HISTORY, PRESENT UTILIZATION AND FUTURE PROSPECTS OF GEOTHERMAL ENERGY WORLDWIDE

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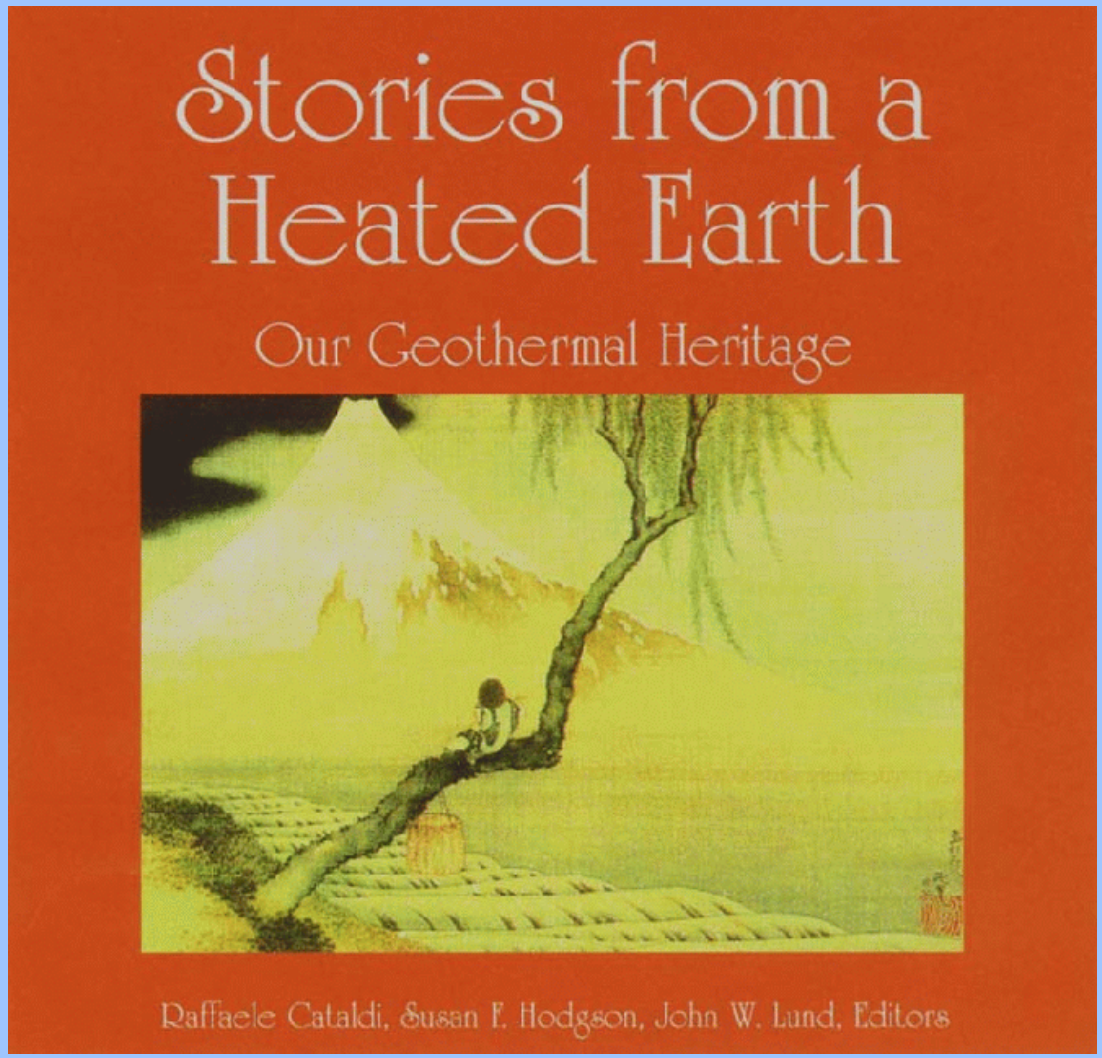
INTRODUCTION

- **Geothermal electric power used since 1904 – Prince Conti - Lardarello, Italy**
- **Geothermal direct-use used for over 10,000 years - early inhabitants of the World – bathing and cooking**
- **District heating and industrial uses 1700s – Chaudes-Aiges, France & Larderello, Italy**
- **Geothermal (ground-source) heat pumps described in 1852 - Lord Kelvin – England – first installation, Indianapolis in 1945**



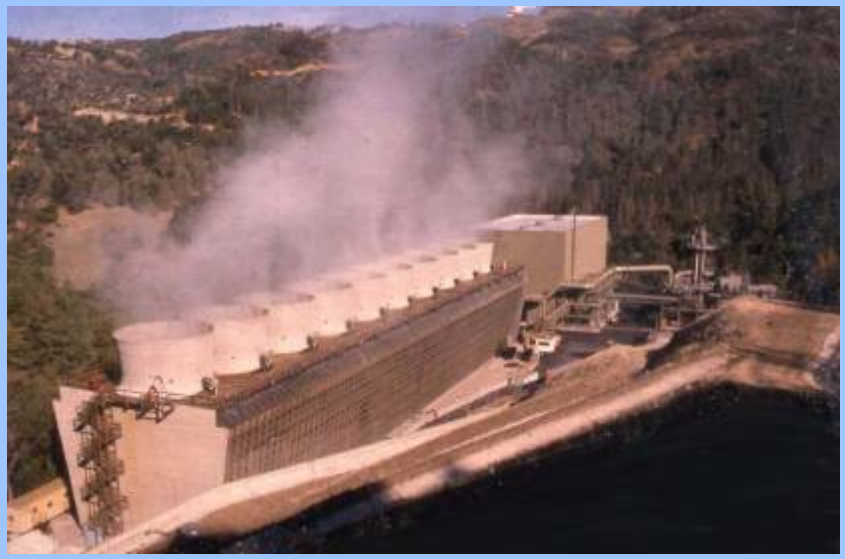
- Describes early uses prior to the industrial revolution
- 34 chapters covering over 25 countries
- Edited by:

R. Cataldi, S. Hodgson, and J. Lund

Available from Geothermal Resources Council

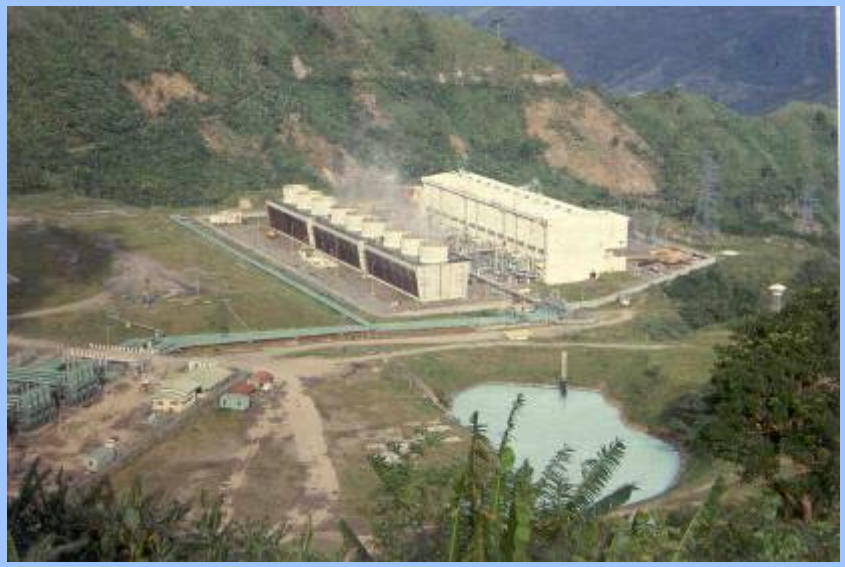
GEOTHERMAL TODAY

- **9,000 MWe installed electrical capacity**
  - **Producing 57,000 GWh/yr – 73% C.F.**
  - **In 24 countries**
- **29,000 MWt installed direct-use capacity**
  - **Producing 76,000 GWh/yr (274,000 TJ/yr)**
  - **In 72 countries – 31% C.F.**



