GALGARO ANTONIO
Università di Padova
Centro Levi Cases
Dipartimento di Geoscienze

Corso Energia e sostenibilità nel XXI Secolo

Modulo di Geotermia

1 LEZIONE: GEOTERMIA PER LA PRODUZIONE RINNOVABILE DI ENERGIA ELETTRICA

FONTI ALTERNATIVE

• SONO QUELLE FONTI , NON RINNOVABILI, ALTERNATIVE AGLI IDROCARBURI (PETROLIO E DERIVATI , CARBONE , GAS NATURALE).

FONTI RINNOVABILI

• SI RINNOVANO IN TEMPI BREVI
• SONO INESAURIBILI
• SONO PRESENTI SU TUTTO IL PIANETA TERRA
• HANNO UN IMPATTO AMBIENTALE RIDOTTO





FONTI ENERGETICHE RINNOVABILI PERCHE':

MOTIVI AMBIENTALI
(riduzione effetto serra e inquinamento dell'aria)

DIVERSIFICAZIONE DELLE FONTI ENERGETICHE (miglioramento della sicurezza degli approvvigionamenti)

RIDUZIONE DEL RISCHIO DI FLUTTUAZIONE DEI PREZZI DEI PRODOTTI PETROLIFERI (quale riserva esauribile)

RICADUTA ECONOMICA ED OCCUPAZIONALE (investimenti in una nuova industria ad elevato contenuto tecnologico)

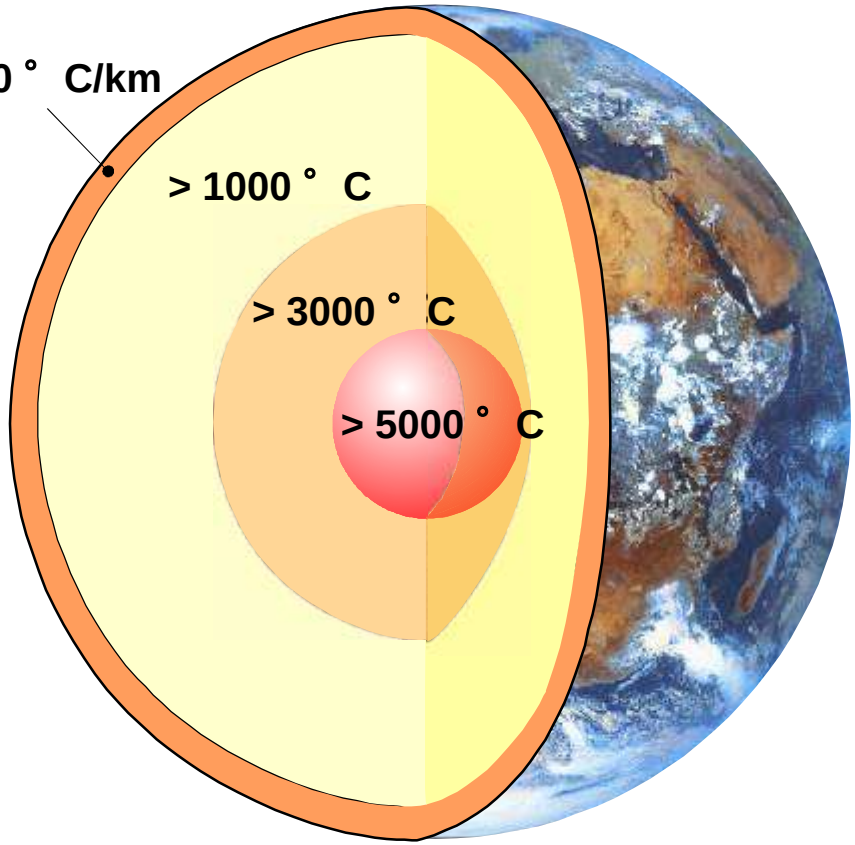
SVILUPPO SOSTENBILE (COME DEFINITO DALLA COMMISSIONE DELL'AMBIENTE E SVILUPPO DELL'ONU)

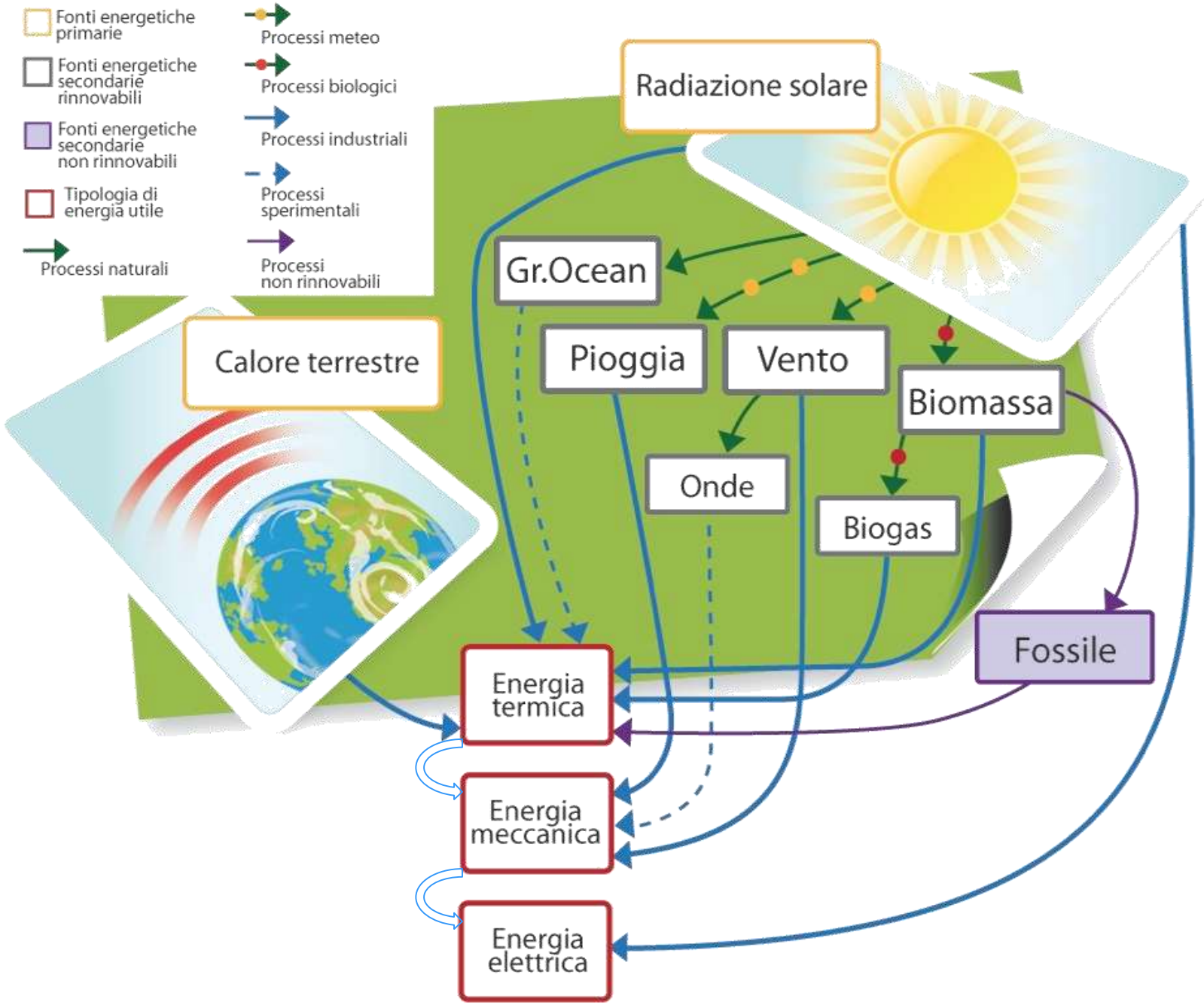
"LO SVILUPPO SOSTENIBILE È UNO SVILUPPO CHE SODDISFA LE ESIGENZE DEL PRESENTE SENZA COMPROMETTERE LA POSSIBILITÀ PER LE GENERAZIONI FUTURE DI SODDISFARE I PROPRI BISOGNI".

Concetti principali

L'energia geotermica, nella sua accezione completa, è l'energia termica immagazzinata sotto la superficie terrestre.

In principio lo 0.1% dell'energia immagazzinata nella crosta terrestre potrebbe soddisfare la richiesta energetica mondiale per 10.000 anni




Fonti energetiche primarie
Fonti energetiche secondarie rinnovabili
Fonti energetiche secondarie non rinnovabili
Tipologia di energia utile
Processi naturali
Processi meteo
Processi biologici
Processi industriali
Processi sperimentali
Processi non rinnovabili
Radiazione solare
Calore terrestre
Gr.Ocean
Pioggia
Vento
Biomassa
Onde
Biogas
Fossile
Energia termica
Energia meccanica
Energia elettrica

What is Geothermal Energy?

⇨ **Geothermal energy is a "green nuclear power"**

Occurrence of „primordial" radionuclides (existing since formation of elements) :

Uranium: ^{238}**U** - 4,5 · 10^9 y, decay chain, 1 ppm ≙ 12,4 Bq/kg

^{235}**U** - 0,7 · 10 [illegible] Bq/kg

Thorium: ^{232}**Th** - 1,4 · 1 [illegible] 07 Bq/kg

Potassium: ^{40}**K** - 1,2 · 10^{9} [illegible]

element	mean content in earth's crust	[illegible]ion
U	2,5 ppm	0,24
Th	10,3 ppm	0,26
K	2,87 %	0,09
Σ		**0,60**

total heat production:

Radioactivity (crust):

≈ 0.9 · 10^{21} J/ y

Gravitation (mantle, core):

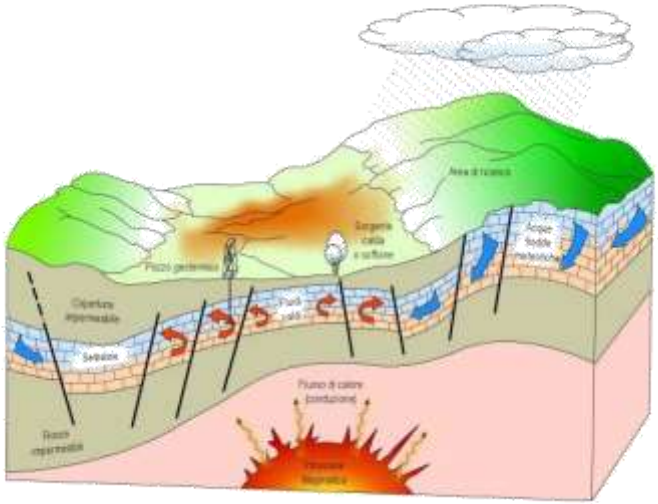
≈ 0.3 · 10^{21} J/ y

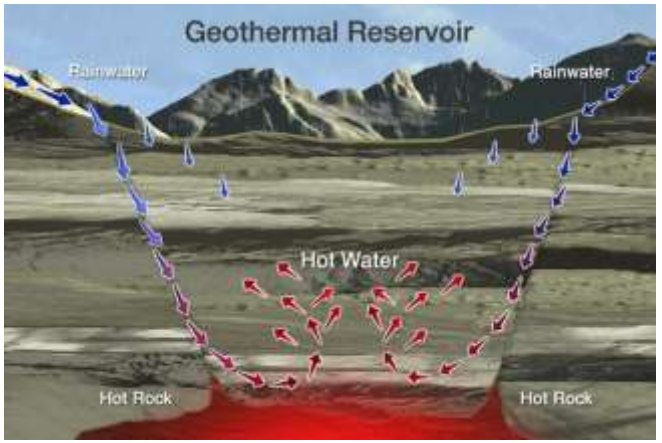
Stober, I., Bucher, K.: Geothermie, Springer Berlin Heidelberg 2012

Introduzione (1)

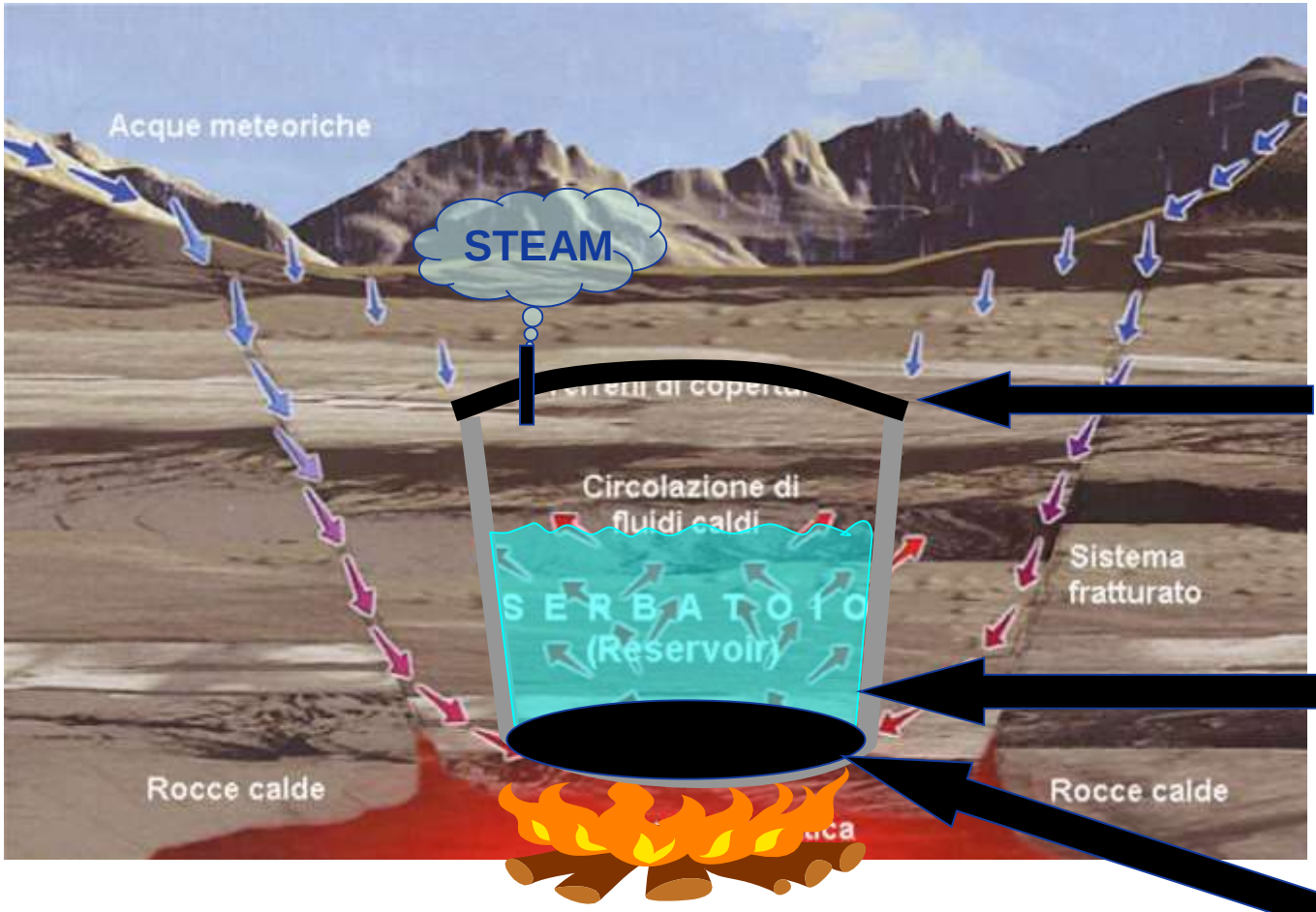
L'energia Geotermica è generata dal calore terrestre.
L'origine di questo calore è legato alla natura interna del nostro pianeta e con i processi fisici che in esso hanno luogo;
E' una risorsa diffusa praticamente inesauribile (se sfruttata correttamente), costantemente disponibile nel tempo, rinnovabile e a bassissimo impatto ambientale.

Figura 4
Rappresentazione schematica di un sistema geotermico





What is Geothermal Energy?

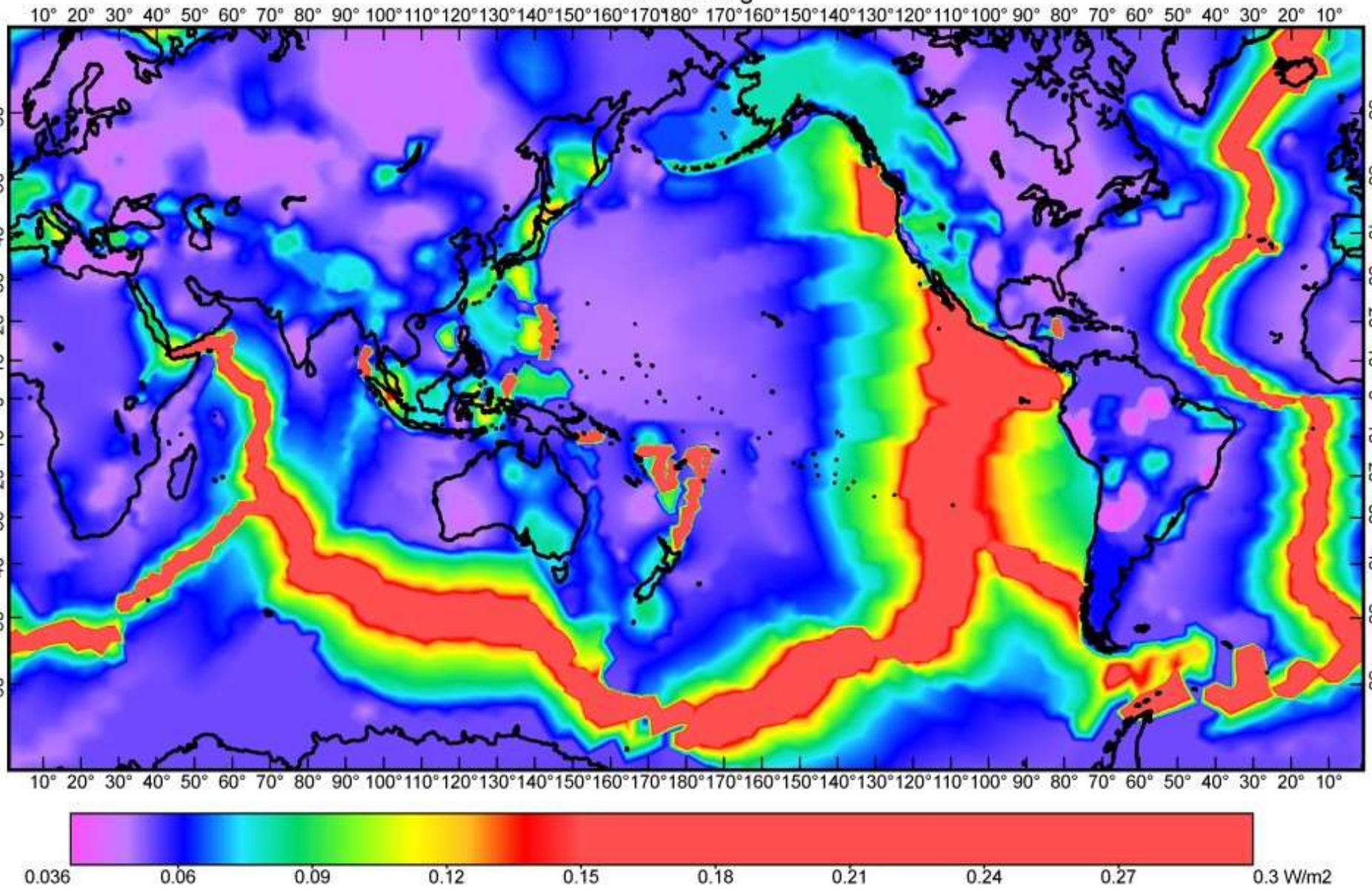


Impermeable coverage

Reservoir: fluid inside a porous and permeable rock)

Impermeable basement

Heat source


Heat Flow
Earth5E.feg
10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180° 170° 160° 150° 140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40° 30° 20° 10°
60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60°
0.036
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27
0.3 W/m2

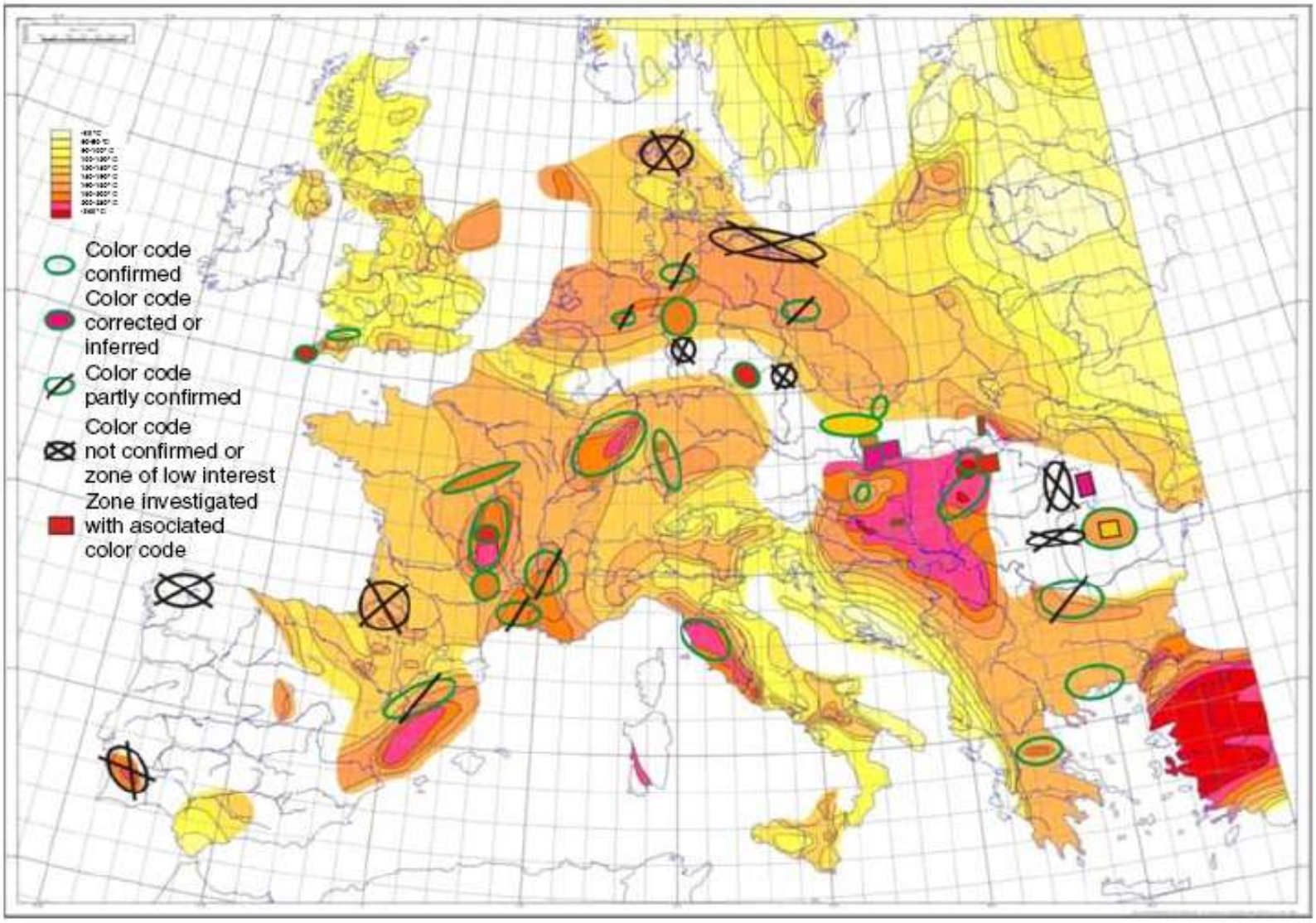


Figure 1.11 Map of temperature at 5 km depth, as inferred from unavailable (confidential) BHT measurements (Hurtig *et al.*, 1992; EIEG, 2000) and critical analysis by Genter *et al.*

What is Geothermal Energy?

