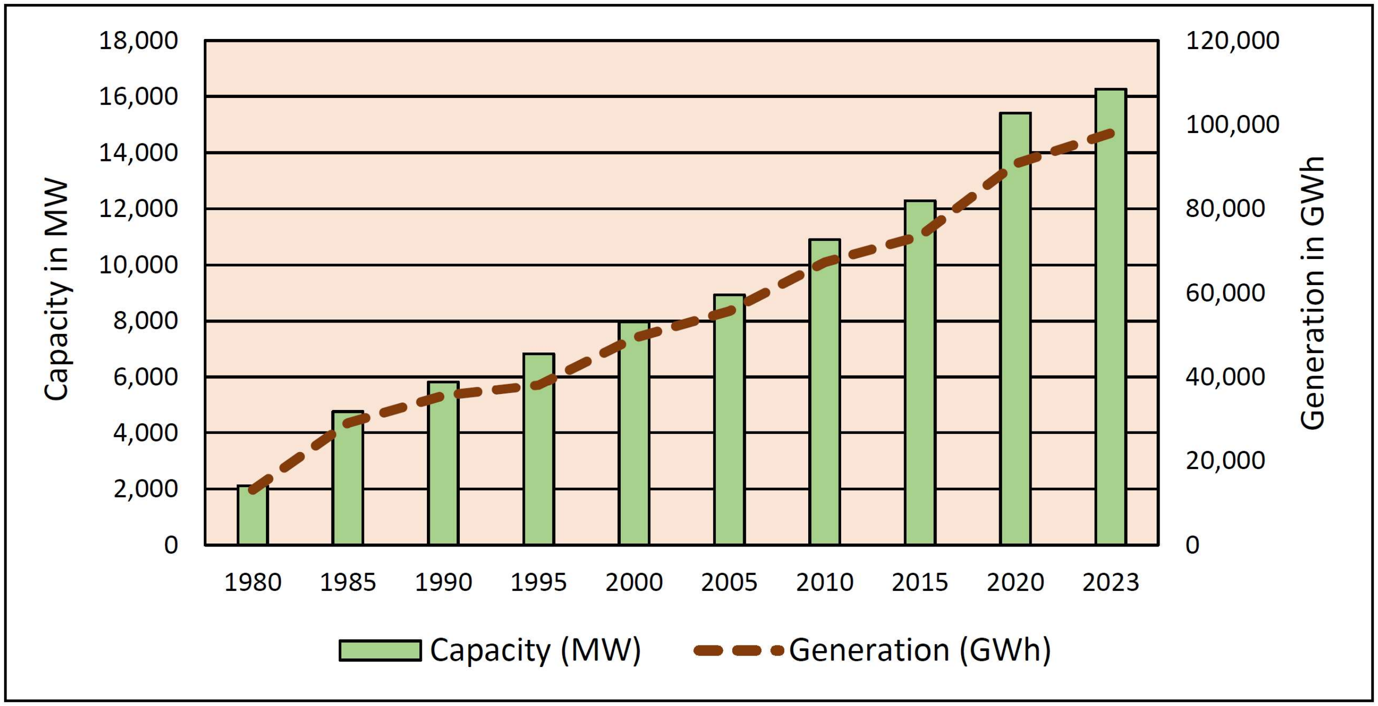

Fig. 1. World geothermal capacity and electric generation between 1980 and 2023. Electric generation in 1980 and 1985 are estimated.

Current geothermal power generation
0.30 percent of total global electricity generation in 2024

For the picture see

https://www.thinkgeoenergy.com/global-top-10-geothermal-power-countries-at-year-end-2025/

Source: Richter, A. (2026), **Global Top 10 Geothermal Power Countries at Year-End 2025.**. ThinkGeoEnergy webiste,. published January 12, 2026