The Geysers, USA

Larderello, Italy



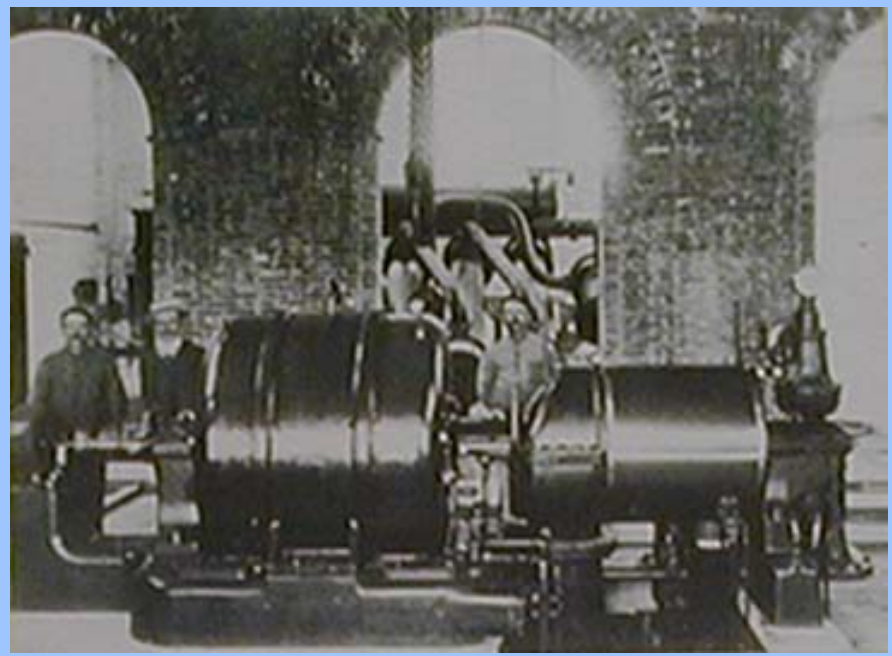
Electric Power Generation

EARLY DEVELOPMENT

- **1904 – Larderello, Italy – first experimental work by Prince Ginori Conti – 5 light bulbs from 10 kWe dynamo – “indirect cycle”**

EARLY DEVELOPMENT II

- **1913 – first commercial geothermal power plant at Larderello – 250 kWe fed into local network – use by villages in the region – resource 200-250ºC**



EARLY DEVELOPMENT
New Zealand

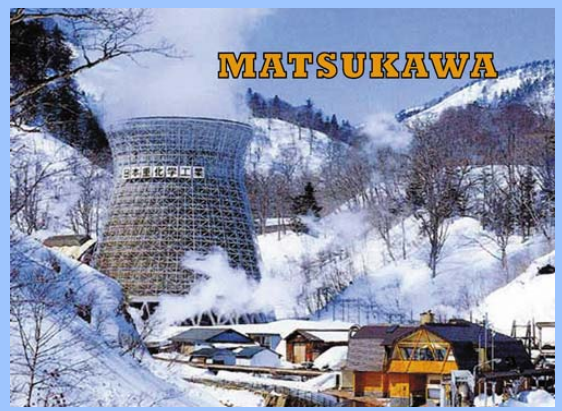
- **1947 – New Zealand engineers visit Italy**
- **1958 – Wairakei “A” station on line in New Zealand – 69 MWe – “wet steam”**
- **Separators needed - producing HP, IP and LP steam - 230ºC**

EARLY DEVELOPMENT
North America

- **1932- first geothermal power plant at The Geysers – 35 kWe - 152ºC**
- **1959 – first geothermal power plant in Mexico– Pathé – 3.5 MWe - >250ºC**
- **1960 – first modern US plant on line at The Geysers in northern California – 12 MWe - 230ºC**
- **All are “dry steam” plants**

EARLY DEVELOPMENT
Asia

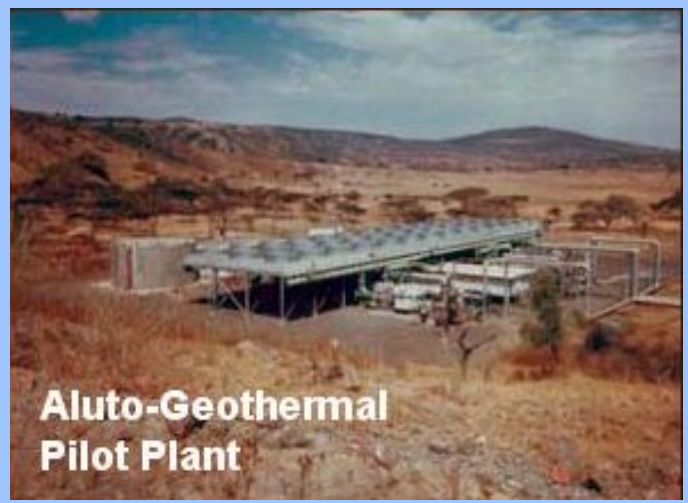
- **1966 – first “dry steam” plant on line in Japan – 23 MWe at Matsukawa on northern Honshu**

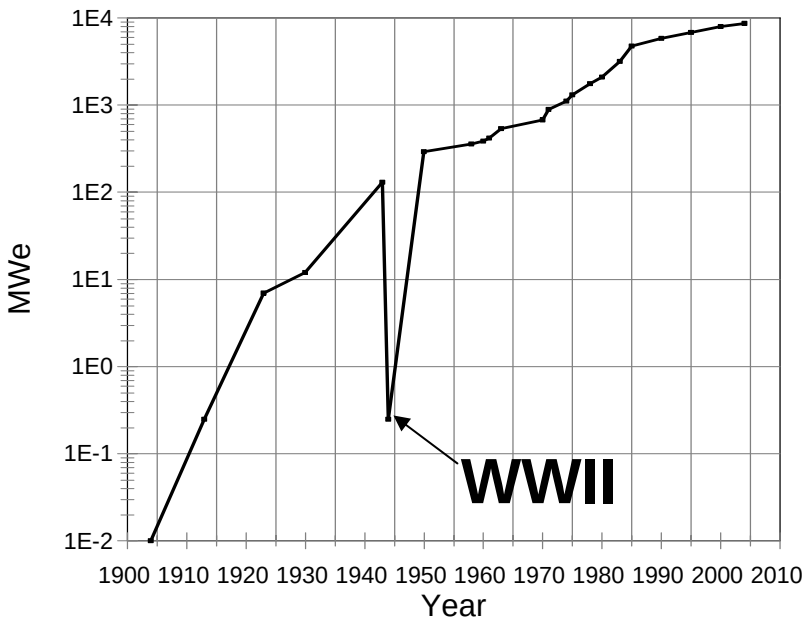


- **1967 - USSR producing power from the first binary power plant – 680 kWe using 81ºC water at Paratunka, Kamchatka (then, the lowest ever!!).**

EARLY DEVELOPMENT
Africa

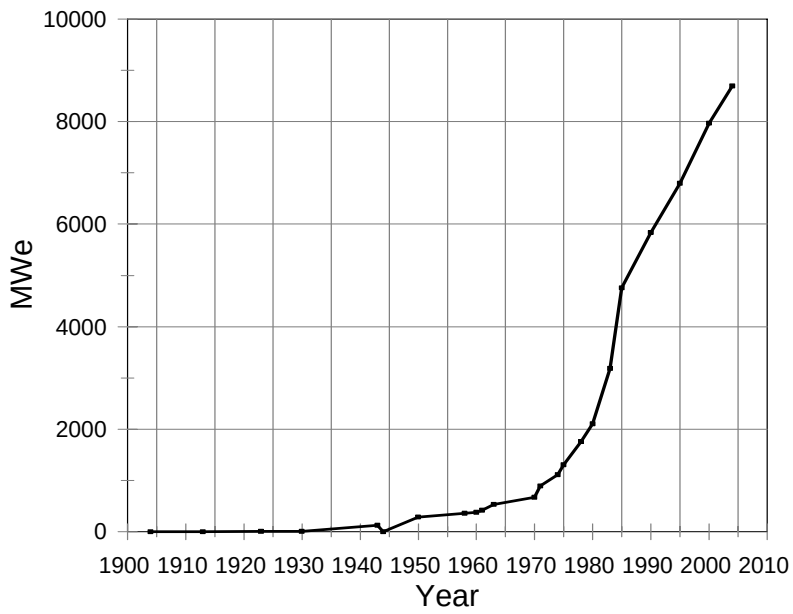
- **Kenya – 1981- 1985 – 45 MWe single flash at Olkaria – now at 127 MWe**
- **Ethiopia – 1999 – 7.3 MWe binary at Aluto-Langano**