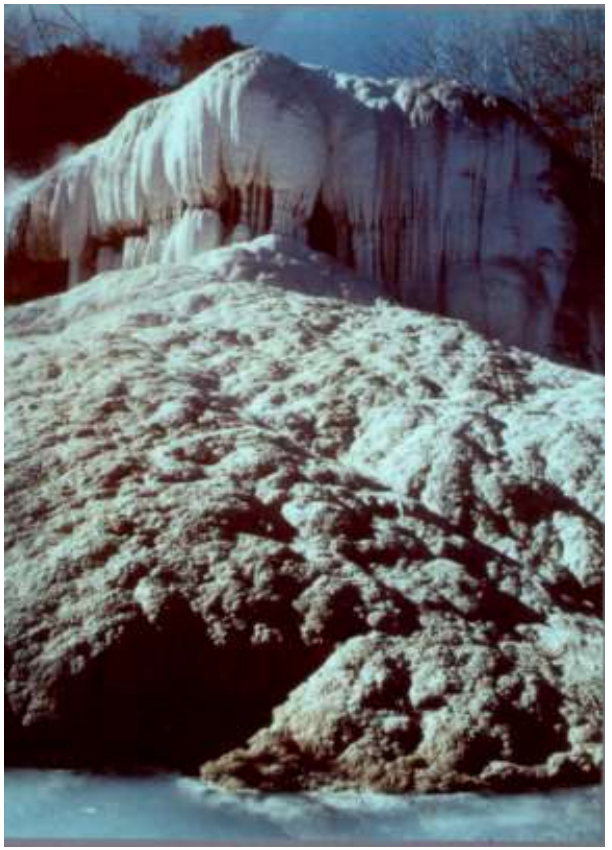
Geyser – Yellowstone Park

What is Geothermal Energy?

El Tatio- Chile

What is Geothermal Energy?

Lagoncelli, putizze and old wells
San Federico c/o Lago Boracifero



“Bocca della Balena” (Whale Mouth)
Bagni San Filippo

What is Geothermal Energy?

Geothermal manifestation
Monterotondo Marittimo

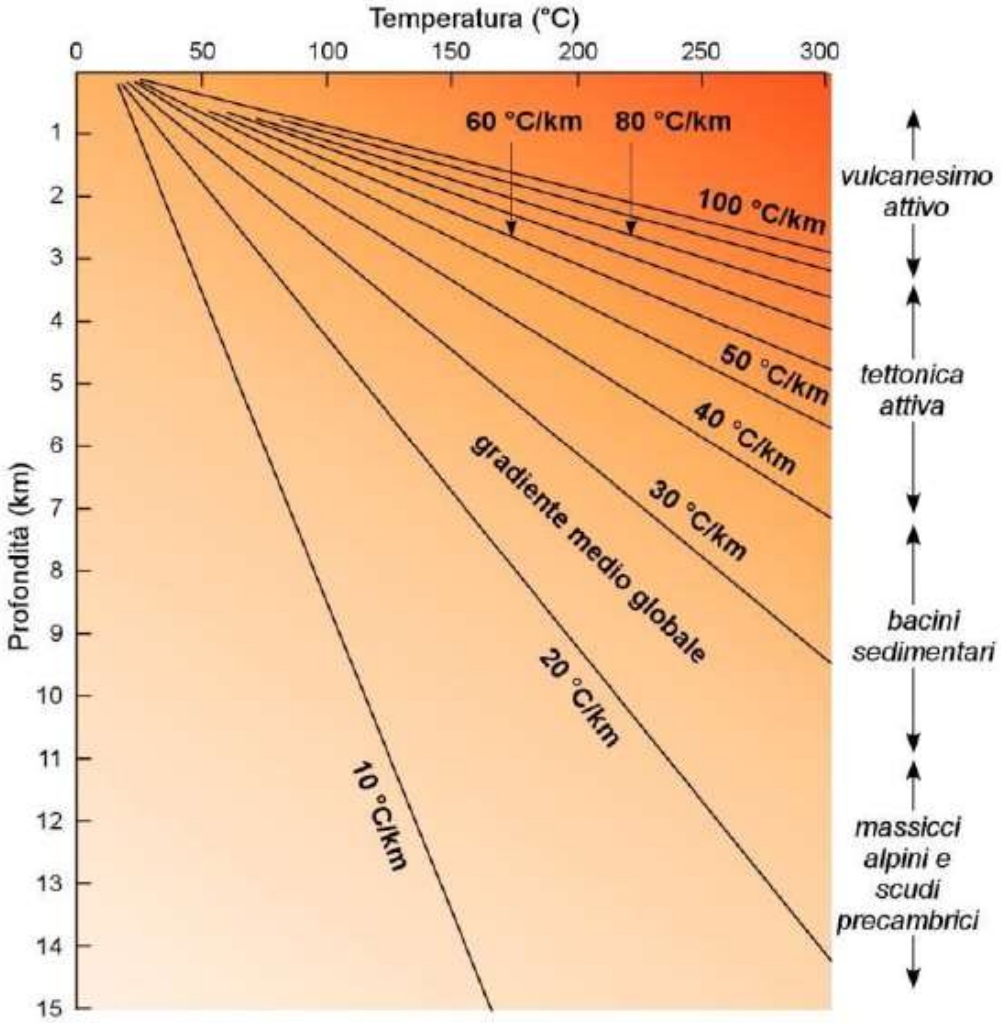
Mud Lagoncelli

Sant'Adriana

What is Geothermal Energy?

Champagne pool – New Zealand

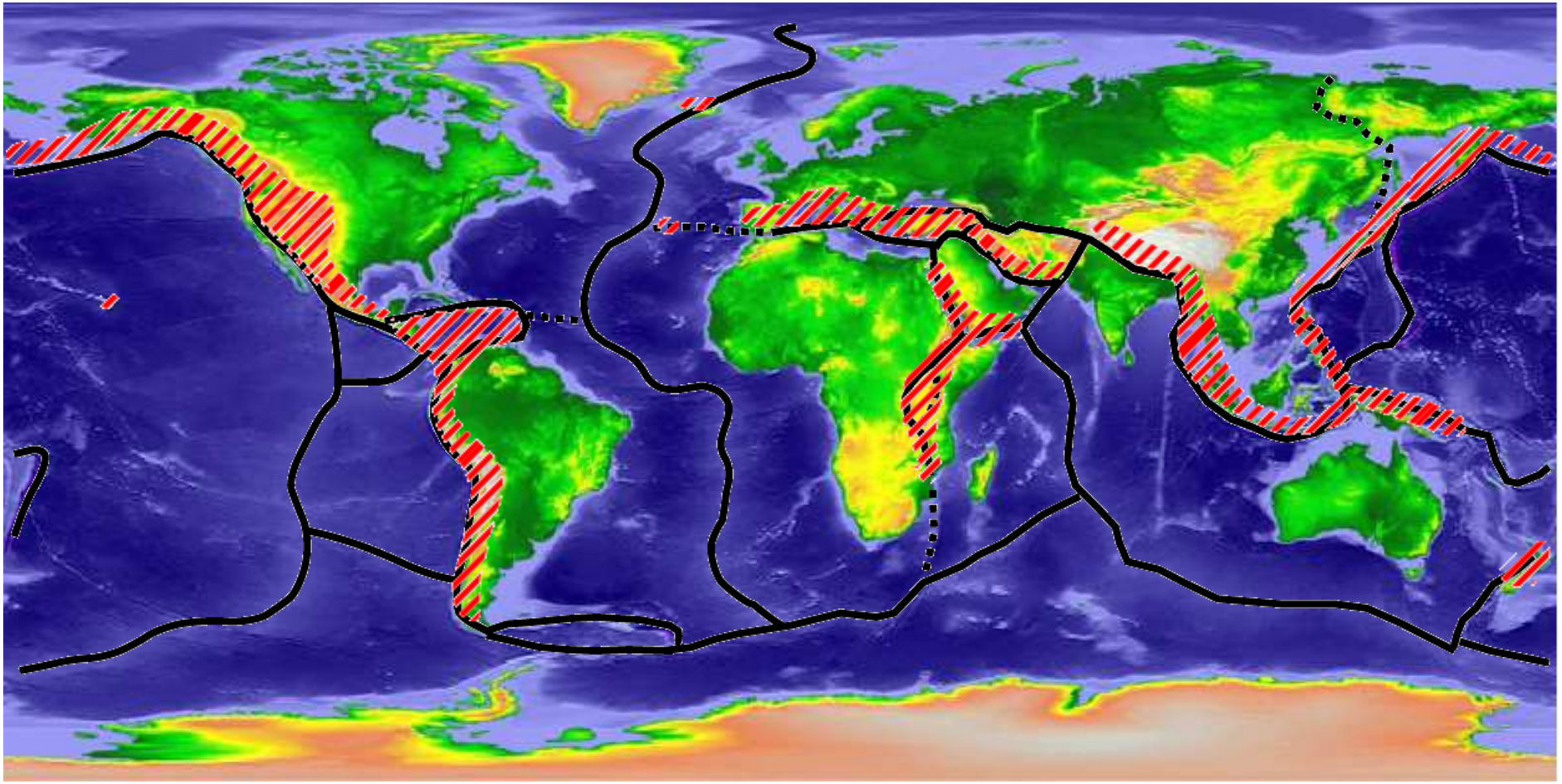
Gradiente geotermico



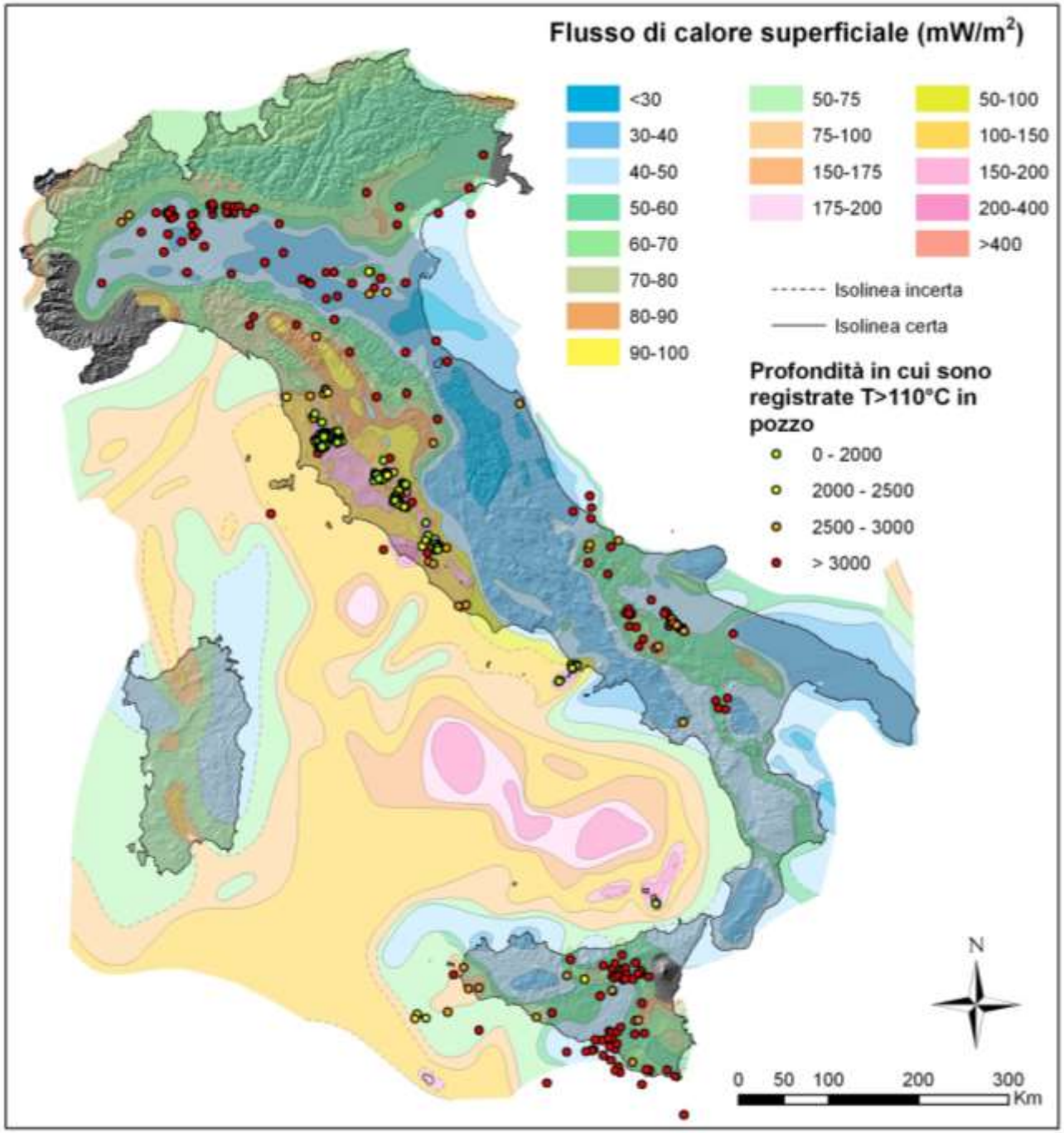
In assenza di circolazione di fluidi il **gradiente geotermico** varia a seconda del contesto geodinamico e geologico dell'area; mediamente varia **1° C ogni 20-40 m** di profondità.

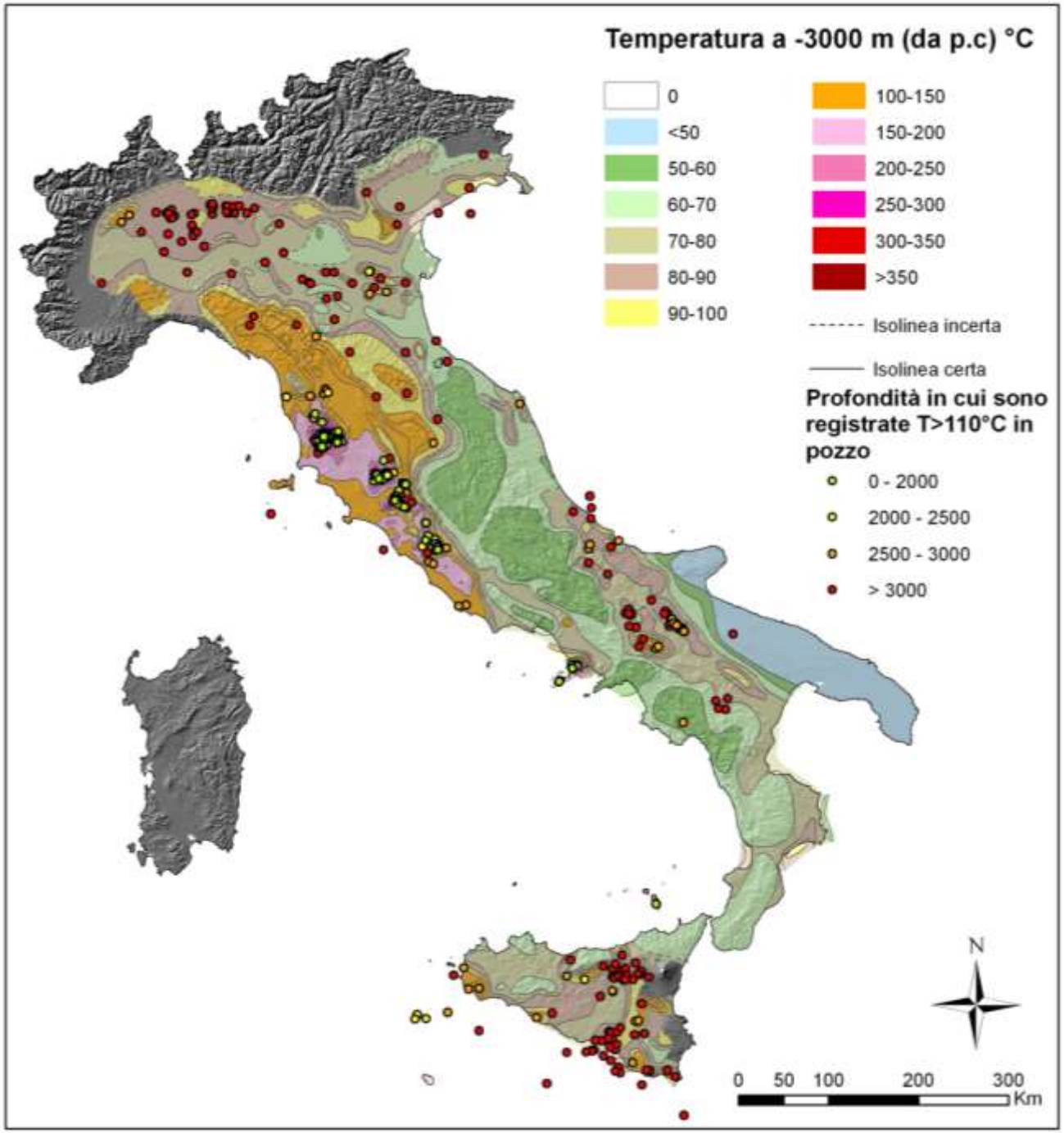
La differenza di temperatura tra le zone profonde, più calde, e quelle superficiali, più fredde, dà origine ad un flusso di calore dall'interno verso l'esterno della Terra. Il **flusso di calore** medio è **65 mWm^{-2}** nelle aree continentali e **101 mWm^{-2}** nelle aree oceaniche, con una media globale di 87 mWm^{-2}.

Dove?