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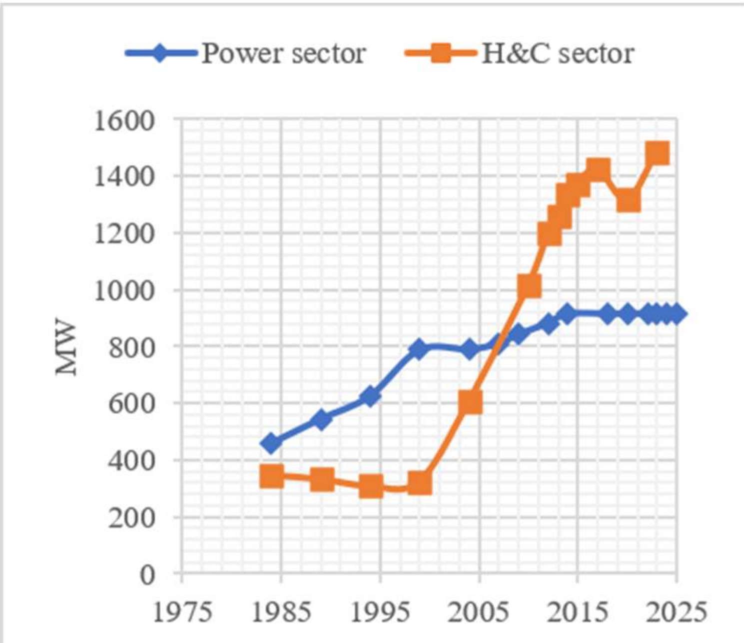
Current geothermal power generation in Italy



Source: ***Country Update: Italy,*** *DELLA VEDOVA, B., CEI, M., CONTI, P., Proceedings of the World Geothermal Congress 2026, Calgary, Canada*

Total Installed power as of 2024: 915.8 Mwe
Gross generation to approximately 5,600 GWh

Geothermal energy

- ✓ represents 2.1% of national electricity production
- ✓ supplies over 30% of Tuscany's needs.

Larderello: 594.8 MWe of installed capacity, 22 units.

Travale-Radicondoli: 200 Mwe, 8 units

Mount Amiata: 121 MWe across seven units.

Next Generation Geothermal

spreading geothermal out of traditional, intrinsically favoured regions

Advances in drilling technology are enabling greater depths at lower costs, paving the way to Next Generation Geothermal

- **EGS - Enhanced / Engineered Geothermal Systems**
- **AGS – Advanced Geothermal systems (closed loop)**
- **SHR – Super Hot Rock**

Next generation geothermal systems provide a very high technical potential but significant progress is needed for economic viability (IEA, 2024).

EGS – Enhanced / Engineered Geothermal System

First concept from the 70's - Unlocked by new drilling technologies derived from O&G,

- **RECENT ACHIEVEMENTS**
- Horizontal drilling
- Improved reservoir stimulation techniques
- Increased fluid circulation rate

- **EGS CHALLENGES**
- Induced seismicity
- Fluid circulation
- Change in permeability over time
- Economics

For the picture see fig. 2

https://doi.org/10.31223/X52X0B

Source: Jack H. Norbeck and Timothy M. Latimer, Commercial-Scale Demonstration of a First-of-a-Kind Enhanced Geothermal System,

EGS – Enhanced/ Engineered Geothermal System

EGS development is driving power plant technology evolution

ORC Technology trend
Standard modules, ORC Turbine capacity scale-up, reaching 50-100 MW , adapting working fluid and plant scheme to increasingly higher geofluid temperatures

Focus on EGS projects:

Cape Station by Fervo Energy

Phase 1: 200°C, 3 x 40 MW, under construction

Phase 2: 220°C, 3 x 60 MW, under construction

For the picture see fig. 6

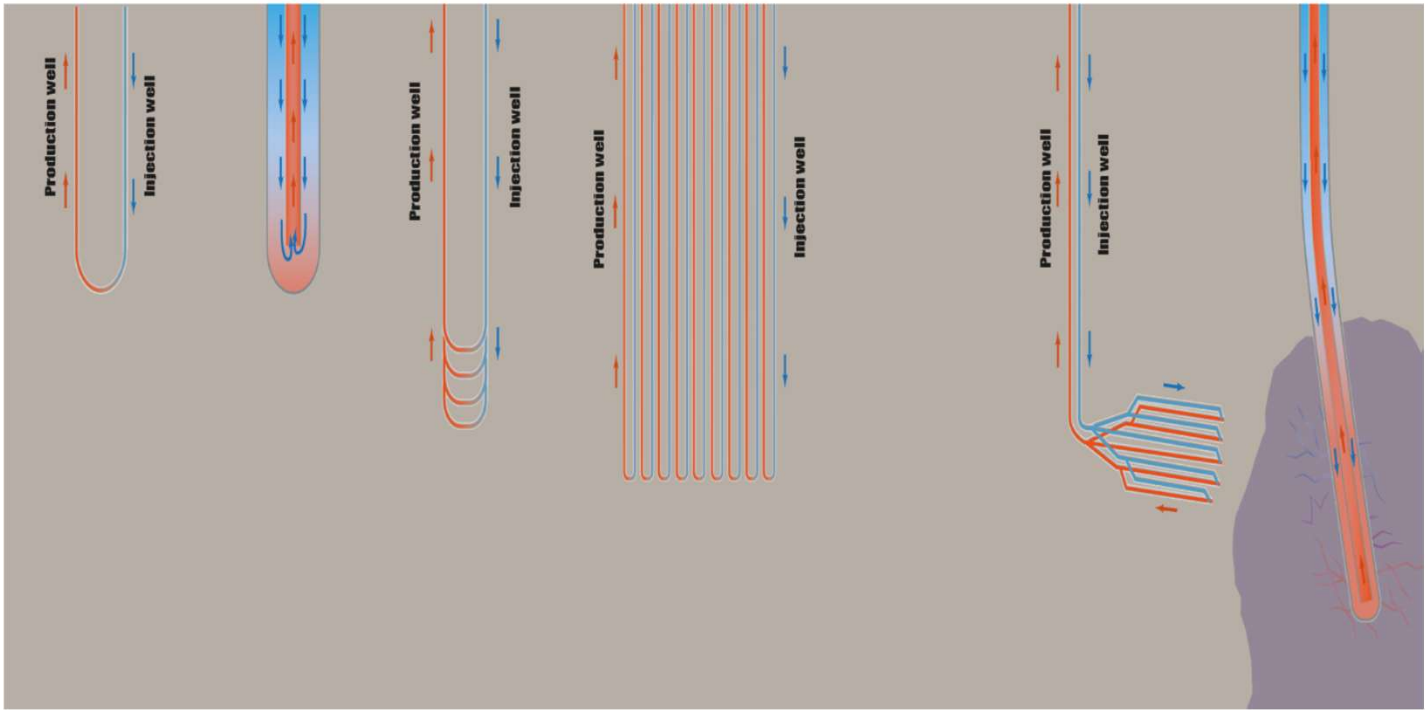
https://doi.org/10.31223/X52X0B

Modified after: Jack H. Norbeck and Timothy M. Latimer, Commercial-Scale Demonstration of a First-of-a-Kind Enhanced Geothermal System,

AGS – advanced geothermal systems (deep closed loop)
create a closed loop artificial geothermal system

Recent advances in drilling technology are facilitating the development and demonstration of closed-loop geothermal systems: a working fluid circulates through a sealed, deep, underground heat exchanger, also called advanced geothermal systems (AGS).

The aim is to reach great depths and high temperatures and produce energy in any area around the world, regardless of the presence of high permeability and fluid content



Source GEOTERMOOC Geothermal Energy: The Value Chain, Adele Manzella, #1 -Introduction to the Geothermal Value Chain

AGS – advanced geothermal systems (deep closed loop)

For picture see fig. 5

https://eavor.com/blog/technical-update-from-geretsried-what-we-built-what-we-learned-and-what-comes-next/

Closed loop – AGS designs range from vertical single-well loops to multilateral horizontal configurations. Coaxial and thermosiphon systems are both in development

Focus on AGS projects:

Geretsried by EAVOR, 8 MW

Only six of the planned twelve lateral pairs in the first Eavor-Loop were completed, with only a portion of those contributing meaningfully to flow. Thus, the output of the Geretsried site is strongly reduced

Source: Technical Update from Geretsried: What we built, what we learned, and what comes next

Other projects under construction (Greenfire)

Next Generation Geothermal
Super Hot Rock

Large scientific and collaborative effort required

A few examples

Krafla Magma Testbed: https://kmt.is/

Project Obsidian by Quaise,
https://www.quaise.com/news/introducing-project-obsidian
«For the first time, we're building a plant designed to generate electricity where Earth's natural heat is most powerful: 300-500°C» - goal 250 MW power plant, expected for 2030

https://kmt.is/

Grazie per l’attenzione

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