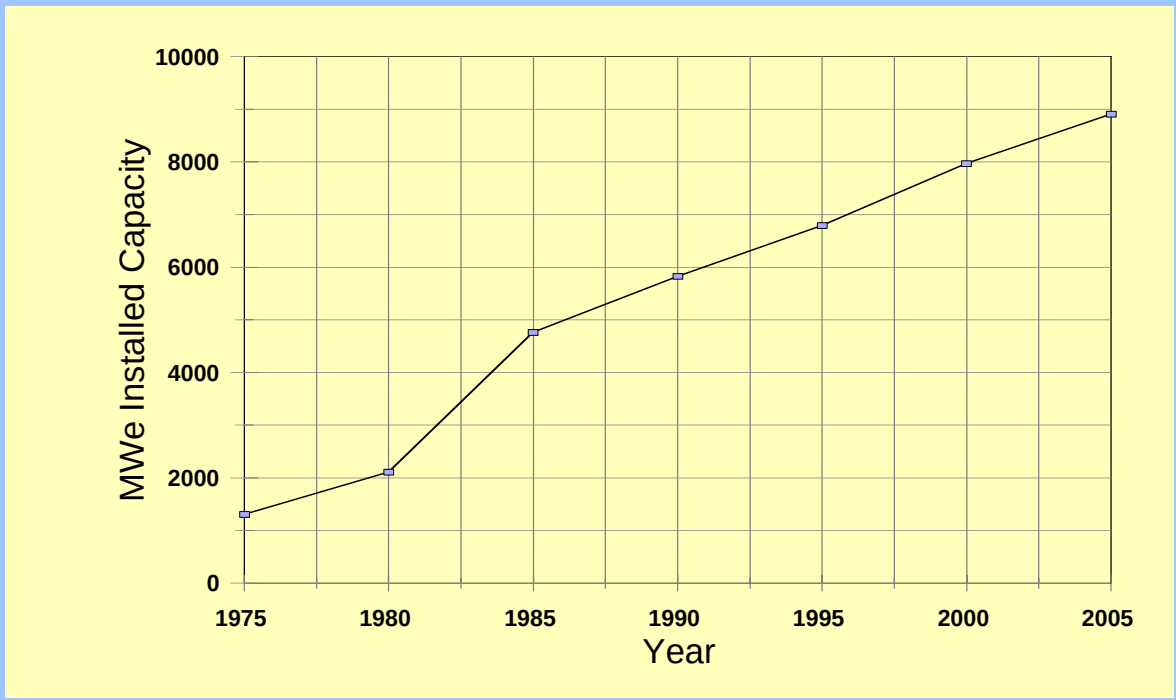
Worldwide Geothermal power production 1904-2005

Production from 1904-1958 entirely from Italian fields

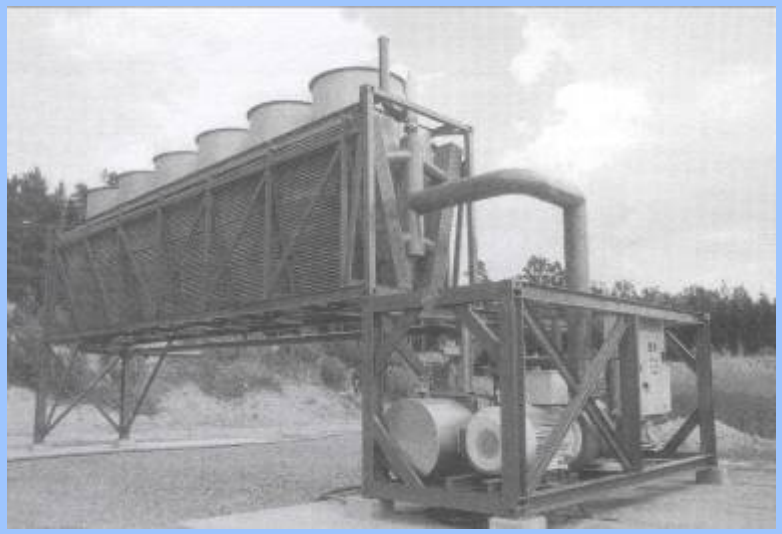


ELECTRICAL GROWTH

- **6.5% per year in capacity since 1975**
- **Almost 1,000 MWe every five years**
- **Germany & Papua New Guinea new players**
- **Binary (ORC) plants using temp. ~100ºC**



Binary plants



250 kWe, Austria – 110°C

1 MWe, Tibet – 110°C

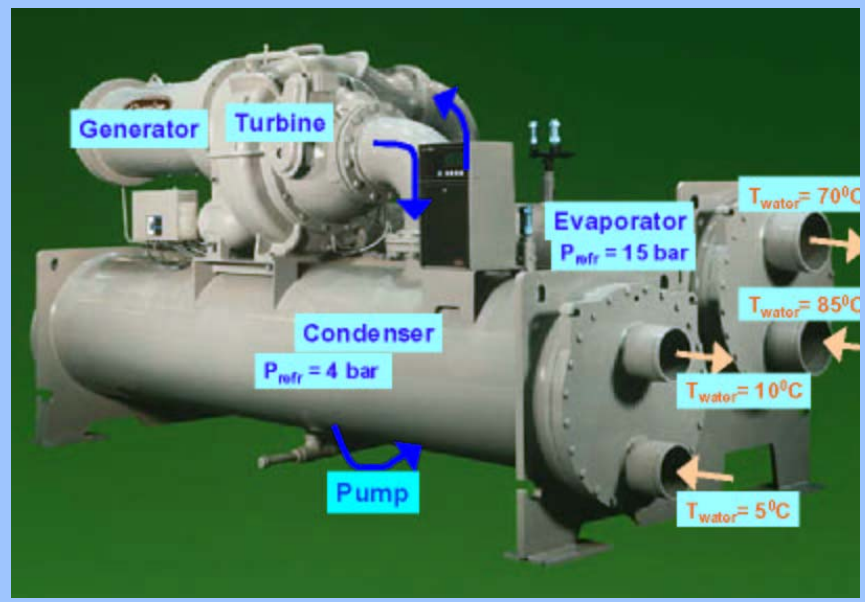
2 x 375 kWe, CA – 110°C

750 kWe, NV – 110°C

CHENA HOT SPRINGS, ALASKA

United Technologies Corporation

200 kW Carrier converted vapor-compression cycle chiller to a Rankine cycle that uses R-134a refrigerant



Installed in July of 2006

Lowest temperature geothermal use for power generation in the world

74ºC resource and 5ºC cooling water

WORLD ELECTRICAL USE 2005

Region	MWe (%)	GWh/yr (%)
Africa	1.5	1.9
Americas	43.9	47.0
Asia	37.2	33.8
Europe	12.4	12.4
Oceania	5.0	4.9

Leading Countries in Geothermal Electric Power Generation

Country	Capacity* MWe	Production GWh/yr	Capacity Factor
United States	2,133	17,840	0.95
Philippines	1,838	9,253	0.57
Mexico	953	6,282	0.75
Indonesia	838	6,085	0.83
Italy	699	5,340	0.87
Japan	530	3,467	0.75
New Zealand	403	2,774	0.79
Iceland	202	1,483	0.84

*Running capacity (Bertani, 2005)