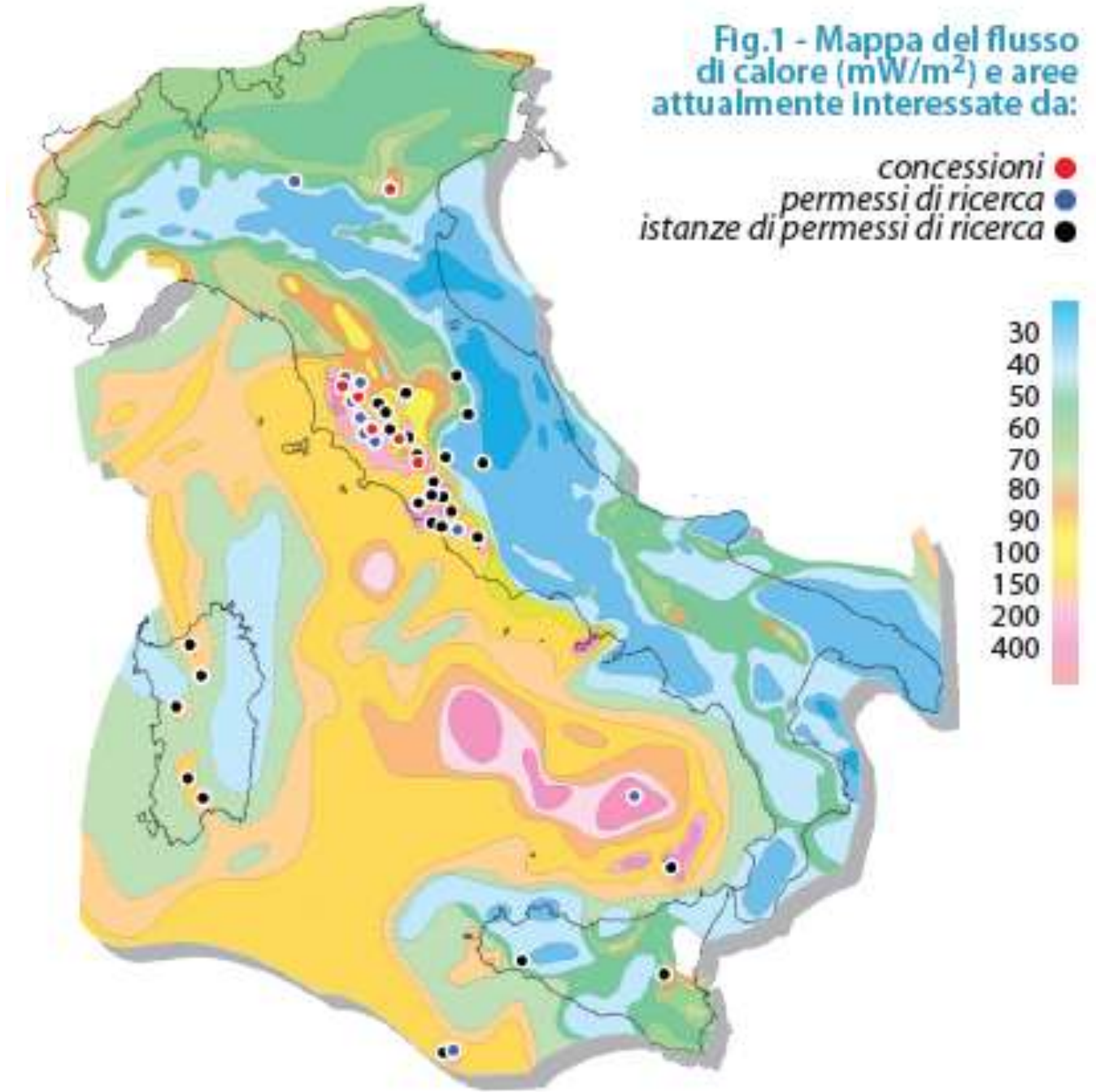


Aree di interesse geotermico


Flusso di calore superficiale (mW/m²)
<30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
50-75
75-100
150-175
175-200
50-100
100-150
150-200
200-400
>400
Isolinea incerta
Isolinea certa
Profondità in cui sono registrate T>110°C in pozzo
0 - 2000
2000 - 2500
2500 - 3000
> 3000
N
0 50 100 200 300
Km



Consiglio Na
Dipartimento



Consiglio
Dipartime

Temperatura del serbatoio *	Fluido	Usi comuni	Tecnologie
>150 ° C Alta entalpia	Acqua o vapore	Generazione energia elettrica Usi diretti	▪ Ciclo a vapore secco ▪ Ciclo a singolo flash ▪ Ciclo a doppio flash ▪ Scambiatori di calore
		Generazione energia elettrica	▪ Ciclo binario

L'entalpia è una funzione di stato che esprime la quantità di energia libera di un sistema termodinamico in una trasformazione isobaroentropica (a pressione ed entropia costanti).

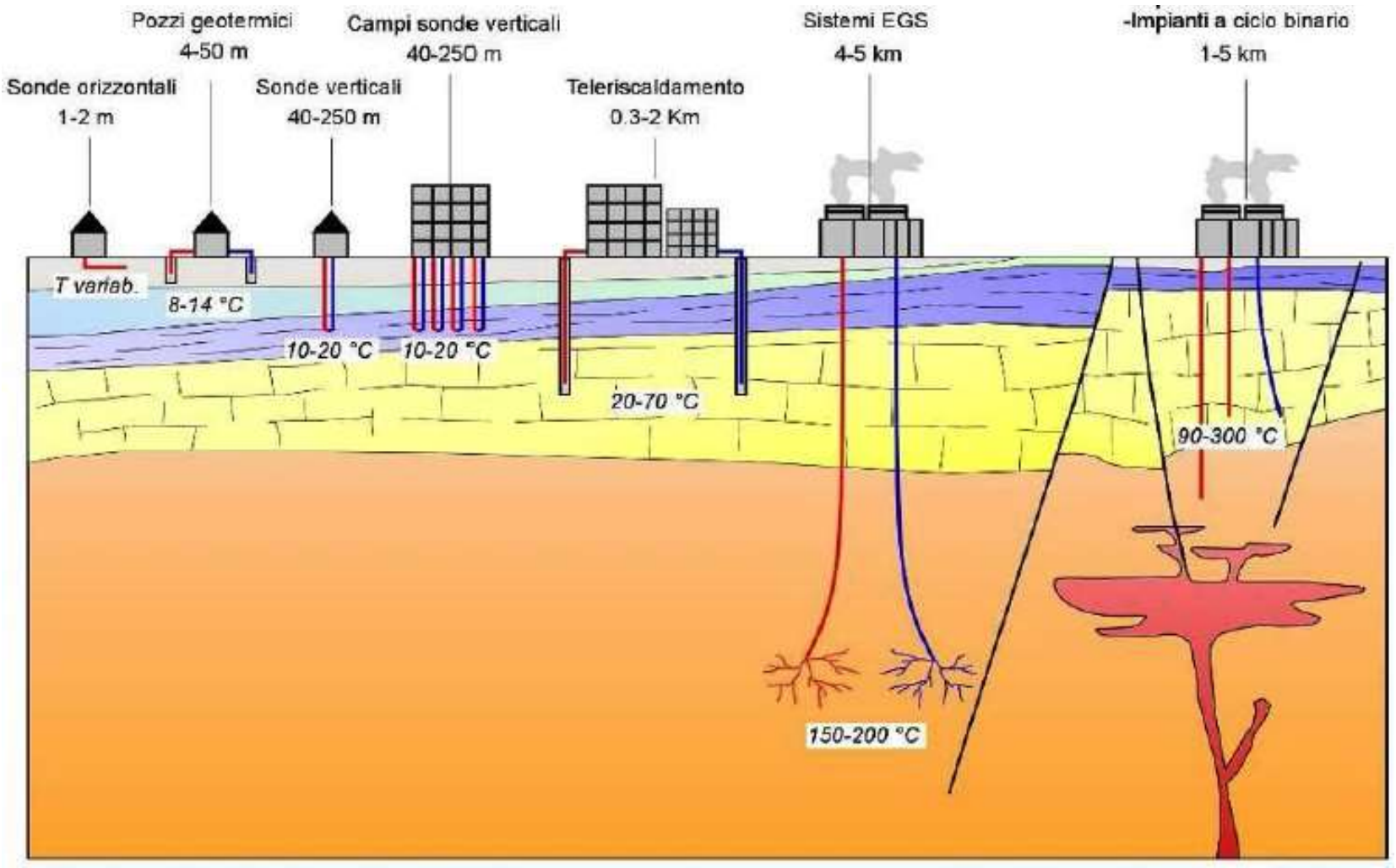
Da Wikipedia, l'enciclopedia libera

* Ai sensi e per gli effetti del Decreto Legislativo 11 febbraio 2010, n. 22

Una denominazione confusa

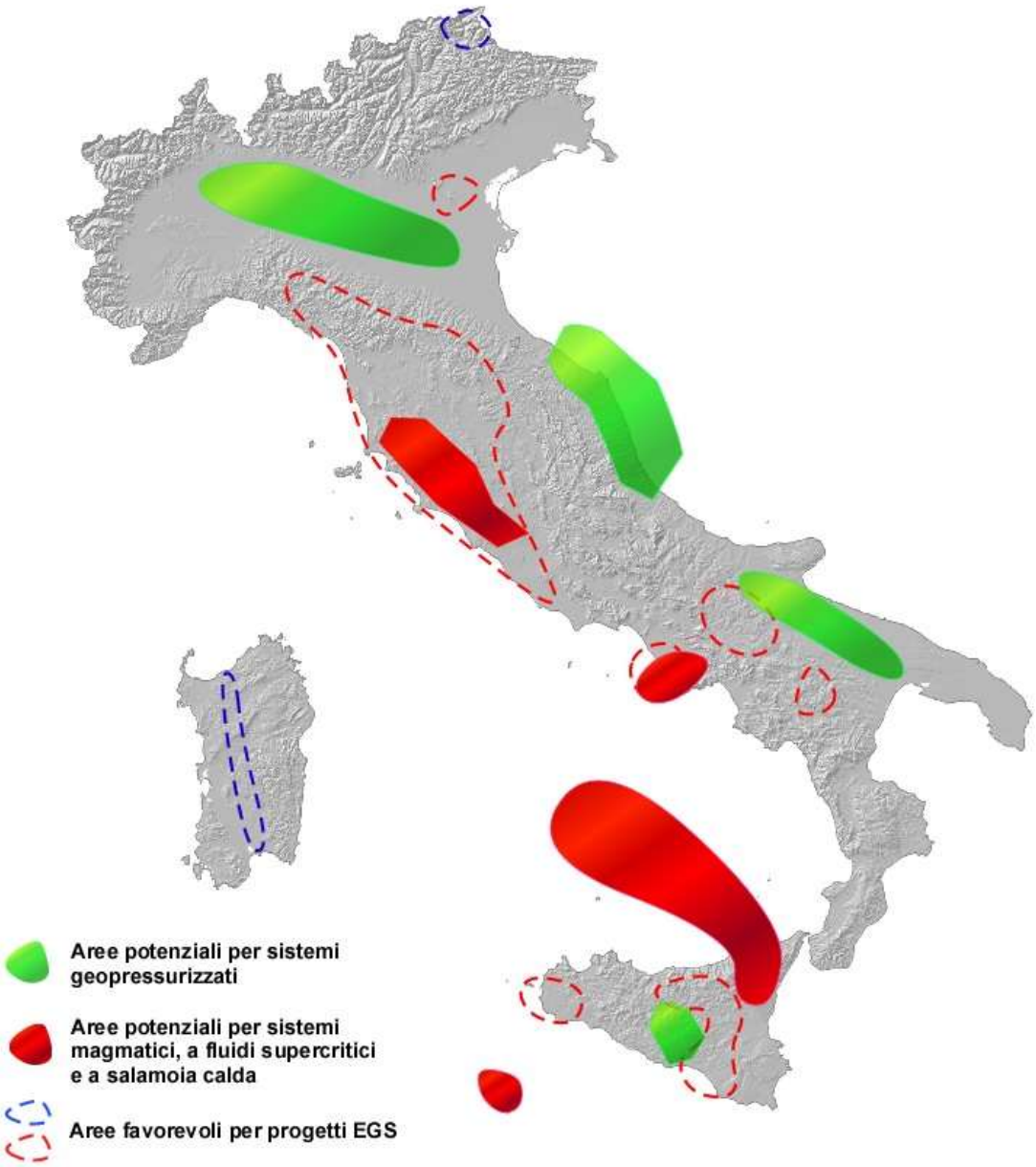
Geotermia superficiale

Geotermia profonda



Geotermia non convenzionale

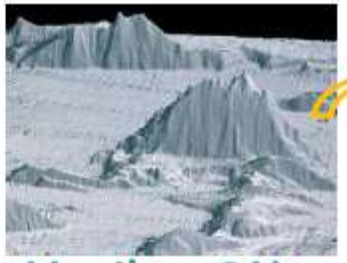
Geotermia non convenzionale



Shallow water resources <200 m
(red and orange patterns)

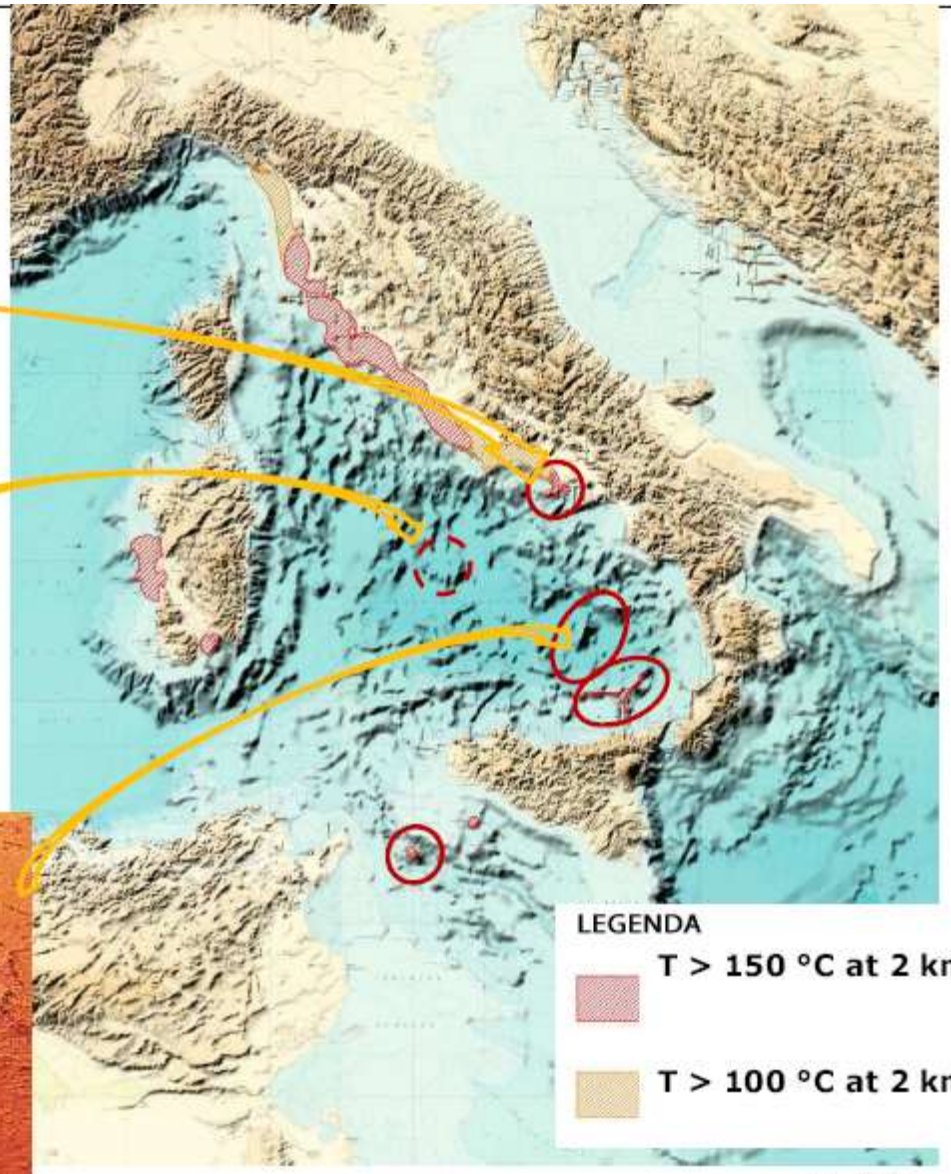
Deep resources (circles)

Campi Flegrei
Deep Drilling
Project



Vavilov SMt.

Marsili SMt.



Produzione di energia

Il calore sotterraneo non viene utilizzato direttamente per la produzione di energia, ma attraverso una massa d'acqua che scambia ed estrae il calore immagazzinato nelle rocce (sistemi idrotermali)

La potenza elettrica è prodotta dalla conversione di energia termica immagazzinata nella massa d'acqua (T da 90° C a 350° C) in energia meccanica attraverso una turbina, direttamente (tecnologia convenzionale flash) o indirettamente (tecnologia binaria), ed infine in energia elettrica grazie al generatore

1 MW_e richiede:

- 7 - 10 t/h di vapore secco
- 30-40 t/h di fluido bifase a 200-250° C (tecnologia flash)
- 400 - 600 t/h di acqua se si utilizzano cicli binari ORC a bassa entalpia (120-160° C)

Larderello: the birthplace of geothermal industry

Before the beginning…

The Devil Valley in Larderello

No exploration activity needed……

LA STORIA DELLA GEOTERMIA

Proprio **in Italia**, a Larderello in Toscana, nel 1904 è stato ideato per la prima volta l'utilizzo del vapore caldo che usciva spontaneamente dal terreno per la produzione di energia elettrica mediante una turbina.

Ancora oggi l'Italia è **uno dei maggiori produttori di energia geotermica al mondo**: in Toscana oltre trenta impianti forniscono una produzione energetica superiore a 5000 GWh all'anno, che corrisponde a quasi il 2% del fabbisogno nazionale.