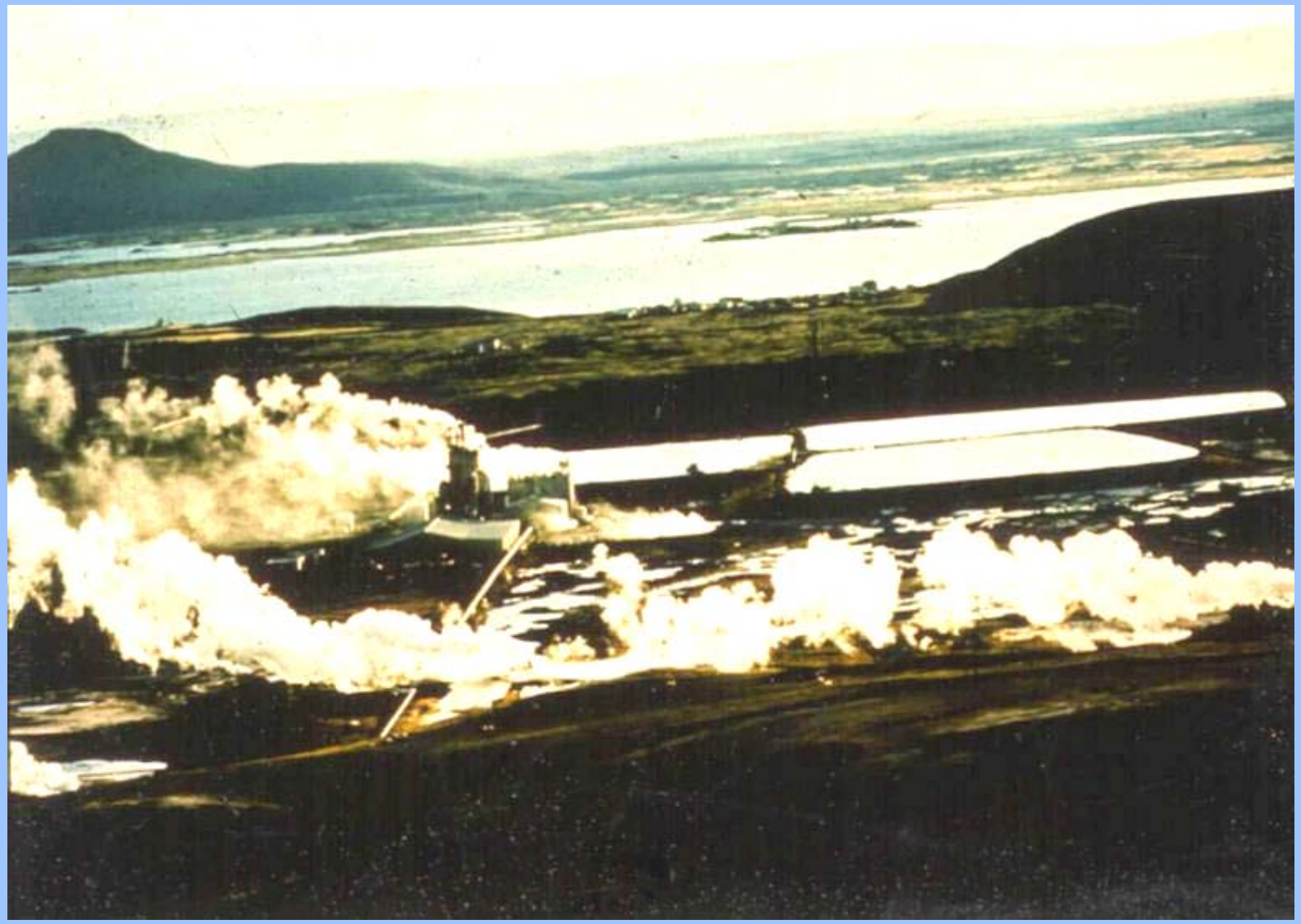
NATIONAL GEOTHERMAL CONTRIBUTIONS

Country/region	% Capacity	% Energy
Tibet	30.0	30.0
Tuscany, Italy	25.0	25.0
San Miguel, Azores	25.0	n/a
El Salvador	14.0	24.0
Iceland	13.7	16.6
Philippines	12.7	19.1
Nicaragua	11.2	9.8
Kenya	11.2	19.2
Lihir Is., PNG	10.9	n/a

POWER PLANTS MWe Installed Capacity

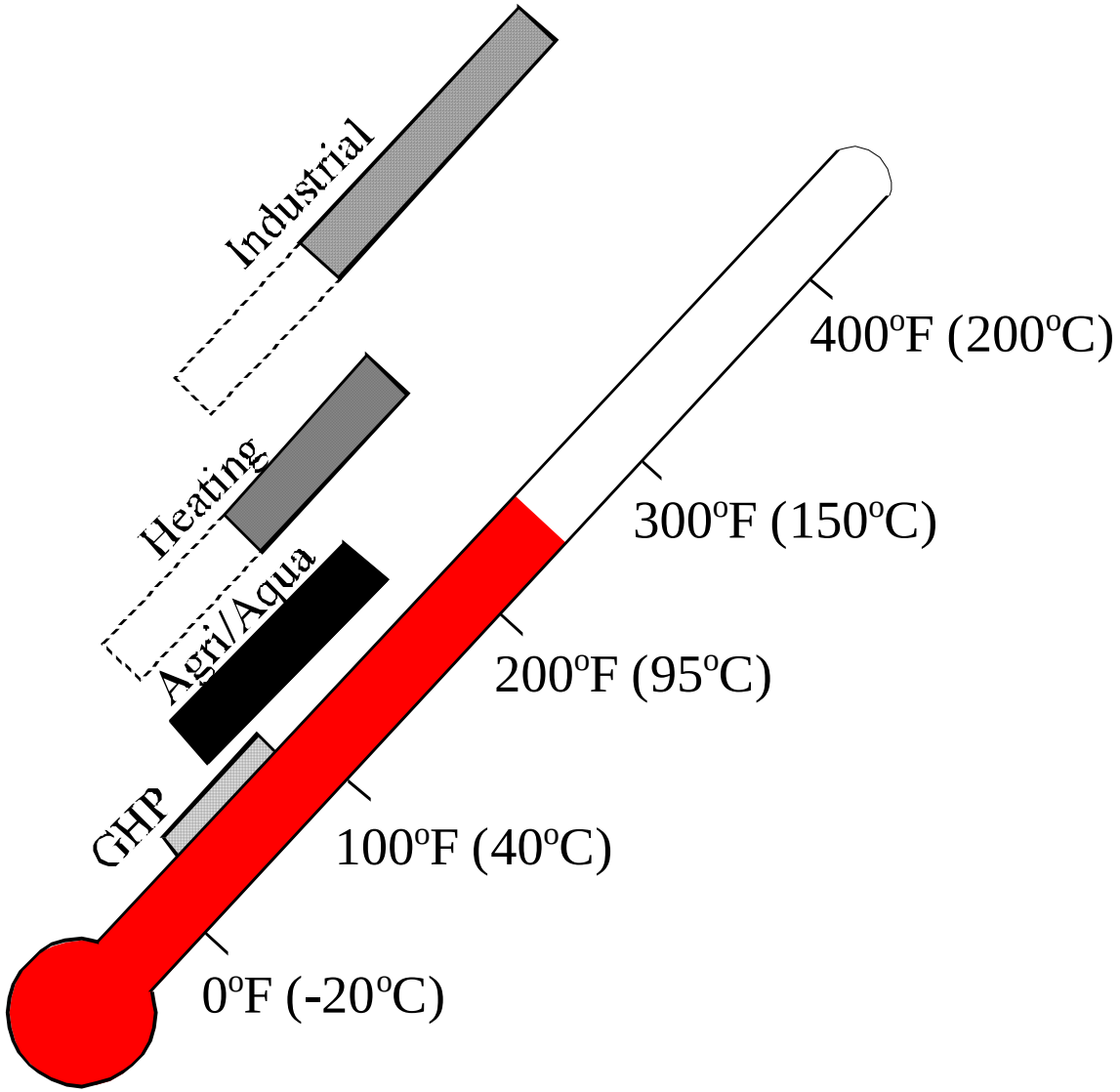
• 28% dry steam	44 MWe/unit	58 units
• 37% single flash	26 MWe/unit	126 units
• 26% double flash	34 MWe/unit	67 units
• 8% binary/hybrid	3 MWe/unit	208 units
• 1% back pressure	4 MWe/unit	29 units

- Ref: Bertani, 2005



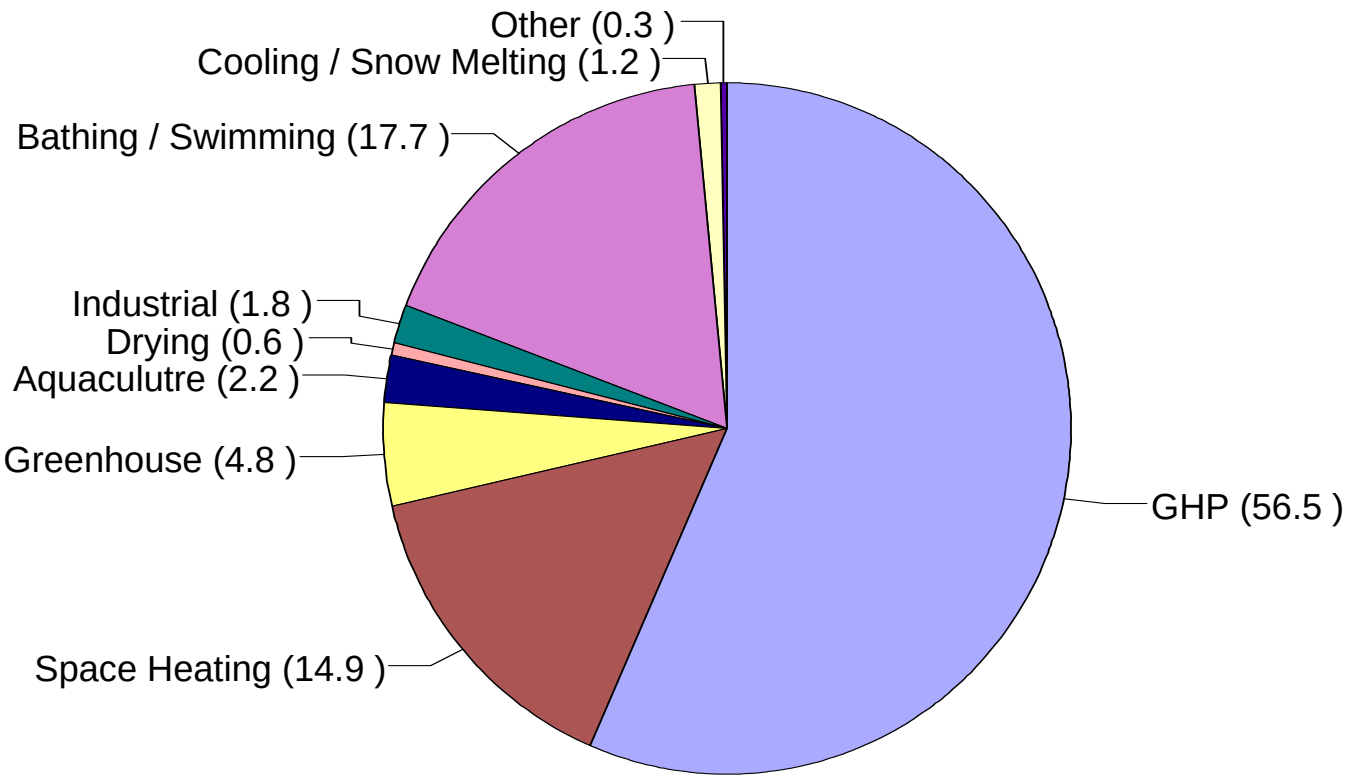
Direct Utilization

(Diatomite drying plant, Iceland)



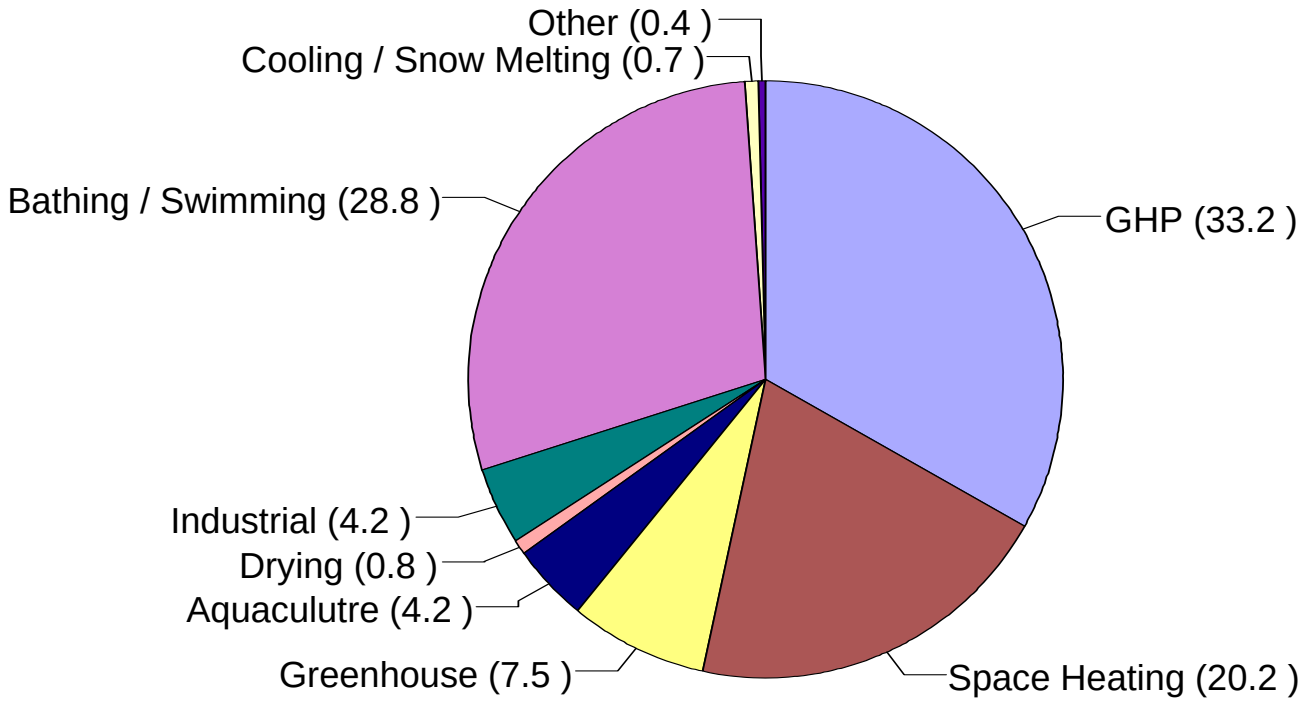
Temperature use for direct use applications

World Installed Capacity (%)



2005 installed capacity (MWt)

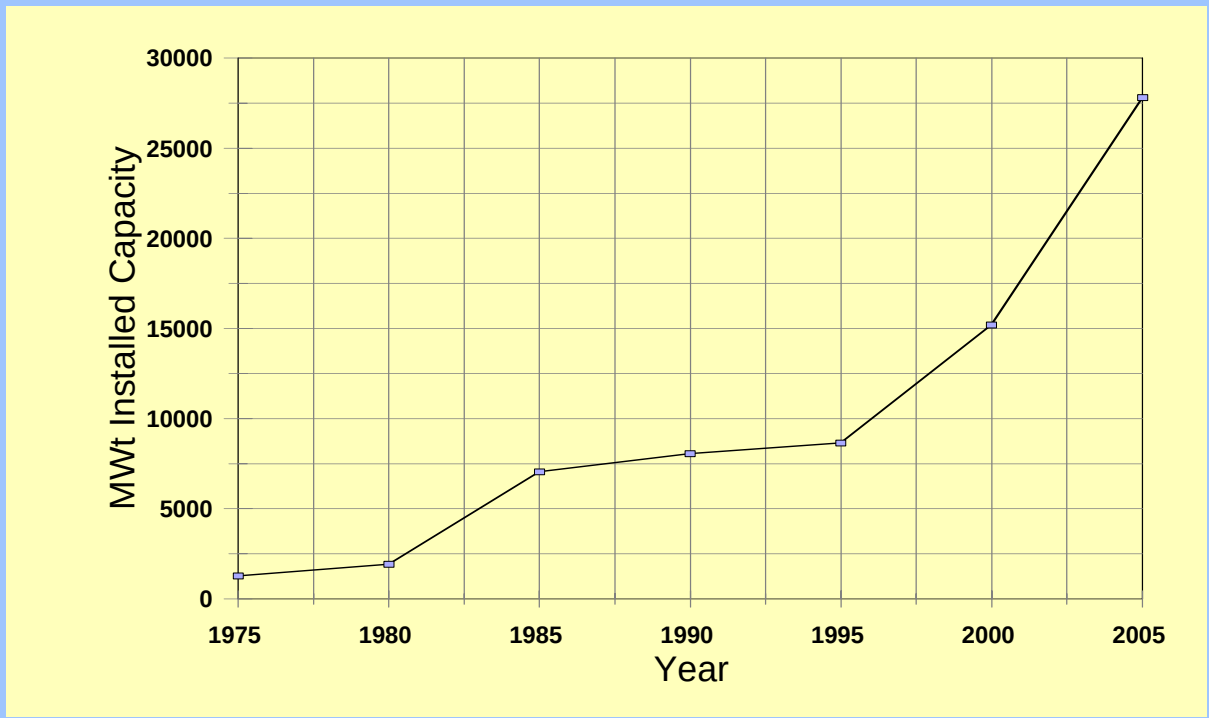
World Annual Energy Use (%)



2005 energy use (GWh/yr)