1904: first experiment

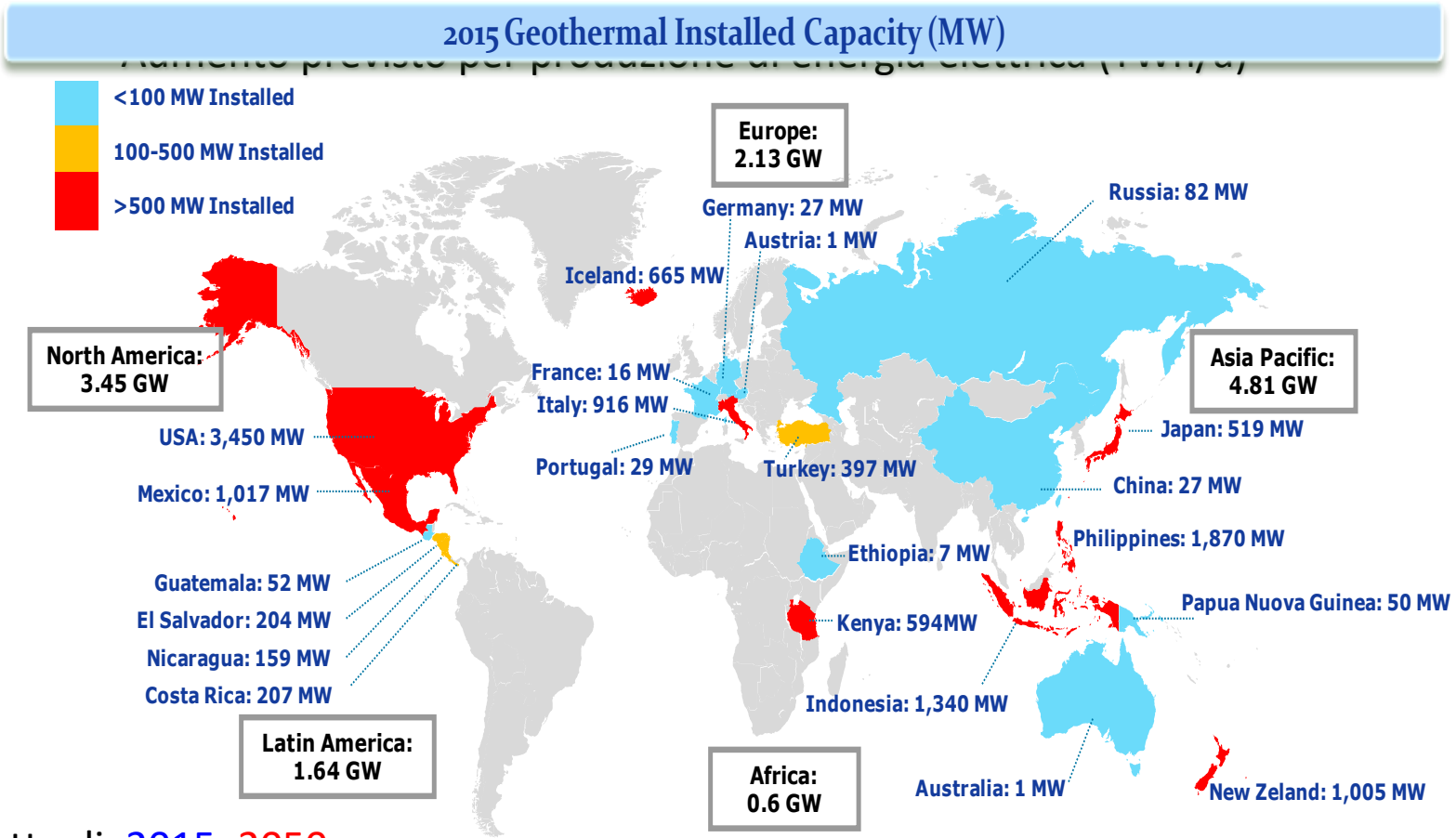
1913: first 250 kW unit

The pioneering stage

Power plants

CANTIERI DI PERFORAZIONE GEOTERMICA

Prospettive di sviluppo

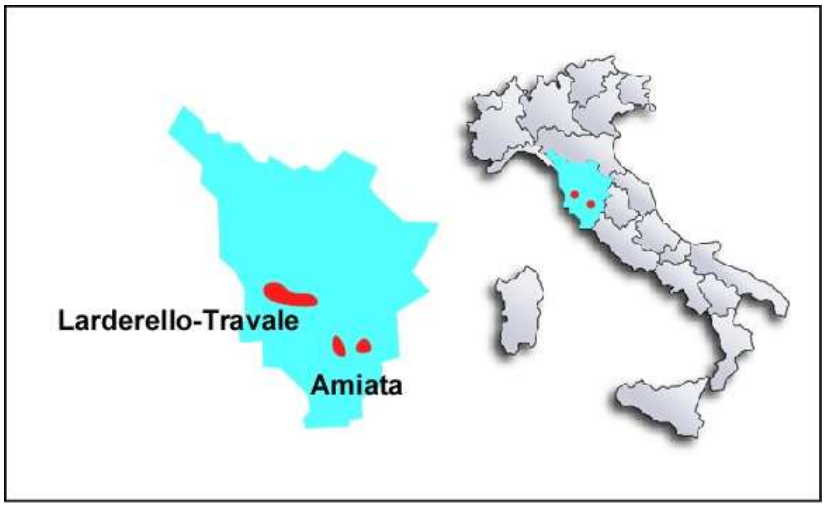


Valori attuali, 2015, 2050

Corrisponde a 10.7 GW nel 2010, 18.5 GW nel 2015 e 140 GW nel 2050

Da Bertani, WGC 2010

Produzione di energia

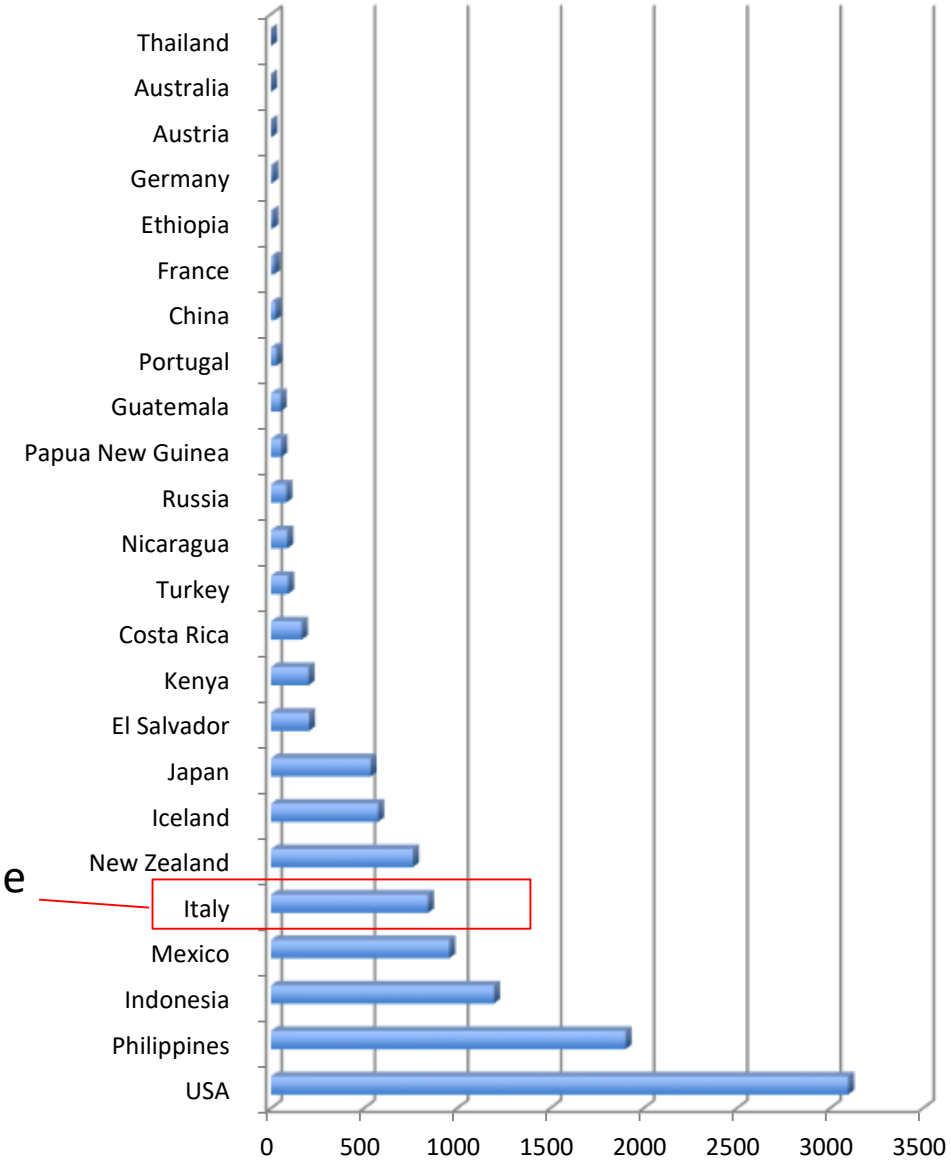


La generazione geotermoelettrica italiana corrisponde a:

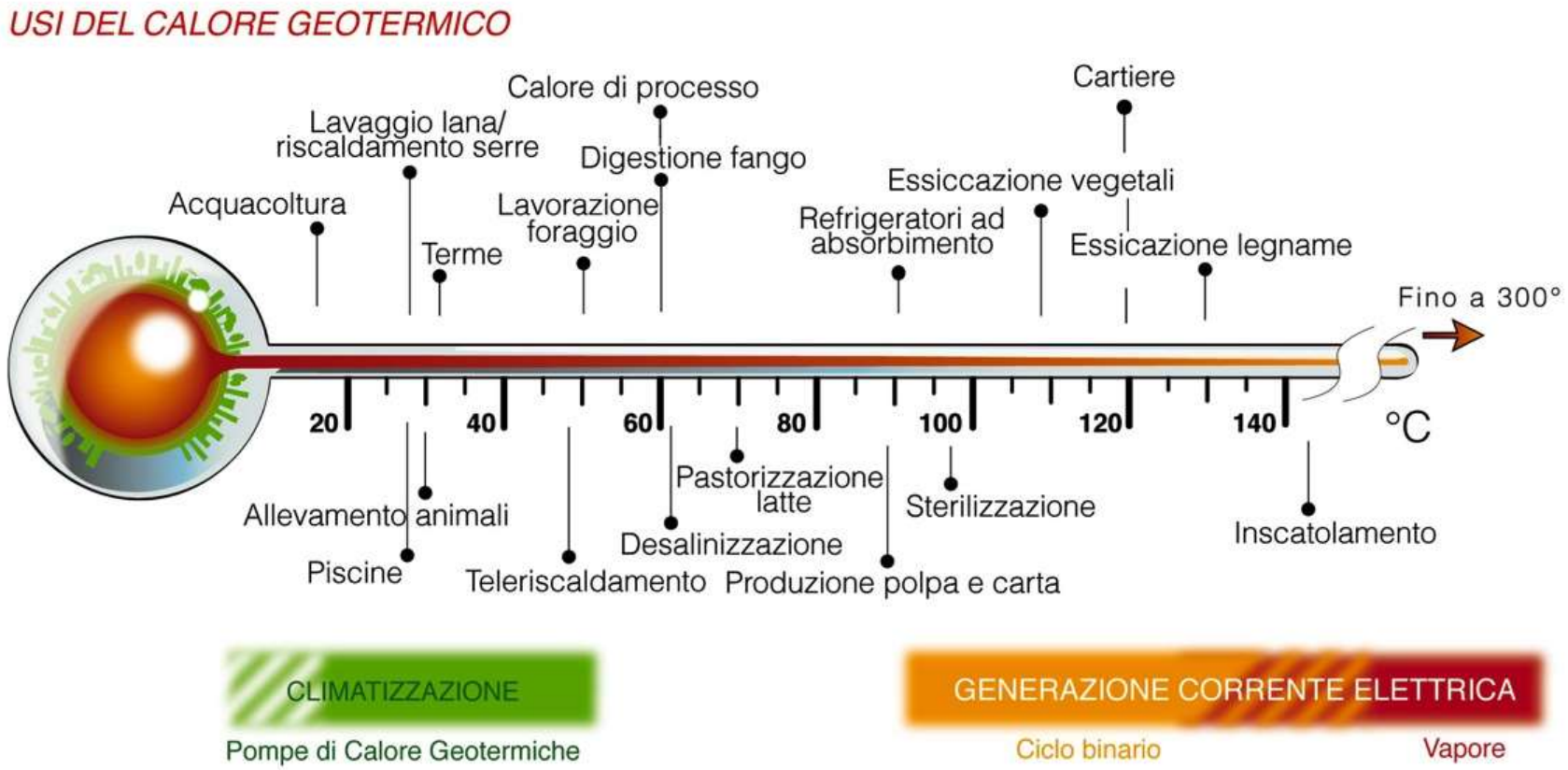
8,5 % di quella mondiale,

1,9 % della generazione nazionale

30 % dei consumi elettrici della Toscana.



Geotermia: **opportunità?**

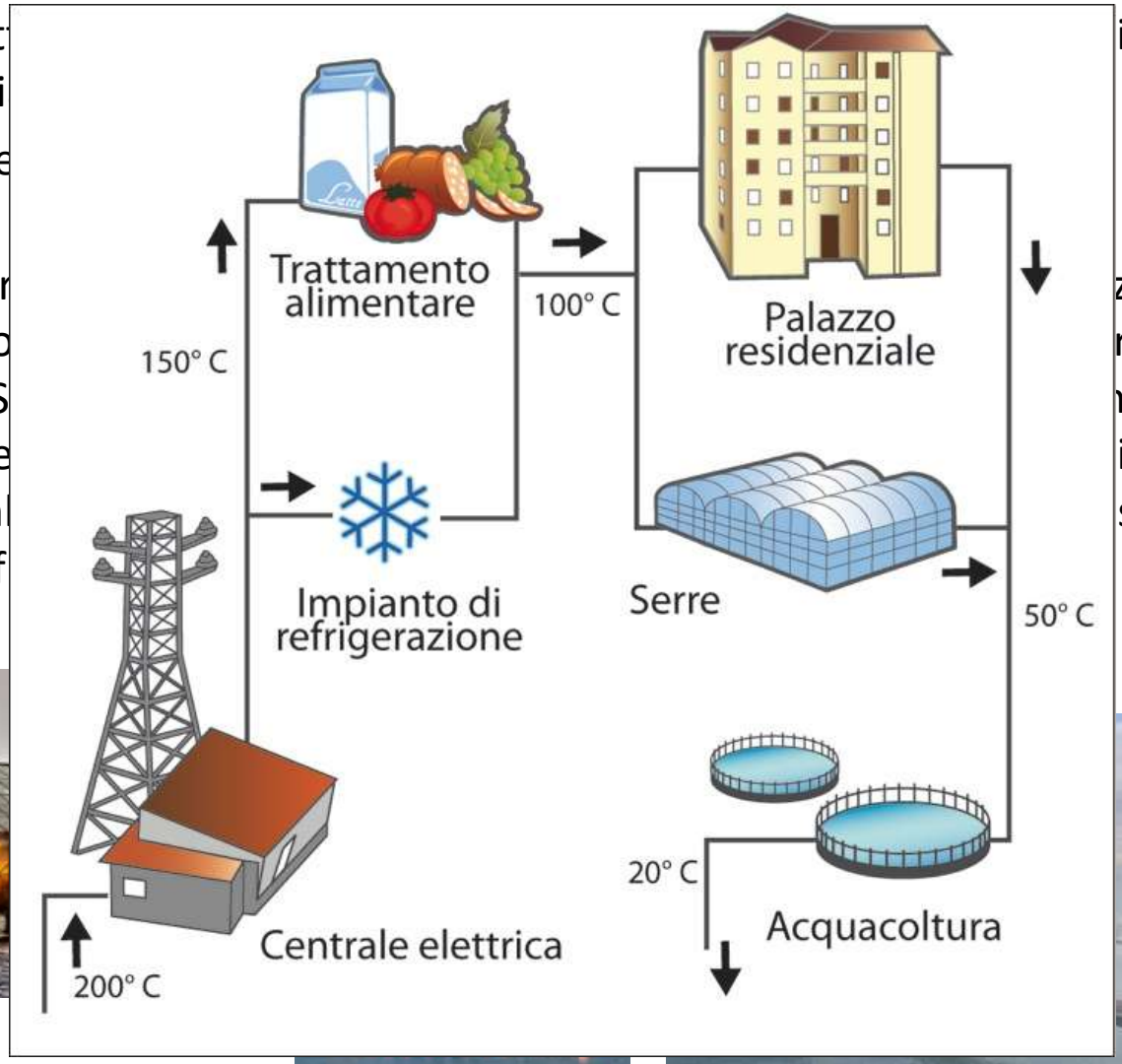


Ampio spettro di usi

sito web: www.vigor-geotermia.it

Uso diretto del calore

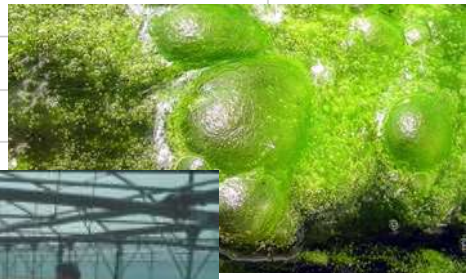
- L'uso diret ilizzo dell'energi
- Generalme e nei processi agricoli ed
- La maggior zzare le risorse geo rolio o gas naturale. S mente elevata, può essere icità, carbone o olio com sari per portare il f



Agricoltura

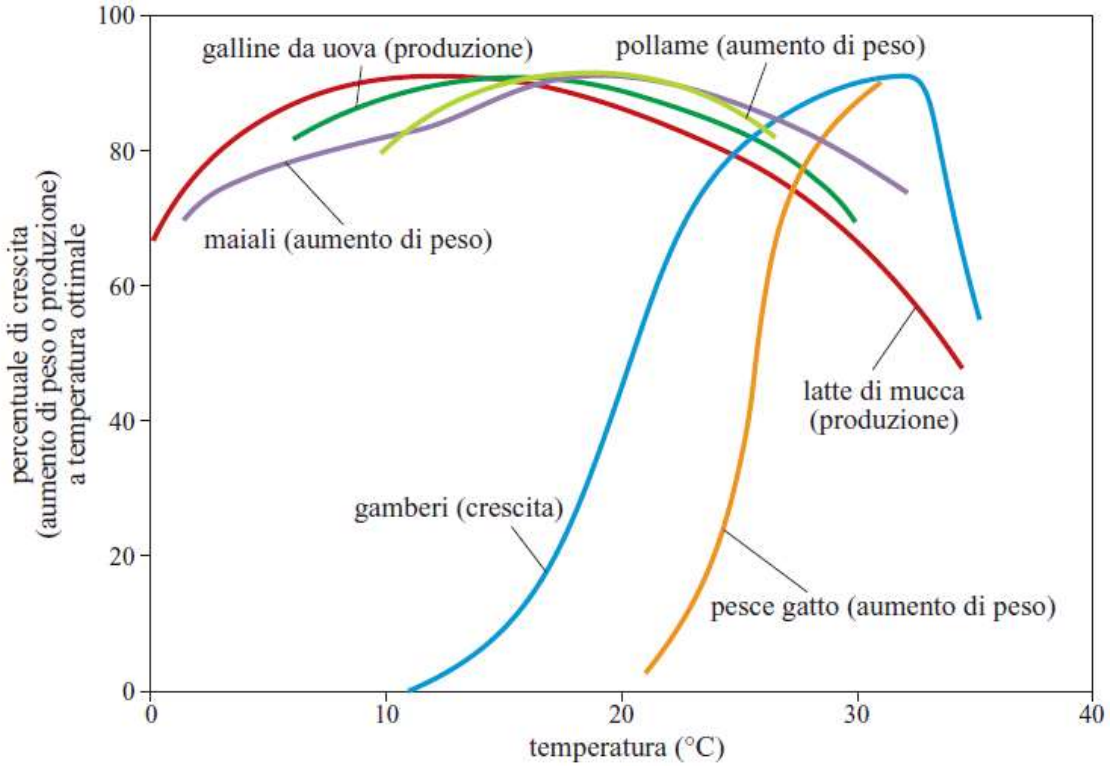
- La risorsa geotermica può essere usata in un ampio spettro di applicazioni per il riscaldamento di serre, alghe , l'essiccazione di prodotti agricoli e, in generale, per aiutare ed accelerare la crescita della flora:

- Riscaldamento di serre con verdure e fiori.
- Coltivazione e produzione di Alghe per l'estrazione di olii essenziali e la produzione di biocombustibili
- Riscaldamento del sistema radicale in spazi aperti (per esempio: asparagi)
- Riscaldamento delle piscine speciali con alghe (Spirulina) insieme con acqua geotermica a un elevato contenuto di CO_2
- *Essiccazione di ortaggi come pomodori, cipolle, cereali, patate*
- *Essiccazione altro materiale come il legno, frutta e pesci*



Uso diretto del calore

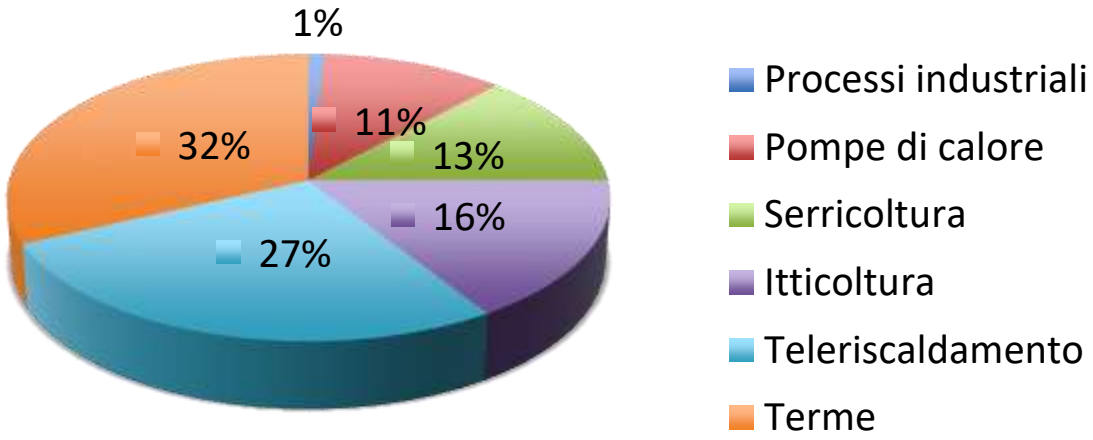
Effetti della variazione di temperatura sulla crescita e la produzione animale (*Beall e Samuels, 1971*)



Uso diretto del calore in Italia

- Nonostante l'Italia possa vantare un importante *know how* geotermico, gli usi diretti dell'energia geotermica sul territorio nazionale sono poco sviluppati

- La mancanza di un censimento ufficiale degli impianti e di chiare regole per la loro classificazione ed utilizzo rende peraltro difficile valutare la reale situazione e monitorarne lo sviluppo.



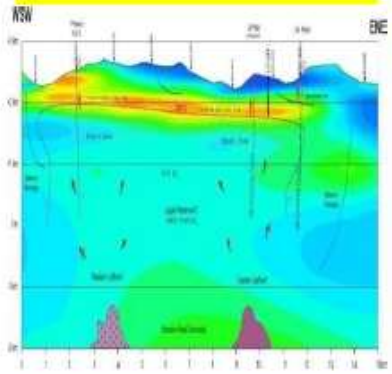
Stime UGI, WGC2010

ESPLORAZIONE

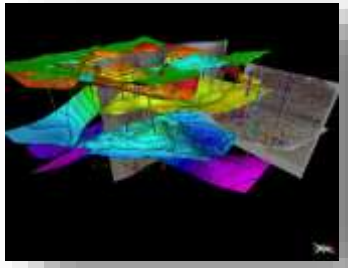
PERFORAZIONE POZZI

COSTRUZIONE IMPIANTI

ESERCIZIO & MANUTENZIONE IMPIANTI



Valutazione, mitigazione e monitoraggio ambientale



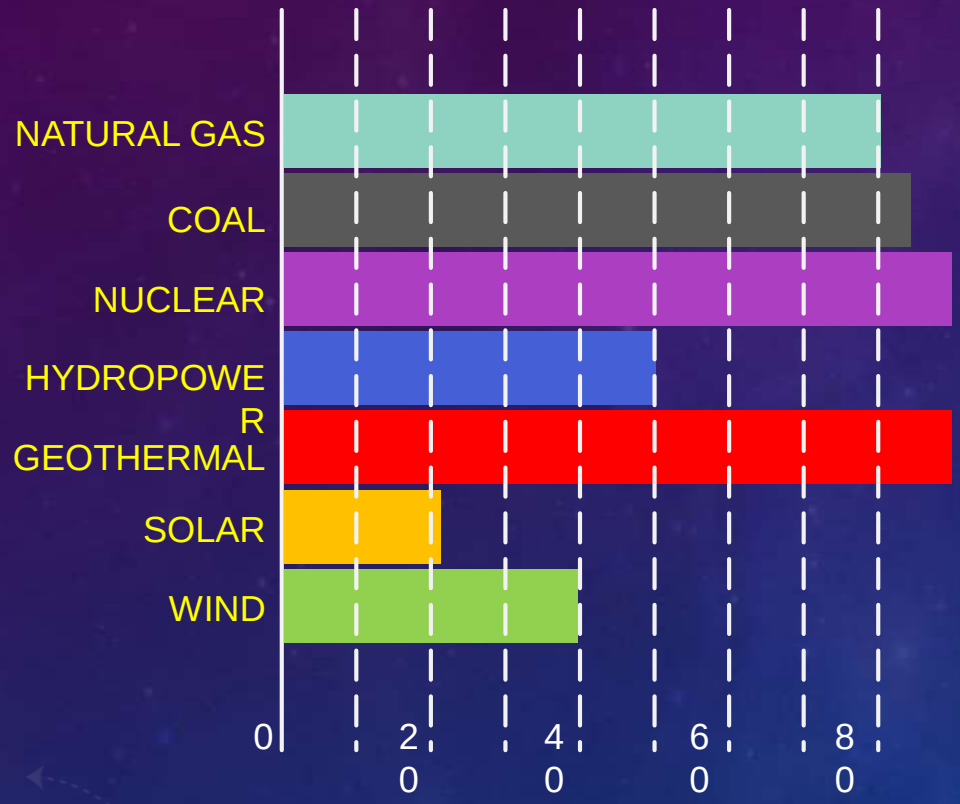
GEOTHERMAL ENERGY AS A SOURCE OF ELECTRIC POWER AND HEATING