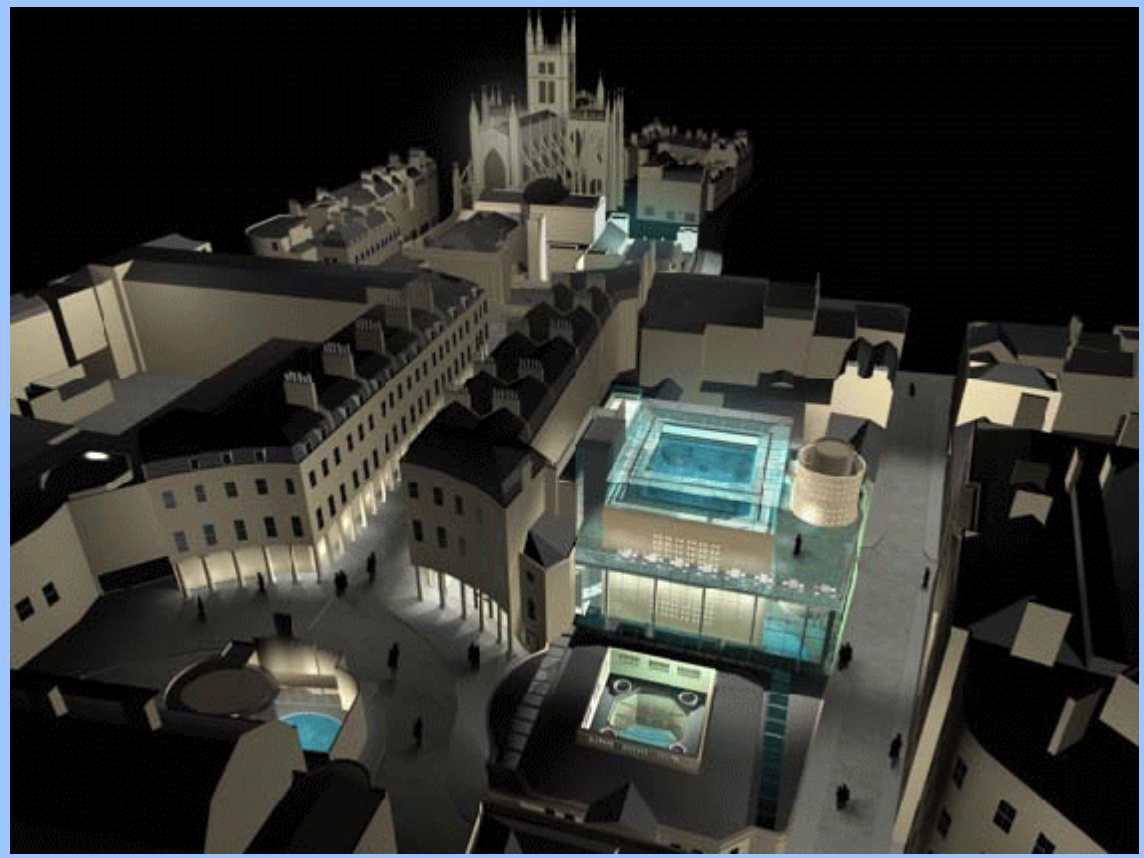
DIRECT-USE GROWTH

- **11% per year in capacity since 1975**
- **2x growth in 5 years – 13 new countries**

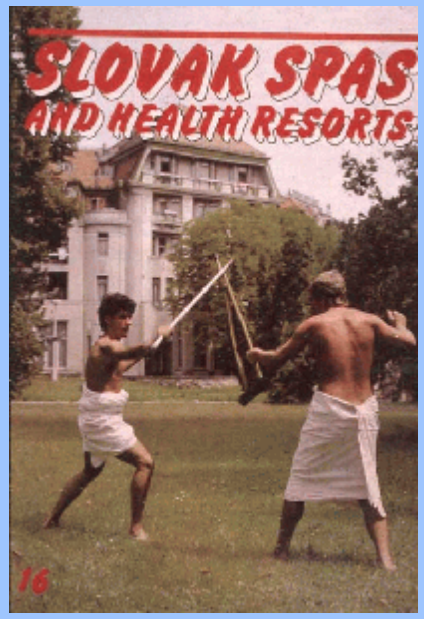


EARLY SPAS

Spa, Belgium



Bath, England



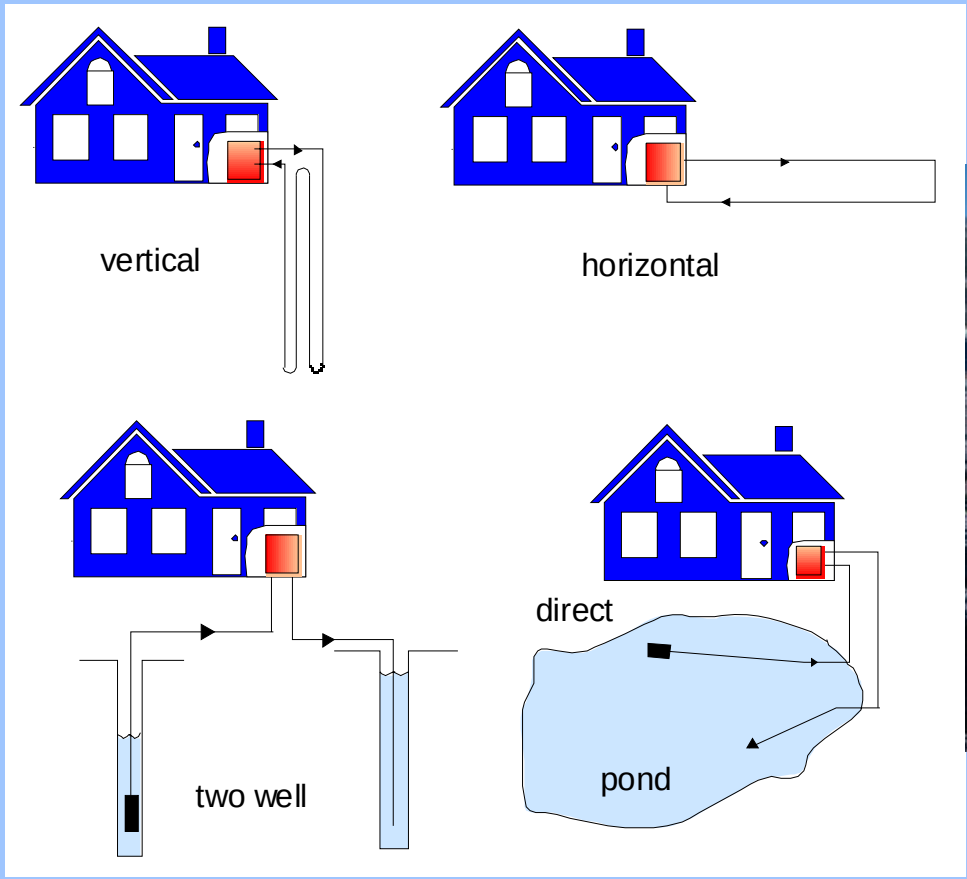
Medical treatment = balneology

SPACE HEATING AND COOLING

GREENHOUSE AND FISH POND HEATING

GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS

- 33 countries report use
- 1.5 million units installed (12 kW each)
- Mostly in North America & Europe
- 24% annual capacity growth in 10 years
- 3x growth in last 5 years
- Provides both heating & cooling
- Uses 5 to 30^{o}C ground or ground-water temperature – available worldwide
- Resource <100 m deep



Norway – 180 boreholes
9 MW heating - 6 MW cooling

Geothermal Heat Pumps

WORLD DIRECT-USE 2005

Region	MWe (%)	GWh/yr (%)
Africa	0.7	1.1
Americas	32.3	16.7
Asia	20.9	29.4
Europe	44.6	49.0
Oceania	1.5	3.8

TOP DIRECT-USE COUNTRIES

Country	GWh/yr	MWt	Main Application
China	12,605	3,687	bathing
Sweden	10,000	3,840	GHP
U.S.A.	8,678	7,817	GHP
Turkey	6,900	1,495	district heating
Iceland	6,806	1,844	district heating
Japan	2,862	822	bathing (onsens)
Hungary	2,206	694	spas/greenhouse
Italy	2,098	607	spas/space heating
New Zealand	1,969	308	industrial uses

DIRECT-USE CONTRIBUTIONS

- **Iceland – provides 86% of country's space heating needs**
- **Turkey – space heating increased 50% past 5 years, supplying 65,000 equivalent residences – 30% of country heated by 2010**
- **Tunisia – greenhouse heating increased from 10 ha to 100 ha over 10 years**
- **Japan - >2000 hot spring resorts (onsens), >5,000 public bath houses, >15,000 hotels, visited by 14.5 million guests per year.**
- **Switzerland – 30,000 GHP – one/2 km^2 – 1,000 boreholes drilled/yr – tunnel water and road deicing**
- **United States – 700,000 GHP units+ - 15% annual growth – 50,000 to 60,000 units/yr installed.**

SUMMARY

- **High temperature >175°C**
  - **flash steam electric power**
  - **industrial applications and refrigeration**
- **Intermediate temperature: >100°C**
  - **binary cycle electric power**
  - **space cooling and some industrial applications**
- **Low temperature: >50°C**
  - **greenhouses, aquaculture ponds, pools and space heating**
- **Normal ground temperature <30°C**
  - **ground source (geothermal) heat pumps**

ENERGY SAVINGS
Electric & Direct-Use

- 270 million barrels, or
- 41 million tonnes of oil/yr
- (about 3.5 days or 1% of world's production)
- 37 million tonnes of carbon/yr
- 118 million tonnes of CO_2/yr
- 0.8 million tonnes of SO_x/yr
- 22 thousand tonnes of NO_x/yr