Geoscience Department,
Padua University

Antonio Galgaro

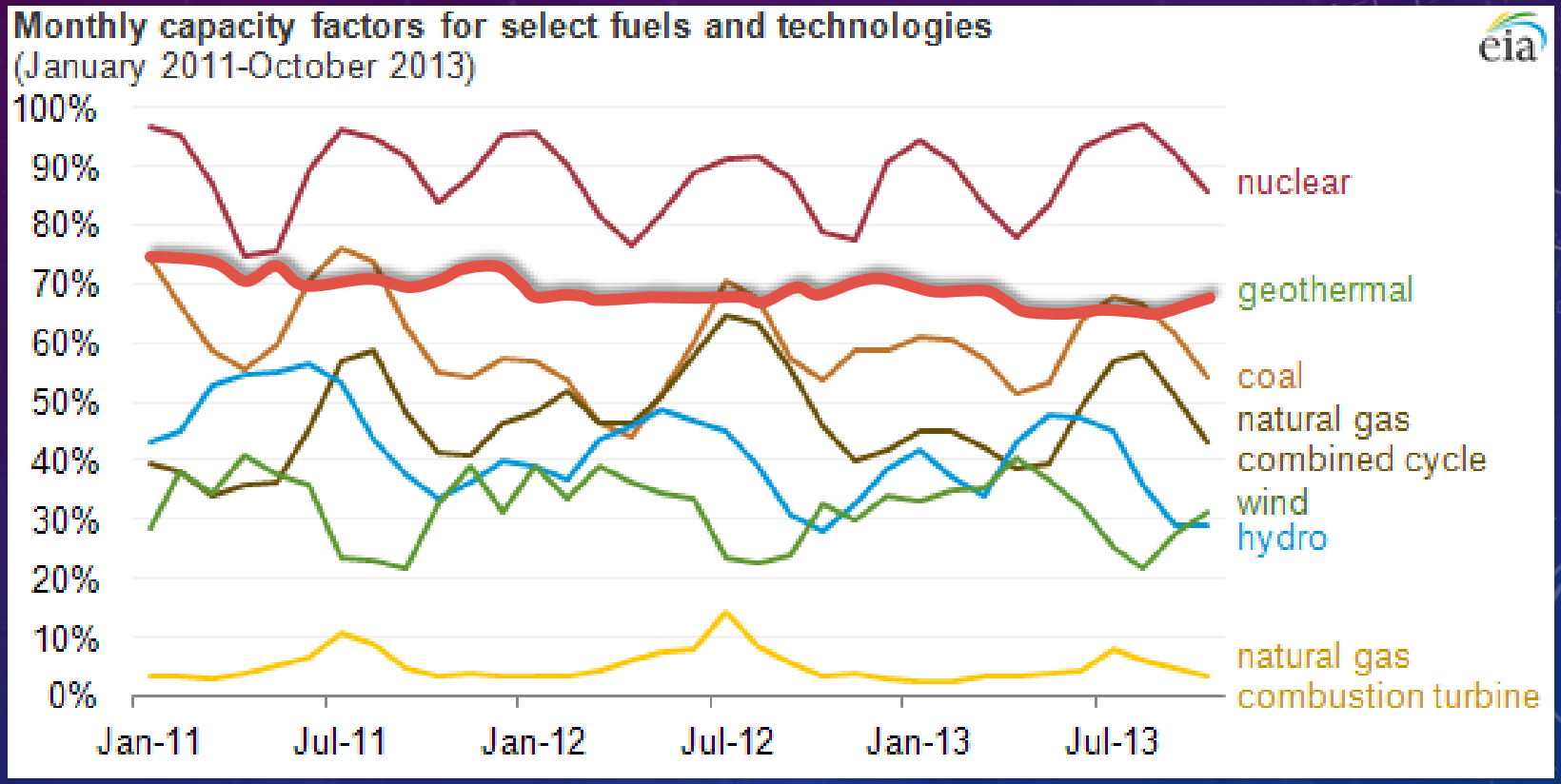
An overview of the financial cashflow,
project management, geothermal resoruce assessment

WHY GEOTHERMAL?

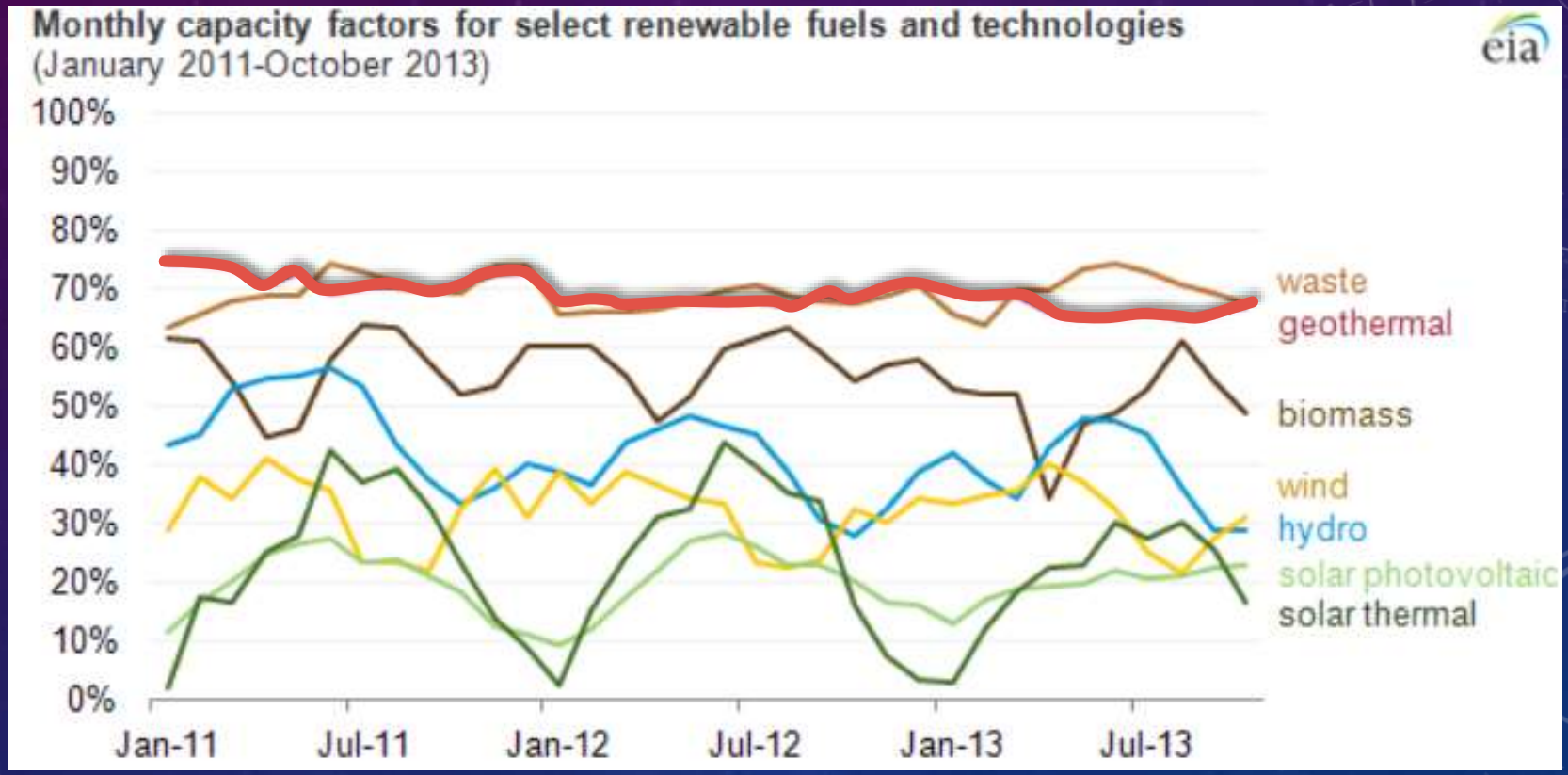


HIGHEST CAPACITY FACTOR AMONG ALL THE FUEL TECNOLOGIES

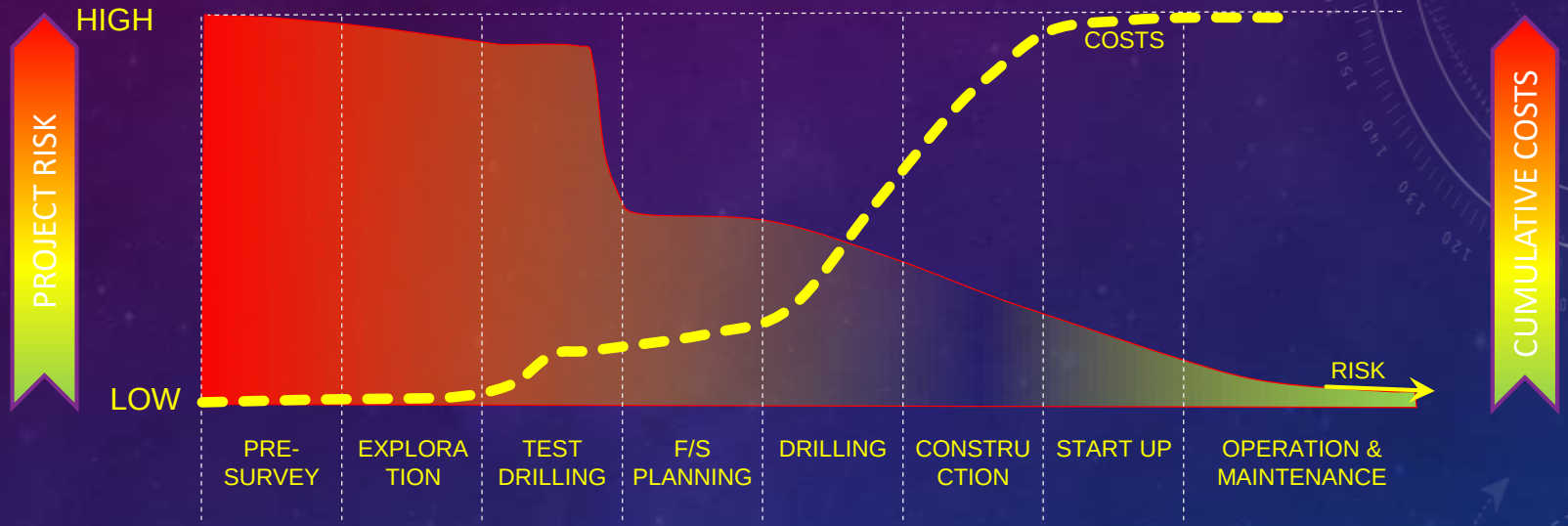
WHY GEOTHERMAL?



WHY GEOTHERMAL?

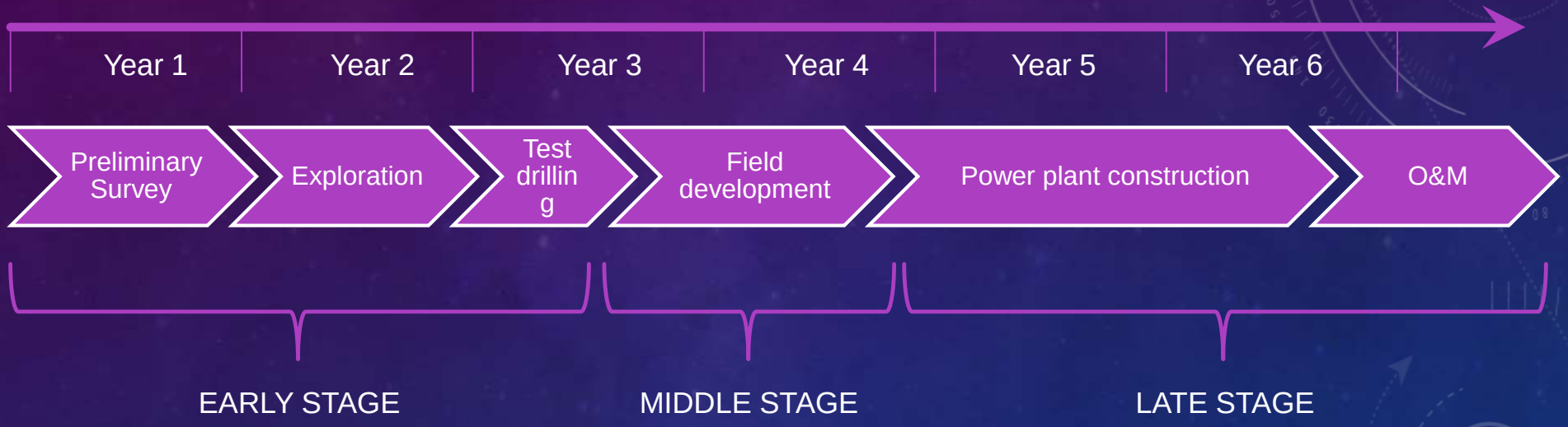


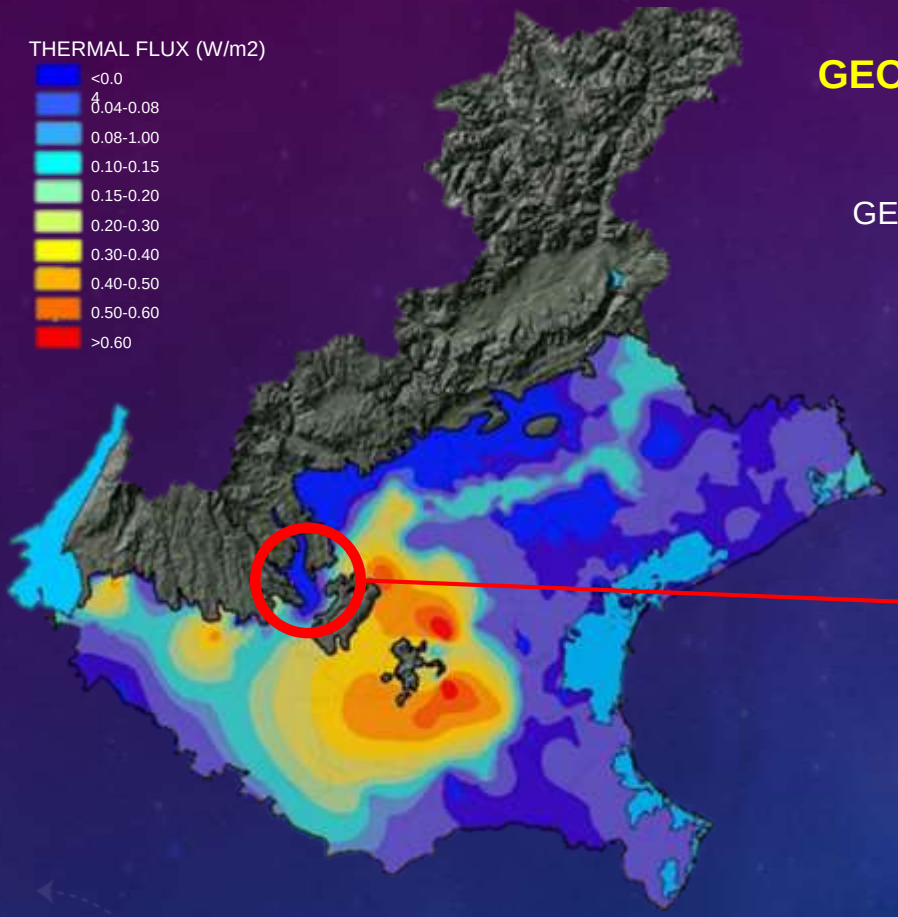
FINANCING A TYPICAL MEDIUM SIZE PROJECT (50 MW)



Investiment required (US$ m)	5	25	6	160

Models of Geothermal Development





GEOTHERMAL POTENTIAL FROM STRIGE PROJECT

GEOSCIENCE DEPARTMENT subsidized by REGIONE VENETO

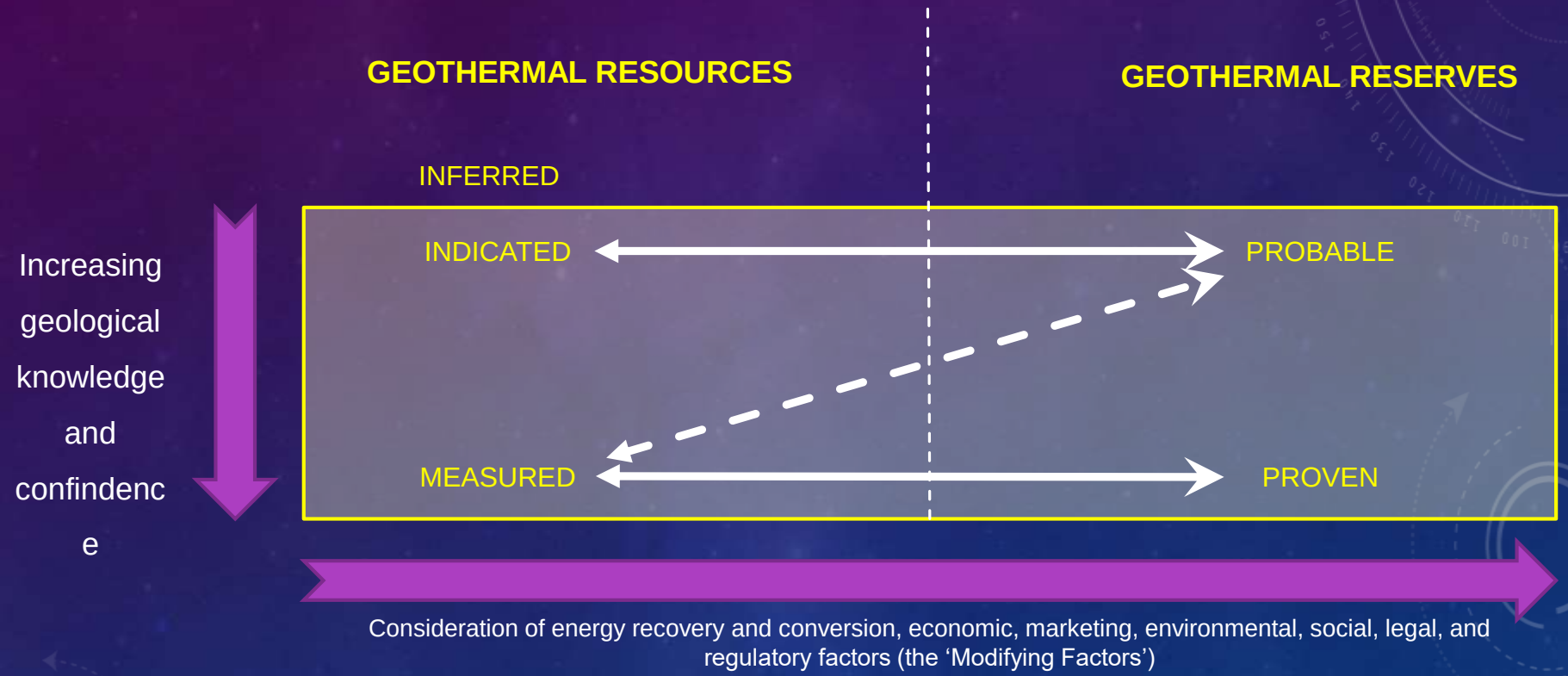
This area is locate between two main geothermal anomalies and in front of the pre-Alps trhust

It might potentially be very interesting.

At the moment a lack of data could suggest further analysis

Geothermal Reporting Code

According to the Australian Geothermal Reporting Code Committee, 2010



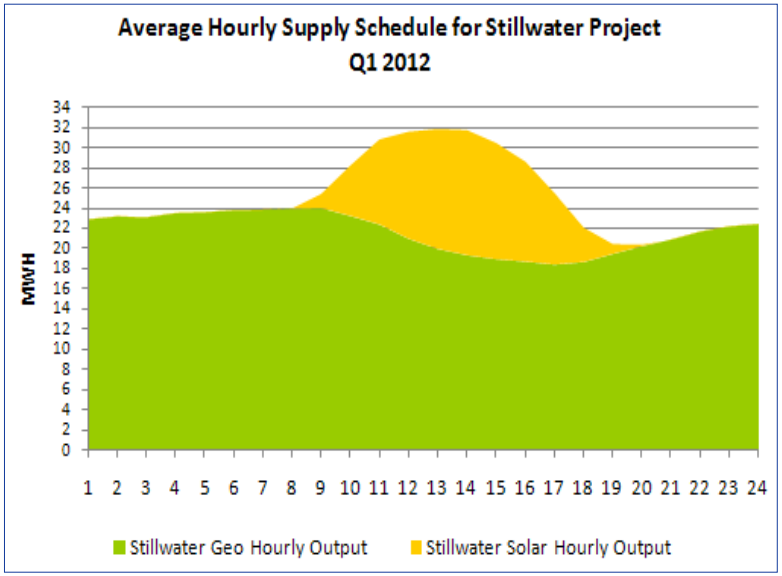
Geothermal Reporting Code

According to the Australian Geothermal Reporting Code Committee, 2010

	Exploration Results	Geothermal Resource			Geothermal Reserve	
		Inferred	Indicated	Measured	Probable	Proven
Commerciality	No implications regarding commerciality.	Commerciality not yet established. Probably feasible with current or future technology, prevailing and/or more favourable market conditions.			Commercial. Feasible with existing technology and prevailing market conditions.	
Definition	Data from exploration that is of material value to Geothermal Resource estimation, but which in itself is insufficient to define a Geothermal Resource category.	The Recoverable Thermal Energy within an area/ volume that has enough direct indicators of Geothermal Resource character or dimensions to provide a sound basis for assuming that a body of thermal energy exists, estimating temperature and having some indication of extent.	The Recoverable Thermal Energy within a more reliably characterised volume of rock than the Inferred Geothermal Resource. Sufficient indicators to characterise temperature and chemistry, although with few direct measures indicating extent.	The Recoverable Thermal Energy within a drilled and tested volume of rock within which well deliverability has been demonstrated, with sufficient indicators to characterise temperature and chemistry and with sufficient direct measurements to confirm the continuity of the reservoir.	That part of an Indicated Geothermal Resource for which commercial production for the assumed lifetime of the project can be forecast, or: That part of a Measured Geothermal Resource for which commercial production for the assumed lifetime of the project cannot be forecast with sufficient confidence to be considered a Proven Geothermal Reserve. The chance of occurrence is 'more likely than not'.	Applies directly to production satisfying all Modifying Factors. Directly related to that part of a Measured Geothermal Resource for which commercial production for the stated lifetime of the project can be forecast with a high degree of confidence.
Correlation with Probabilistic Estimates					~P50	~P90
Required		1. Recoverable Thermal Energy 2. Major assumptions and recovery factor(s)	1. Recoverable Thermal Energy 2. Major assumptions and recovery factor(s)	1.Recoverable Thermal Energy 2. Major assumptions and recovery factor(s)	1. Recoverable Thermal Energy 2. Major assumptions and recovery factor(s)	1. Recoverable Thermal Energy 2. Major assumptions and recovery factor(s)

Is it possible a second exponential growth?

HYBRID PLANTS = FUTURE ?

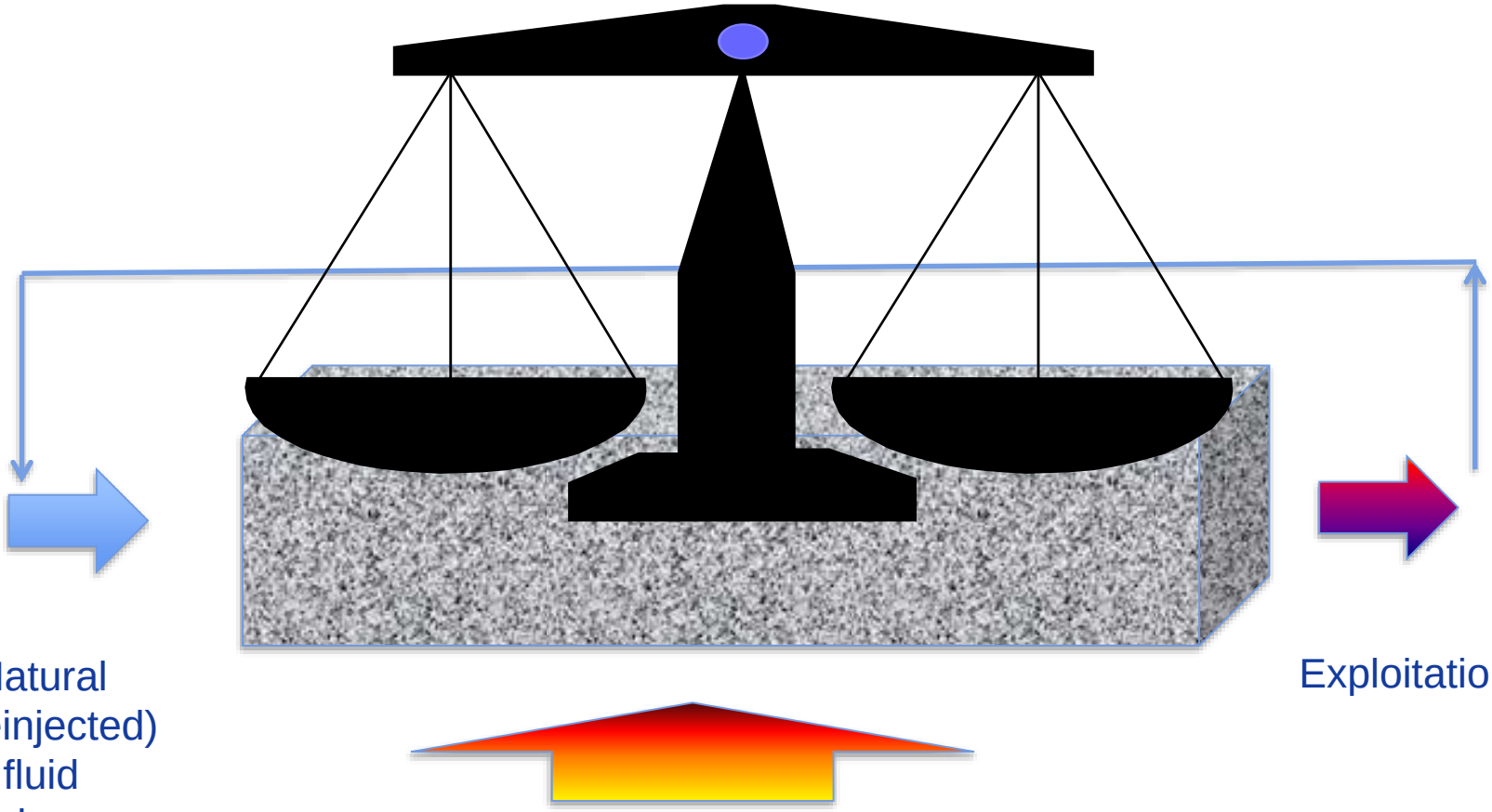


- World's first solar/geothermal hybrid project combines the continuous generation capacity of the medium enthalpy geothermal binary cycle with the peak capacity of solar power thus allowing for synergies to be explored.
- Integrates 26 MW of solar photovoltaic capacity to EGPNA's operating 33 MW Stillwater Geothermal Project
- Consists of over 89,000 polycrystalline silicon PV panels built on 240 acres. It will generate enough energy to meet the needs of 16,000 American households.

In 2012, this state-of-the art plant won EGPNA the Geothermal Energy Association Honor Award for Technology Advancement which recognizes companies that develop innovative or pioneering technology to further geothermal development.

Stillwater Solar Geothermal Hybrid Project

Sustainable Development

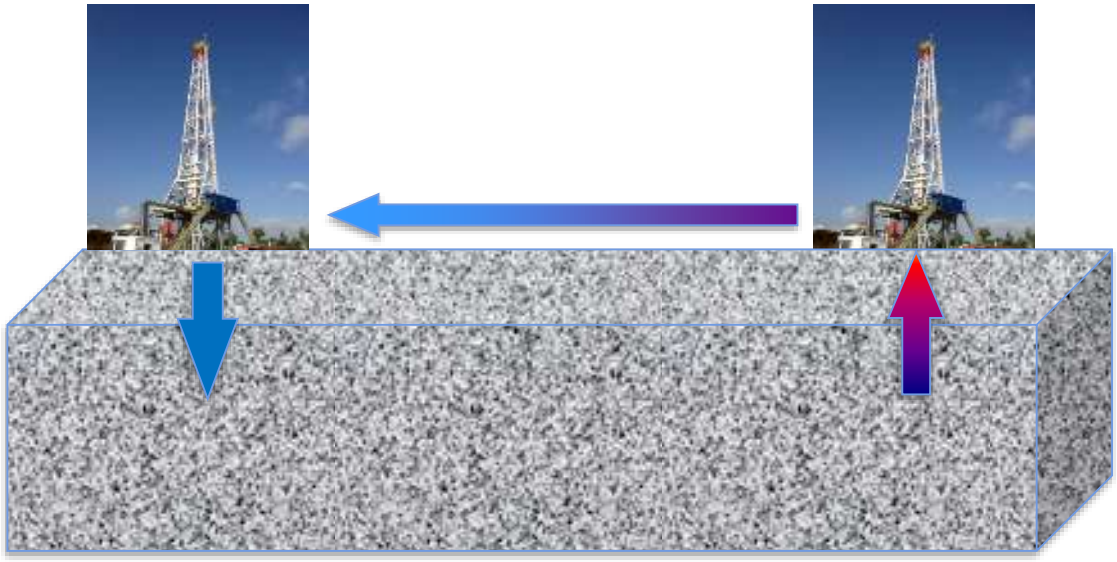


Natural (&reinjected) fluid recharge

Exploitation

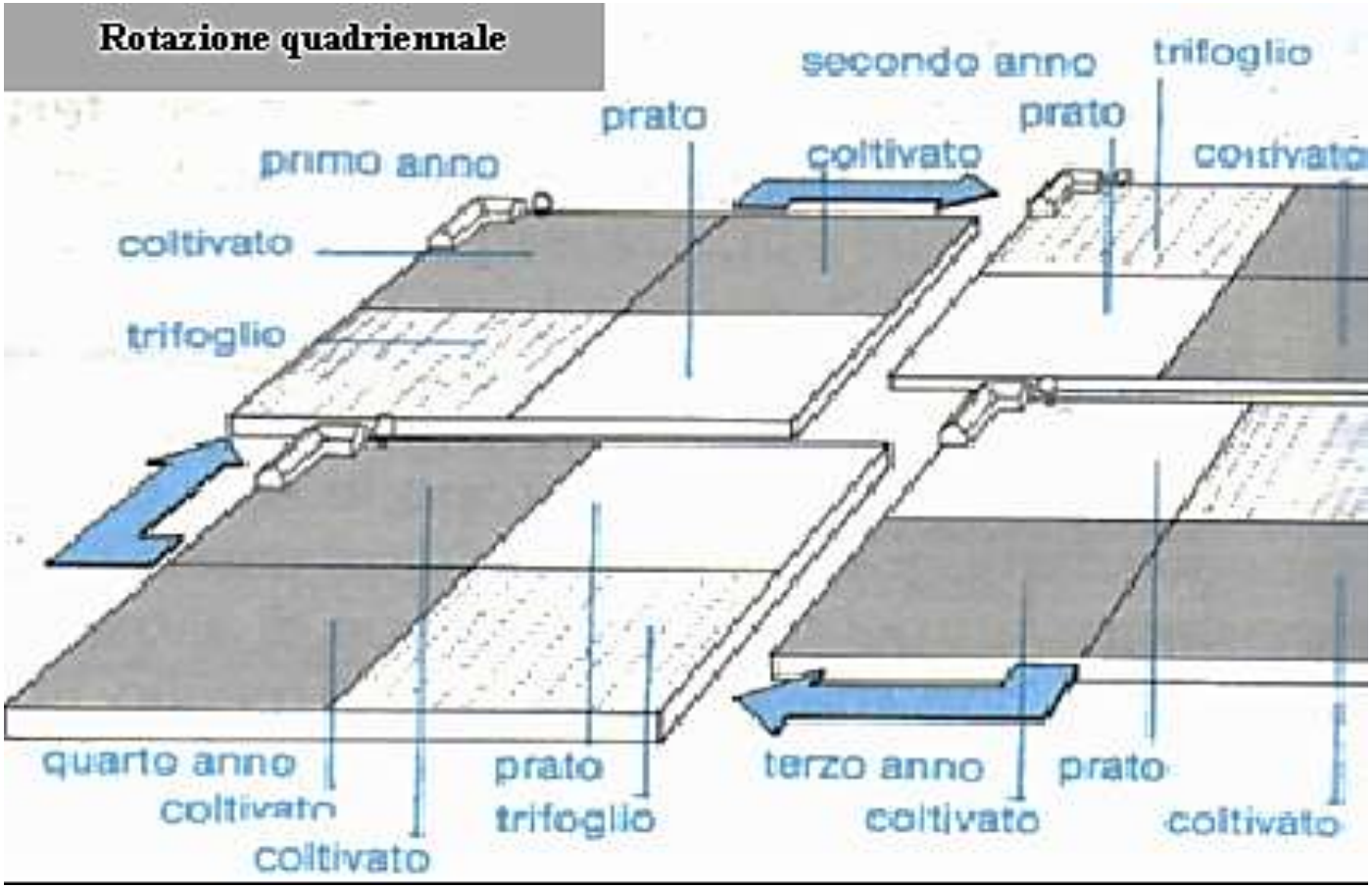
Thermal Flux

Sustainable Development



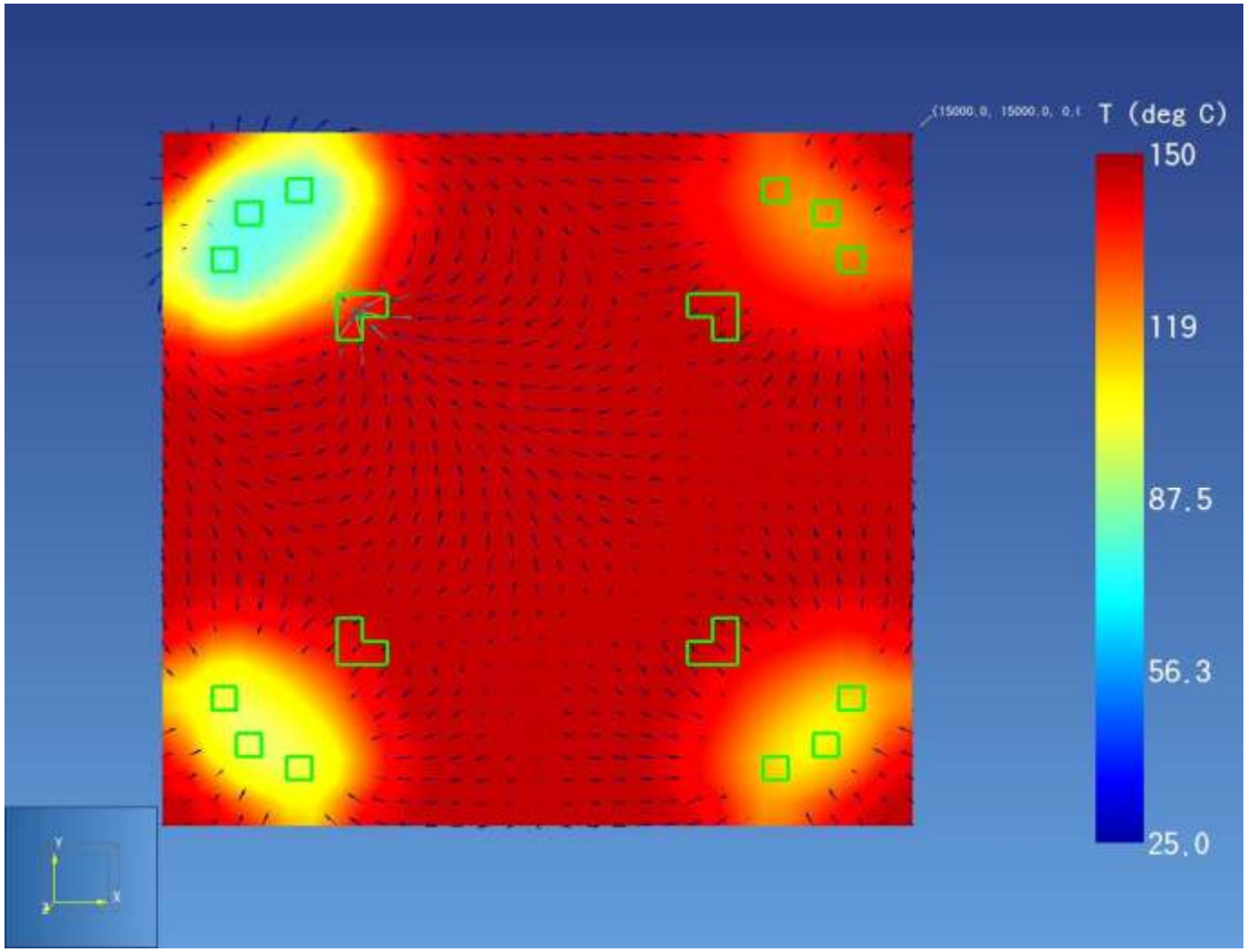
Un pozzo produttivo ed uno di reiniezione, utilizzando l'acqua come mezzo di scambio per asportare il calore contenuto nella roccia

Sustainable Development

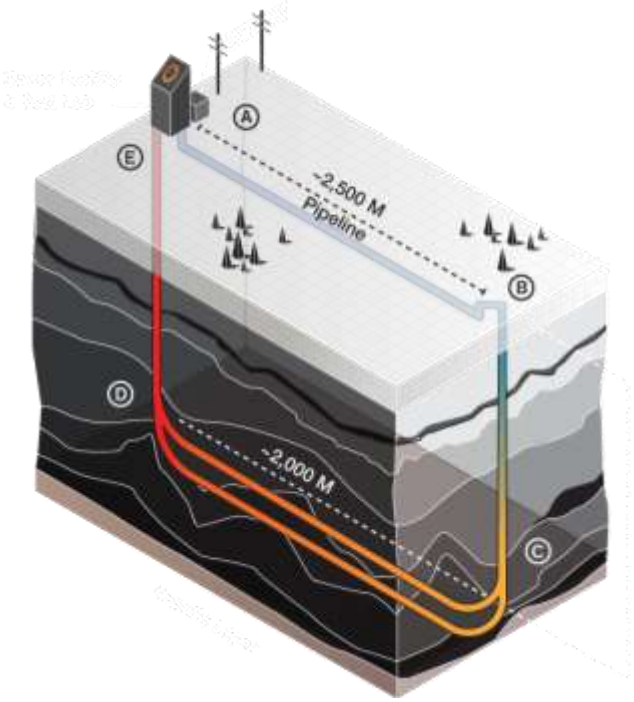


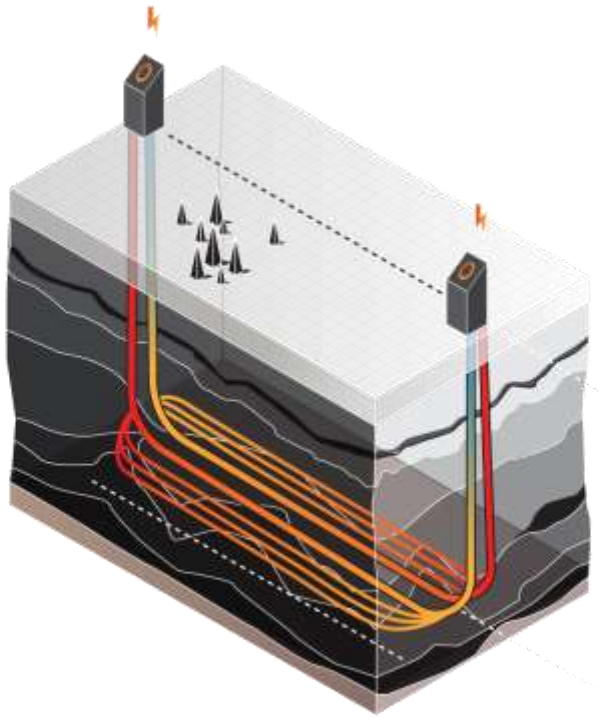
Un nuovo modello di approccio è possibile, basandosi sul concetto della rotazione agraria: sfrutto alternativamente zone diverse di una area più vasta, tenendo a riposo le altre, e consentendone il resupero in termini di sostanze nutritive..