SUCCESSFUL EXAMPLES

- **Direct Use:** USA, Iceland, and Kenya
- **Power Generation:** Russia and Mexico
- **Combined Heat and Power:** Iceland, Austria, and Germany
- **New Technology: Heat mining –** France **and Continental deep drilling –** Iceland **Hot fractured rocks -** Australia

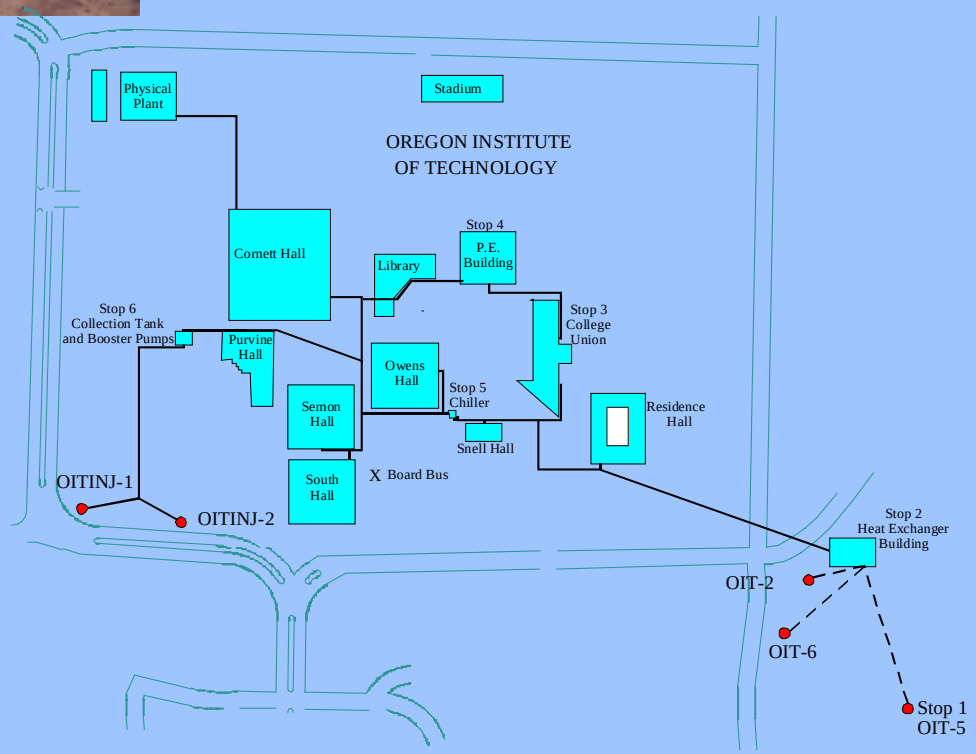
89°C water

3 wells – 600 m

6 MWt – 12 GJ/yr

Saving $1mil/yr

Oregon Institute of Technology



District Heating – Example

Reykjavik, Iceland

- Started 1930
- 190,000 people (99.9% of city)
- 88^{o} to 127^{o}C water – supplied at 80^{o}C
- Adequate to –26^{o}C
- 830 MWt
- 62 wells
- Large storage tanks for peaking
- Oil fired booster station


1980s


today


1933


Reykjavik


Heating

50 MWe (2x25)

15 m of snow

Severe weather - unmanned and remote controlled – planned from Moscow 7000 km away

Winter operation

Turbines – 50 MWe

Mutnovsky power plant, Kamchatka, Russia

Maguarichic, Mexico

- **Isolated village in the State of Chihuahua – power supplied by 90 kWe diesel generator that ran 3 hr/day – homes had no refrigerators, thus,the villagers rarely had meat, cheese, milk, etc. They were not aware of national events since no TV.**

- **1997 - 300 kWe binary plant - 150ºC – 55 t/h - $3,000/kW**

- **Villagers now have street lights, refrigerators, electric sewing and tortilleria machines, and ice cream for the kids.**

ALASKA

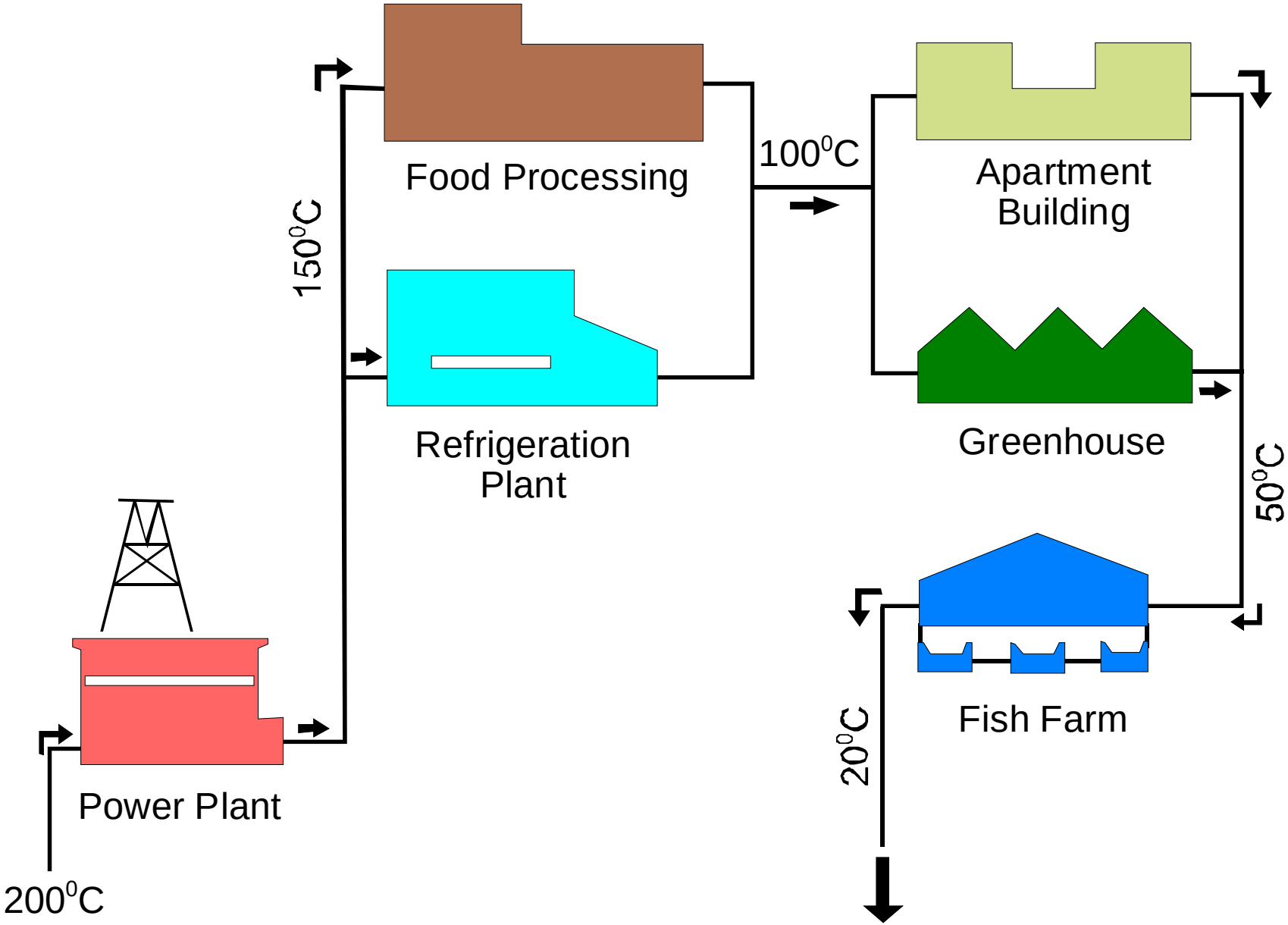
Aurora Ice Museum

Chena Hot Springs

33 kW absorption chiller using 5.4 L/s of 74°C geothermal water and 4°C river water at 5.0 L/s =
- 4°C inside

OSERIAN DEVELOPMENT CO. Greenhouses - Kenya

Olkaria geothermal field – 40 hectares - using geothermal helps reduce humidity and diseases for flowers – uses CO_2 to enrich the atmosphere - 1.2 MWe binary plant to support pumping requirements