Sustainable Development



.. ipotizzo quindi un sistema più complesso, con quattro gruppi di pozzi produzione-reiniezione, su un'area vasta, con sfruttamento a rotazione di 50 anni, posso raggiungere un approccio di sviluppo sostenibile, estraendo costantemente 150 MW elettrici da un area di 15x15 km^2…



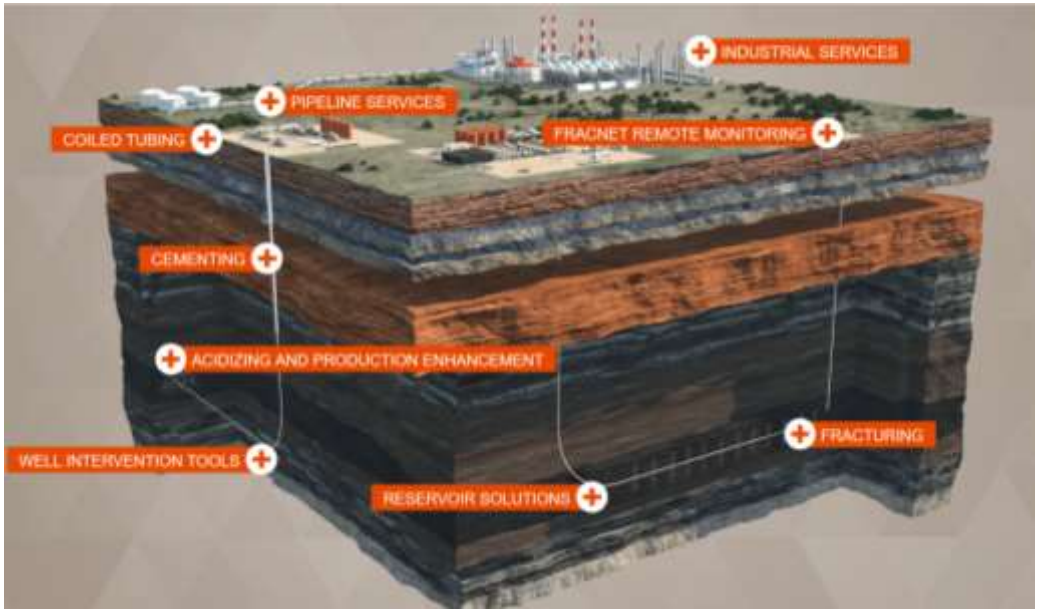


Operational Objectives

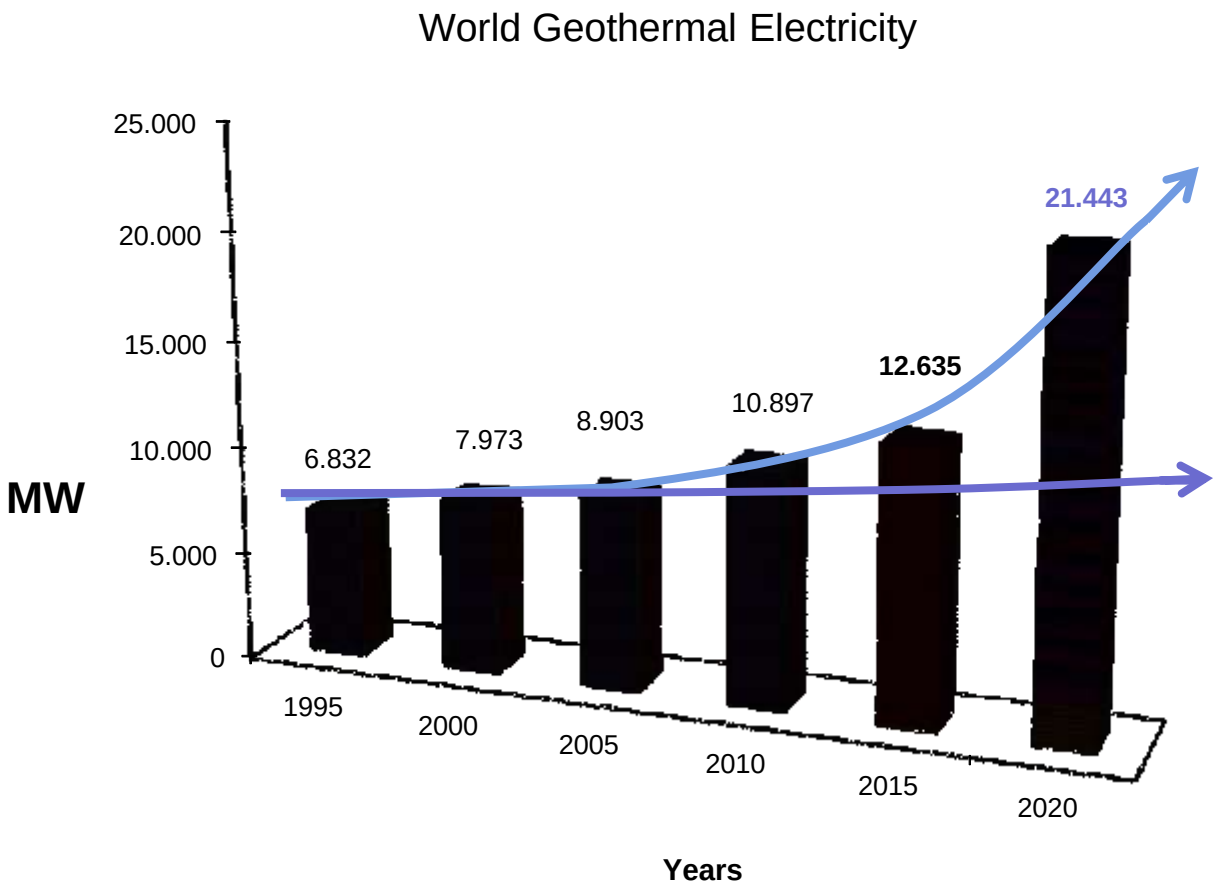
- Phase 1 - Drilling ✓
- Phase 2 - Surface Pipeline & Facilities ✓
- Phase 3 - Testing ✓

Technical Objectives

- Drill and intersect a multilateral Eavor-Loop™ with two laterals ✓
- Seal the Eavor-Loop™ while drilling ✓
- Validate the thermodynamic performance and demonstrate thermosiphon ✓

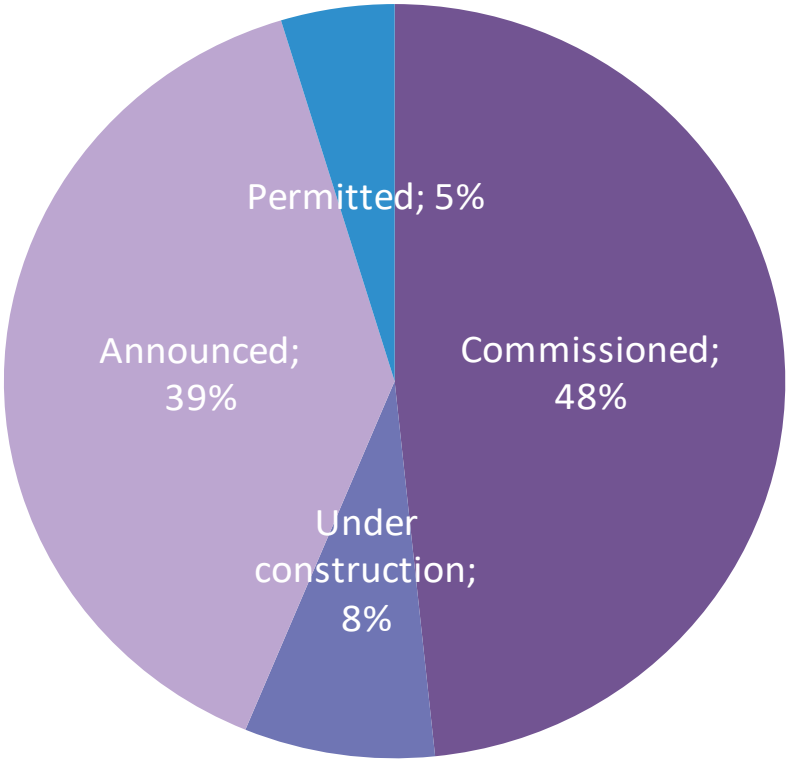


The World Geothermal Electricity Trend



The World Geothermal Electricity Trend

The global project pipeline totals **20 GW** across all development stages



Top 5 Countries: installed capacity>1 GW





COUNTRY	2010 MW	2010 GWh	2015 MW	2015 GWh
USA	3,093	16,603	3,450	16,600
PHILIPPINES	1,904	10,311	1,870	9,646
INDONESIA	1,197	9,600	1,340	9,600
MEXICO	958	7,047	1,017	6,071
NEW ZEALAND	628	4,055	1,005	7,000

Top 5 Countries: incremental capacity>100 MW

COUNTRY	2015 MW	2015 GWh	NEW MW	NEW GWh
KENYA	594	2,848	392	1.418
USA	3,450	16,600	352	
TURKEY	397	3,127	306	2.637
NEW ZEALAND	1,005	7,000	243	2.945
INDONESIA	1,340	9,600	143	

Kenya

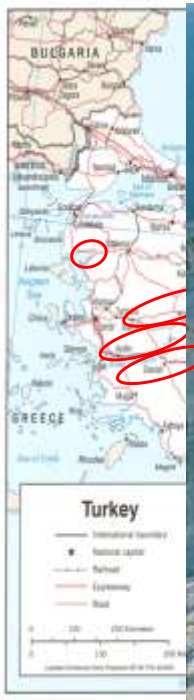
KENYA

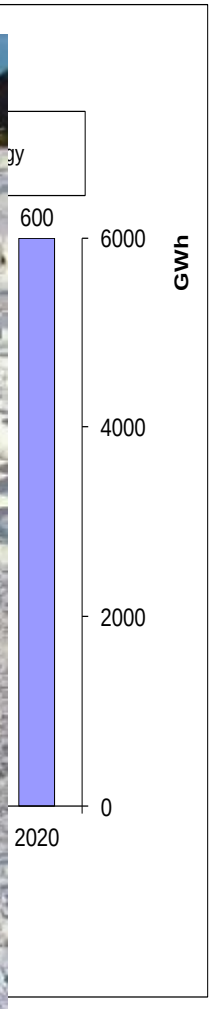
T
M
a

The other geothermal
are
Eb
de

USA

Turkey





14 new Units f
western Anatol
valleys

New Zealand

About 25
from 8
Ngat
Tauh
Wair
fields
part o
exce

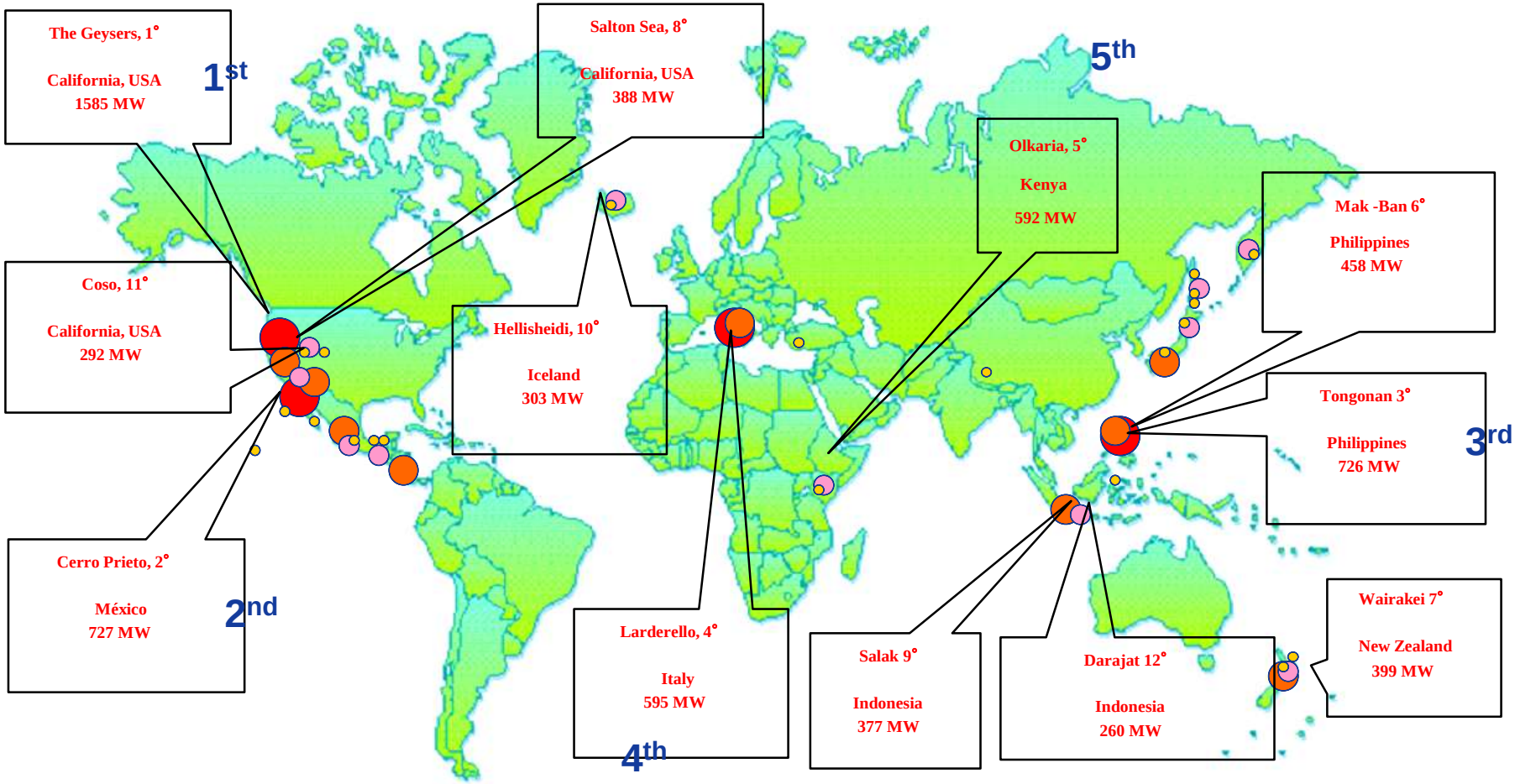
Triple Flash, Fuji, 132 MW, Nga Awa Purua, Rotokawa

Indonesia

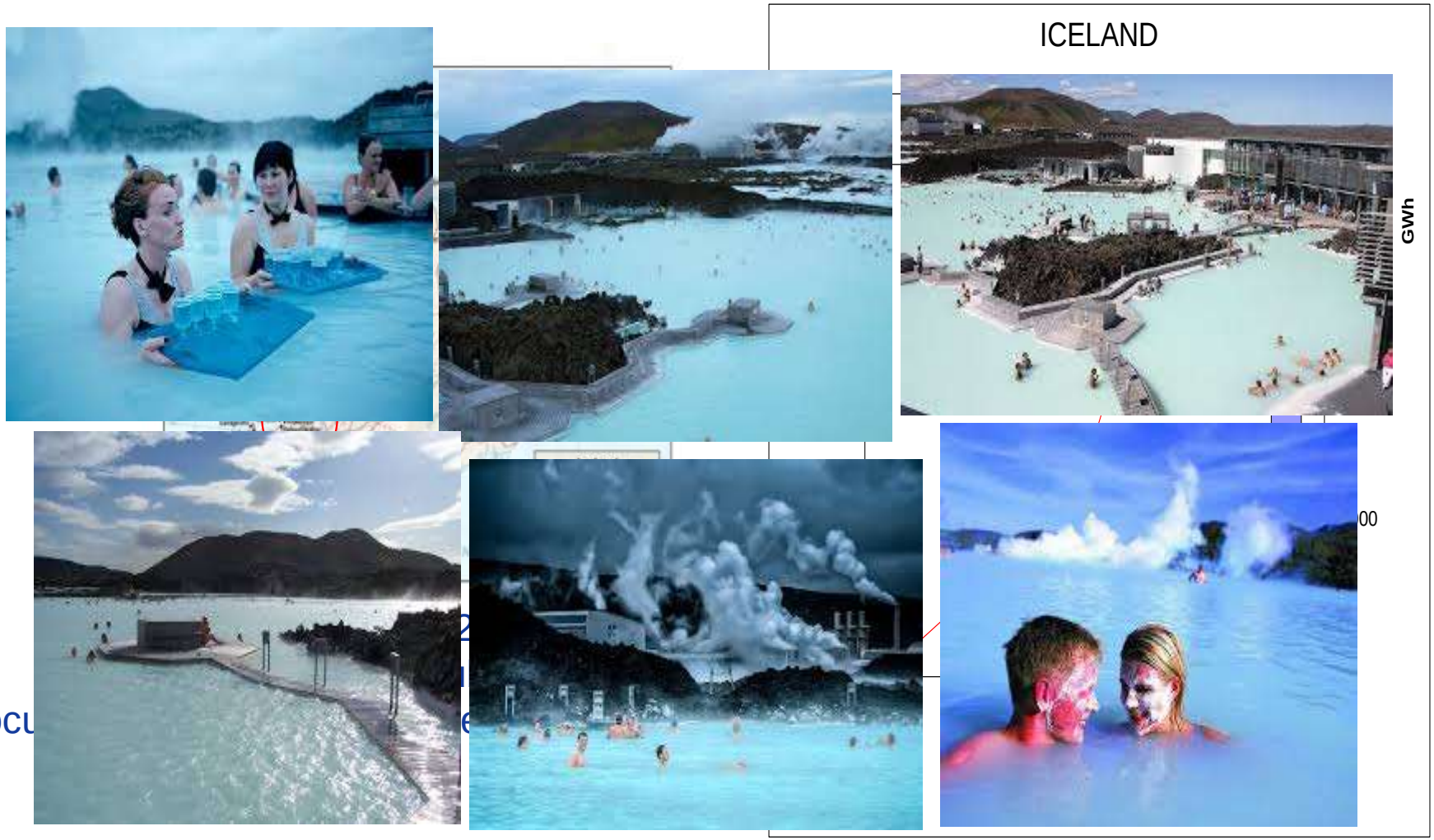
New
hav
comm
at F
Ulun
Ma
Sulawesi –
Lahendong and
Sumatra - Ulu
Belu.

Ulu Belu plant, 2x55 MW, single flash, Toshiba.