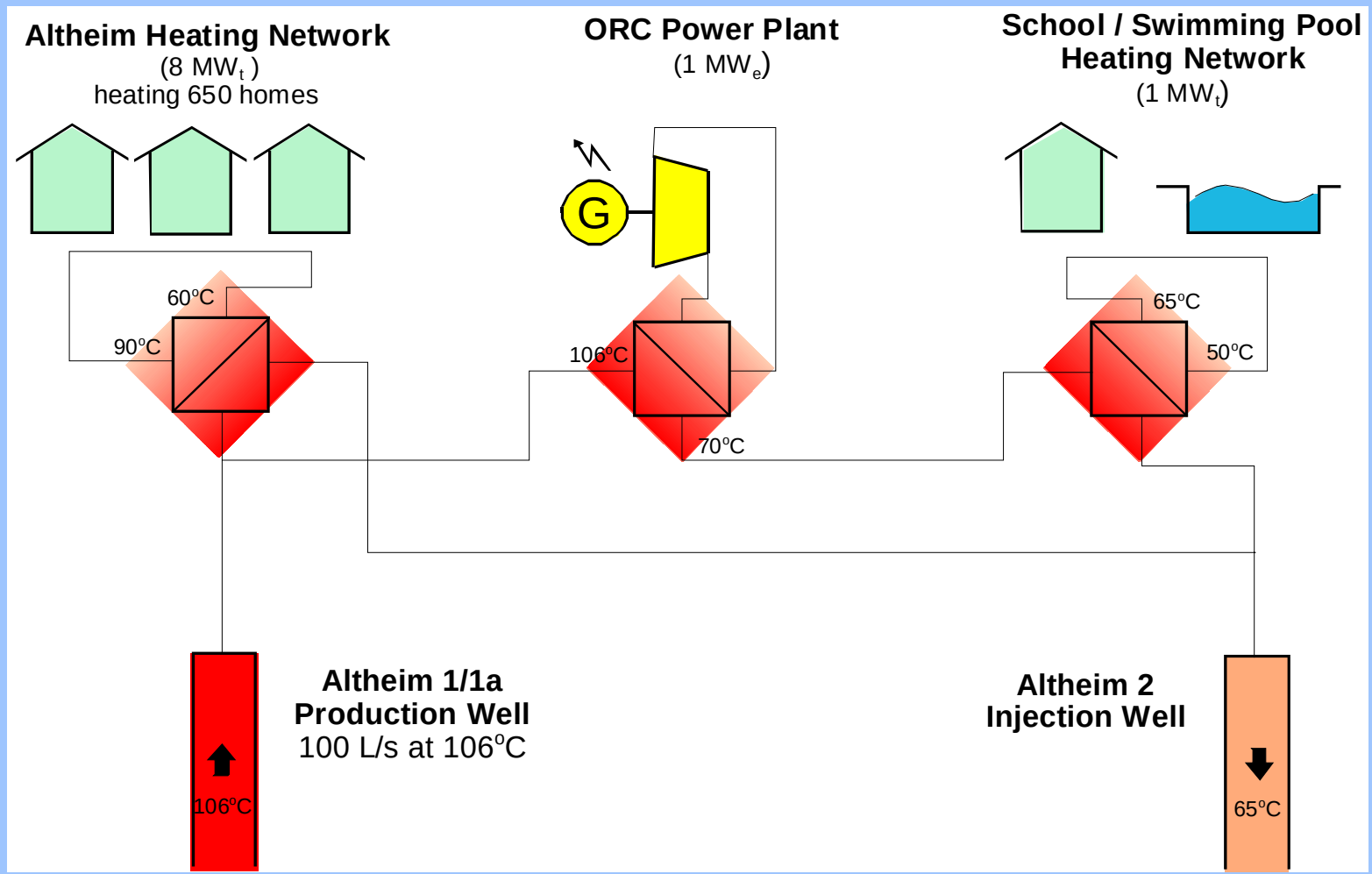
Cascading geothermal fluids – combined heat & power

Sudurnes District Heating System

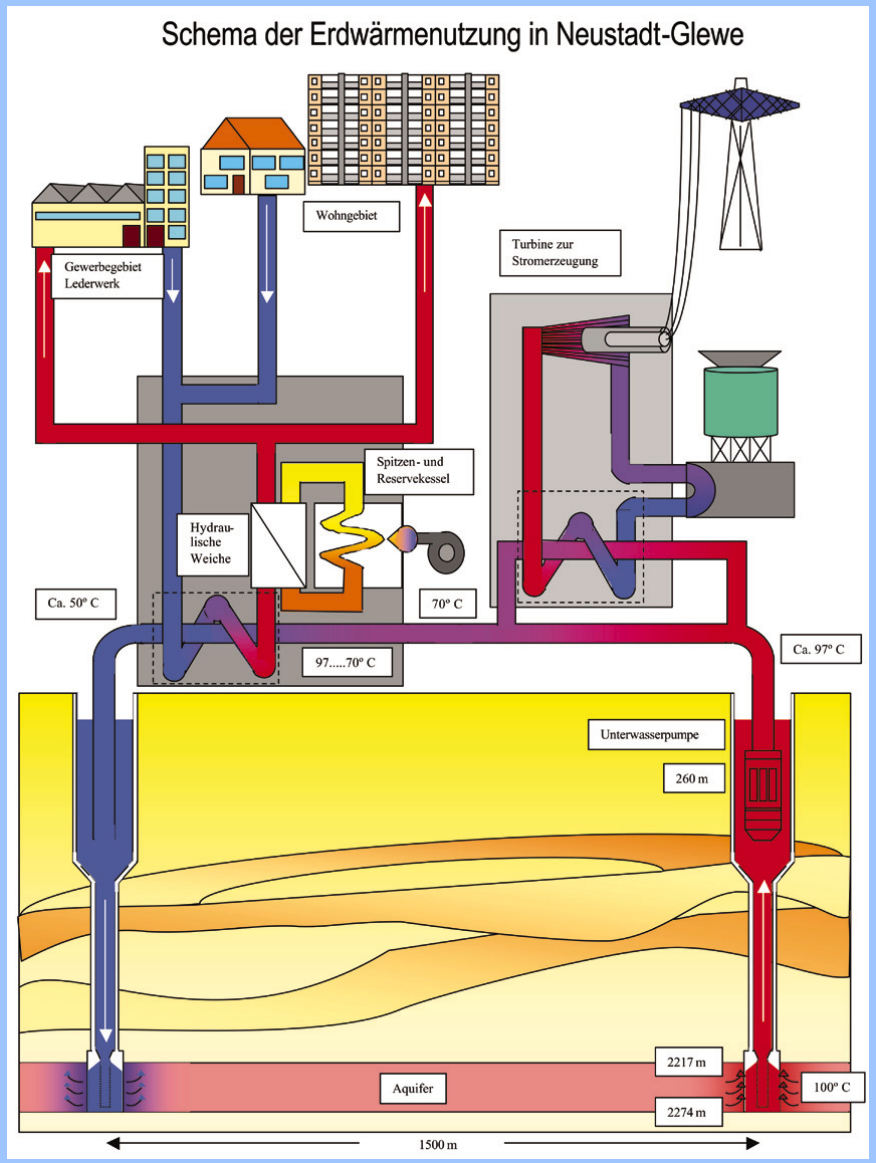
<u>Svartsengi, Iceland</u> combined heat and power plant - 240ºC - 200 MWt heat and 45 MWe electricity (8.4 MWe binary)

COMBINED HEAT & POWER PLANT: ALTHEIM, AUSTRIA

Using geothermal resource at 106°C – 9 MWt & 1 MWe



NEUSTADT GLEWE, GERMANY
combined heat and power plant



98°C – 1,700 L/s
210 kWe & 6 MWt
well at 2,300 m
supply 500 households

Soultz-sous-Forêts – Rhein graben

Hot dry rock project – “Heat Mining”

European Economic Interest Group

4 countries including ENEL

Commercial electricity production

- Inject cold water at 5 km
- Obtain 200°C water/steam
- Produce 6 MWe by 2007
- Suitable European sites

  potential = 110 000 MWe

Iceland Deep Drilling Project

- 4 to 5 km – Reykjanes Peninsula
- 400 to 600°C
- 3 Icelandic companies
- Government of Iceland
- International Continental Scientific Drilling Program

Produce supercritical fluids

Increase well power production – 5 to 10 x

2005: 2.7 km - flow test

Site has since been moved

Hot Fractured Rock (HFR)

Australia's Cooper Basin

(source: Geodynamics Ltd.)

Two wells drilled: 4900 & 4572 m

270 and 250^{o}C into granite rock

2006: 3-5 MWe binary plant

2009: 40 MWe binary station

275 kV powerline – 60 million €

CONCLUSIONS

- In 30 years – the number of countries reporting geothermal use: 10 to 72
- Another 10 countries actively exploring for geothermal – power plants on-line by 2010 to 2015
- In 10 years electrical capacity and direct-use will grow 10%/yr – 2.5x increase
- More combined heat and power plants on-line – especially those using low temperature <120°C
- Increased interest in agriculture crop drying and refrigeration in tropical climates
- Geothermal heat pumps will increase 15%/year

THANK YOU