2015 Top Dozen of Geothermal Fields



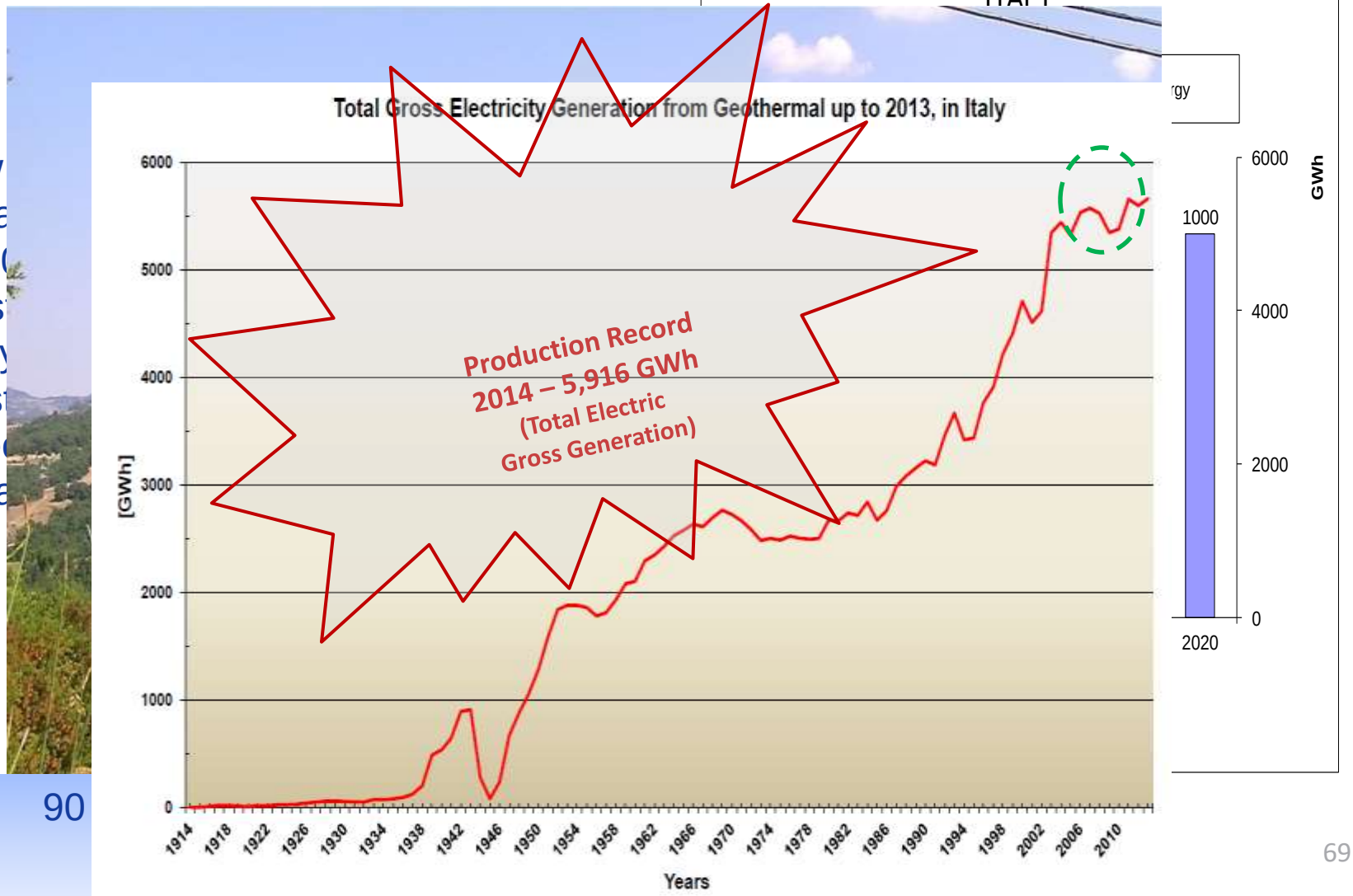
Iceland



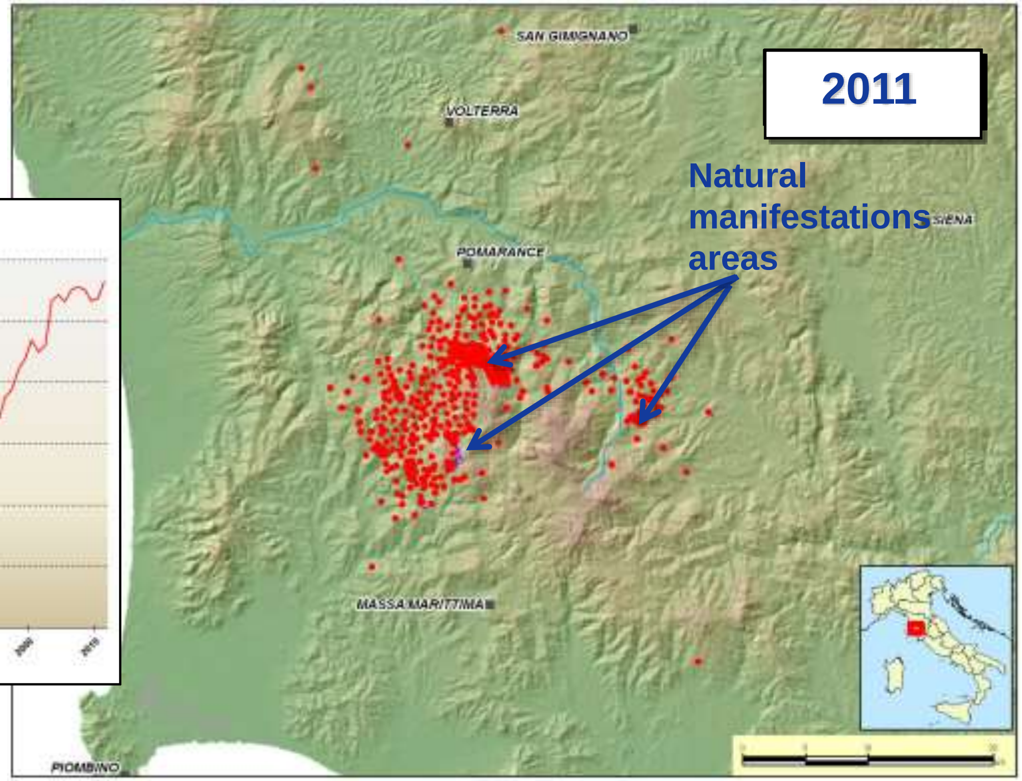
Focu

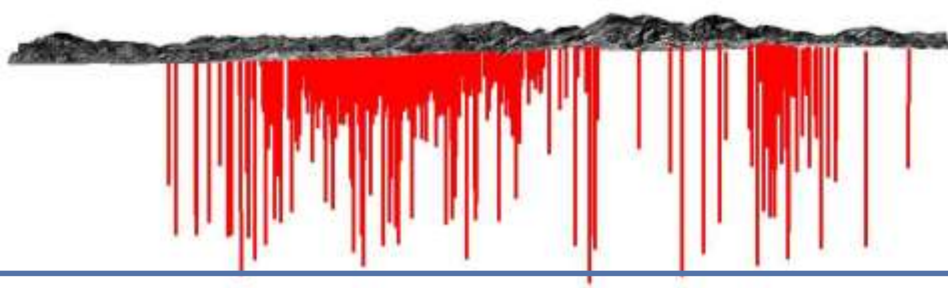
Italy

A new
Ba
(4
the firs
binary
the firs
projet ge
bioma



The history





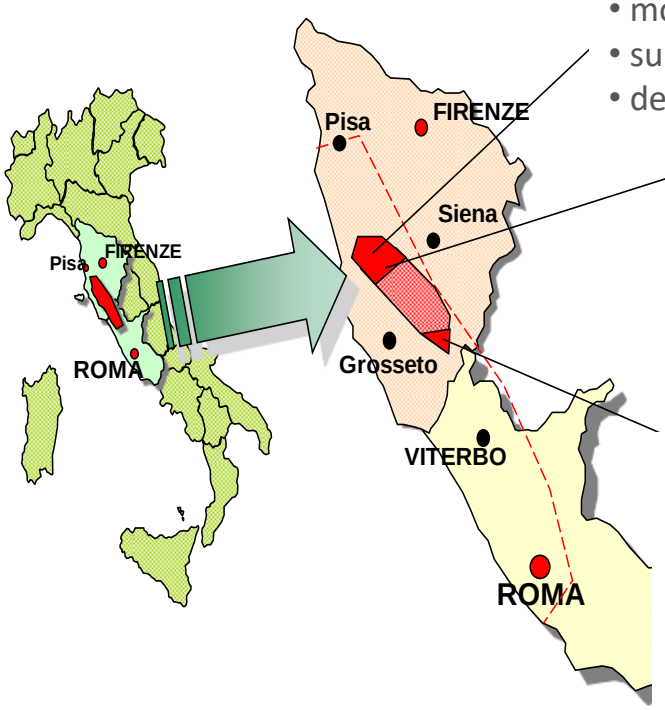
New production record in 2011: 5315 GWh

Reaching the field boundaries

Geothermal power generation in Italy

Where and its characteristics

Currently ***Enel Green Power*** is the only that produces electricity from geothermal sources in Italy.



Larderello

- since 1913
- 250 km^2
- more than 200 wells (production + reinjection)
- superheated steam (2-18 bar & 150-270° C)
- depth: 200 m – 2000 m

Radicondoli

- since 1950
- 50 km^2
- about 30 wells (production + reinjection)
- superheated steam (8-20 bar & 190-250° C)
- depth: 800 m – 4000 m

Mt. Amiata

- since 1955
- 30 km^2
- about 40 wells (production + reinjection)
- liquid dominated (300-350° C)
- depth: 2000 m – 4500 m

Environmental sustainability

Plant design innovation

- Design and construction of a specific plant, know as AMIS© (*Abbattimento Mercurio e Idrogeno Solforato*) for the abatement of H_2S (hydrogen sulphide) and Hg (mercury) from the gases emitted during power plants operation

Architectural innovation

- New design solution and criteria for minimizing visual impact of the power plants in order to make geothermal presence more acceptable to the local community

Innovation also possible to reduce environmental impact

Environmental Sustainability

New design criteria finalized to minimize the visual impact

Reduction of gas emission AMIS
(process for H2S and Hg removal)

Abatement

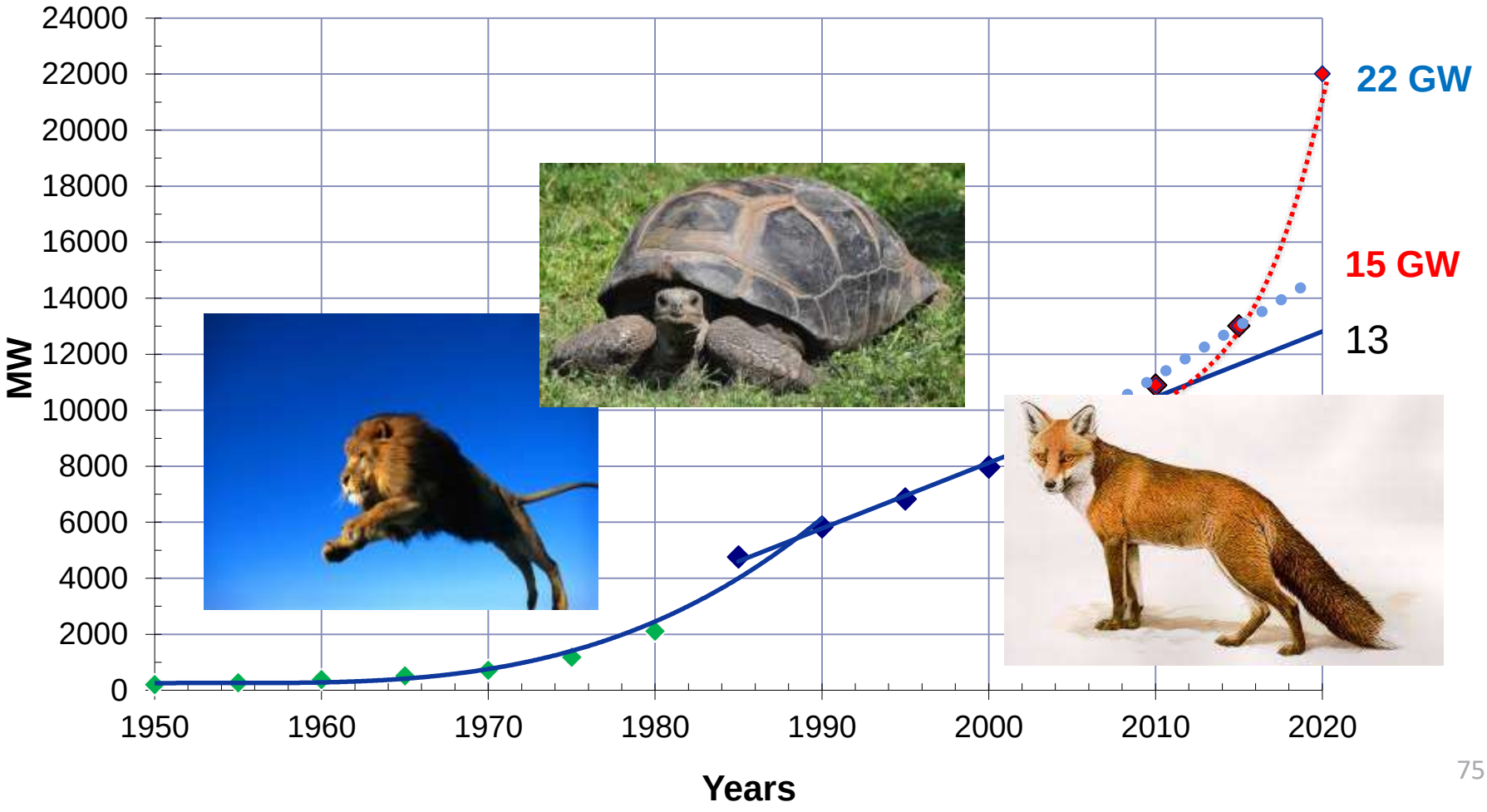
✓ **Hg**	**>90%**
✓ **H_2S**	**70-80%**

Direct use promotion

37% of the heat is delivered to greenhouses

Looking to the future

Medium and long term



Global Geothermal Power Market
Key Barriers and Actions Needed

Barrier	Description	Actions Needed
Resource	• Geothermal resource availability • Well productivity & field capacity • Presence of earthquakes-volcanic activity near the resource	• R&D activity: technology improvements to identify the resource and to exploit geothermal resources at different temperatures • Coordination of activities to share exploration results (i.e. public databases providing location of resources)
Environment	• Regulation for construction and operations • Air emissions & noise pollution • Visual impact	• Coordination of activities to address permitting issues • Technological solutions (i.e. Enel development of AMIS technology) • Architecture solutions
Project economics	• High initial investment costs • High O&M costs • Financial support and incentives	• Coordination at EU, national and regional levels to support and regulate the sector, providing visibility • Support bank financing
Social	• Misleading information • Lack of knowledge • Local hostile institutions / environmental associations	• Creation of consensus through information and communication • Improvement of the relationship with communities
Demand	• Trend of energy demand • Competition from other renewable sources	• Planning of geothermal projects with grid access • Support to distributed generation/smart grids

Is it possible a second exponential growth?

Binary plants

ater dominated reservoir, at very

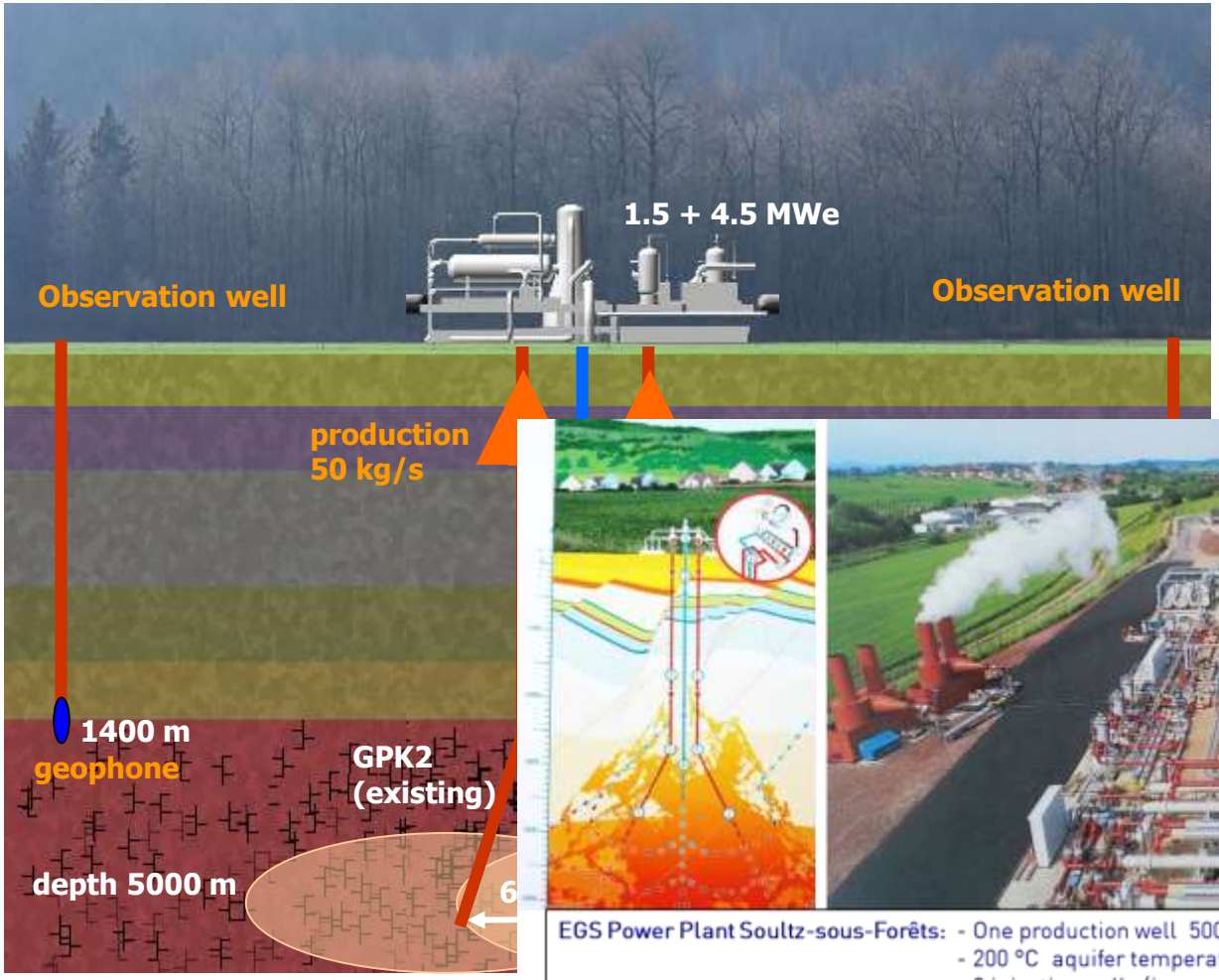
and steam is used for power

of the water, but it is possible
am at 160° C; half of this

mplex for the

Is it possible a second exponential growth?

EGS plants

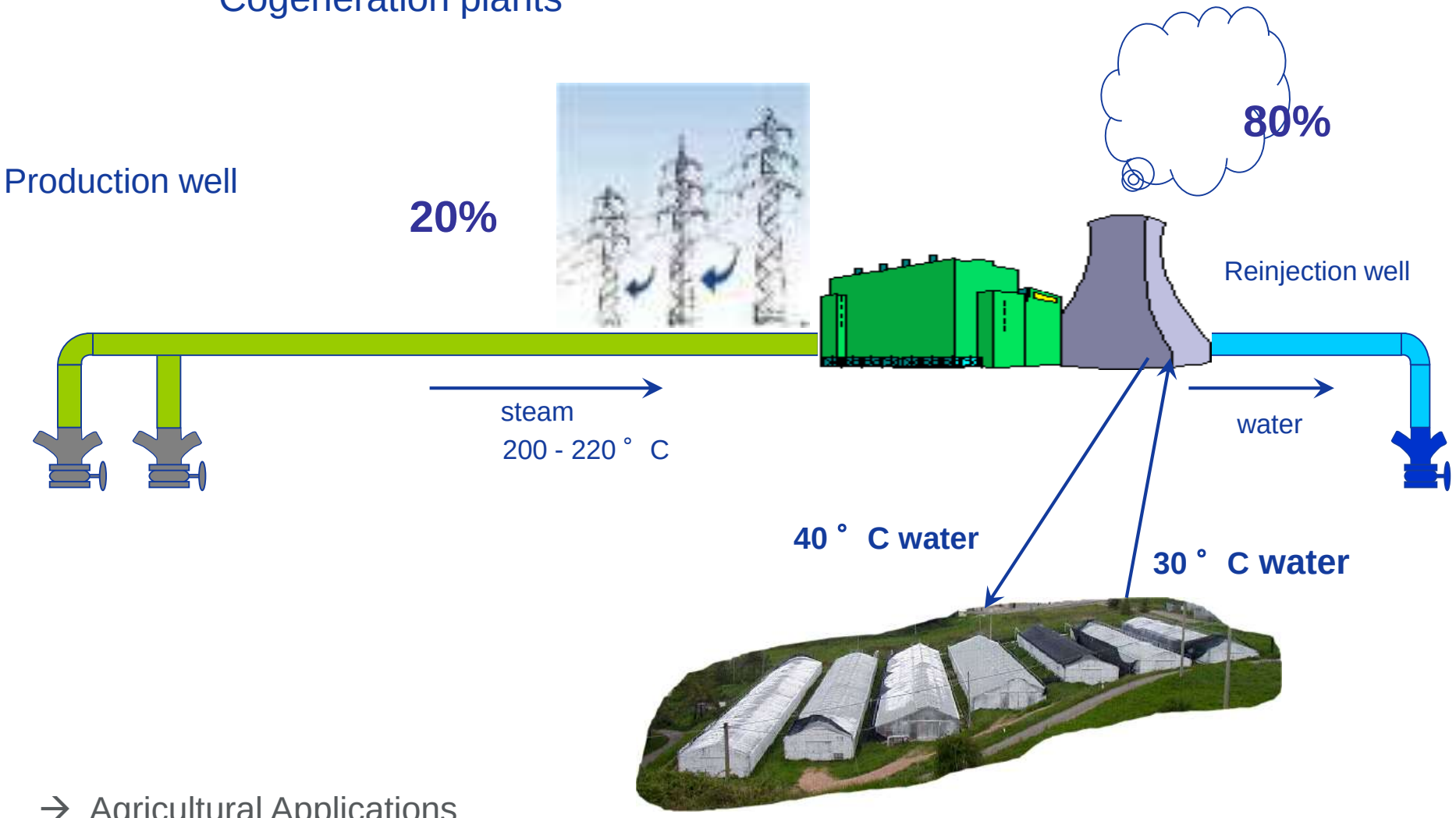


EGS Power Plant Soultz-sous-Forêts:
- One production well 5000 m (in operation)
- 200 °C aquifer temperature
- 2 injection wells (in operation)
- Organic rankine cycle process with 1.5 MWel

Enhanced Geothermal System: **European Soultz project**

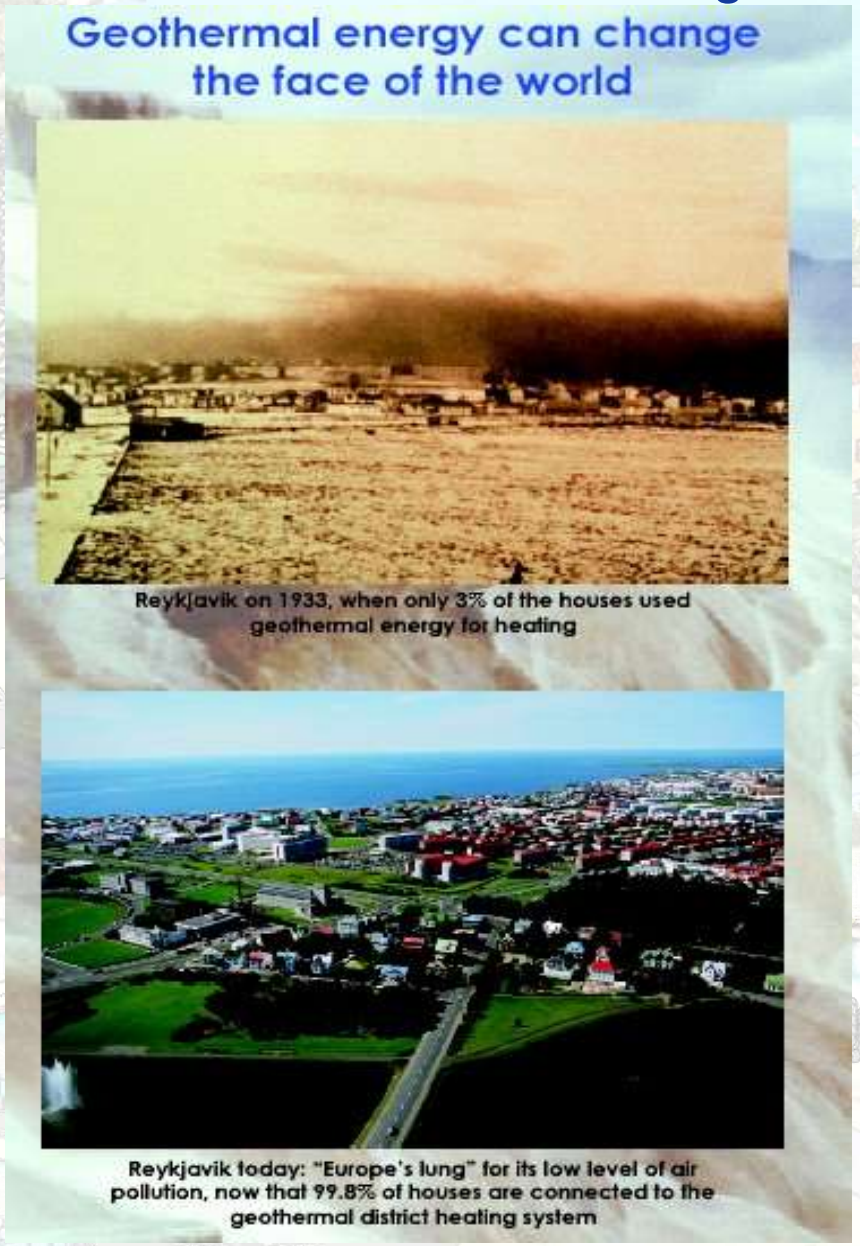
Is it possible a second exponential growth?

Cogeneration plants



→ Agricultural Applications

Geothermal advantages



Geothermal

Energy:

FIRE

WITHOUT

SMOKE