WORLDWIDE GEOTHERMAL UTILIZATION

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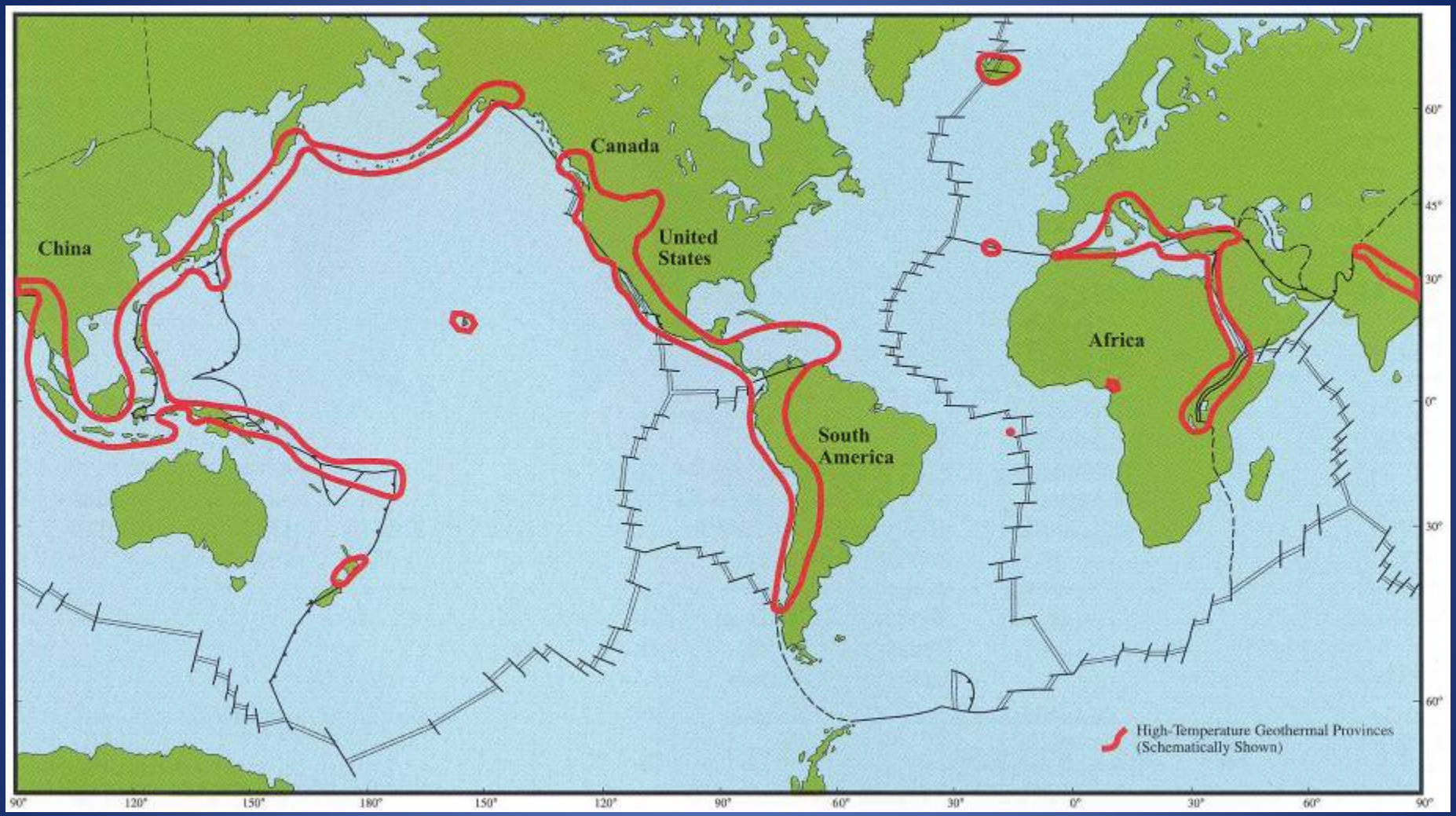
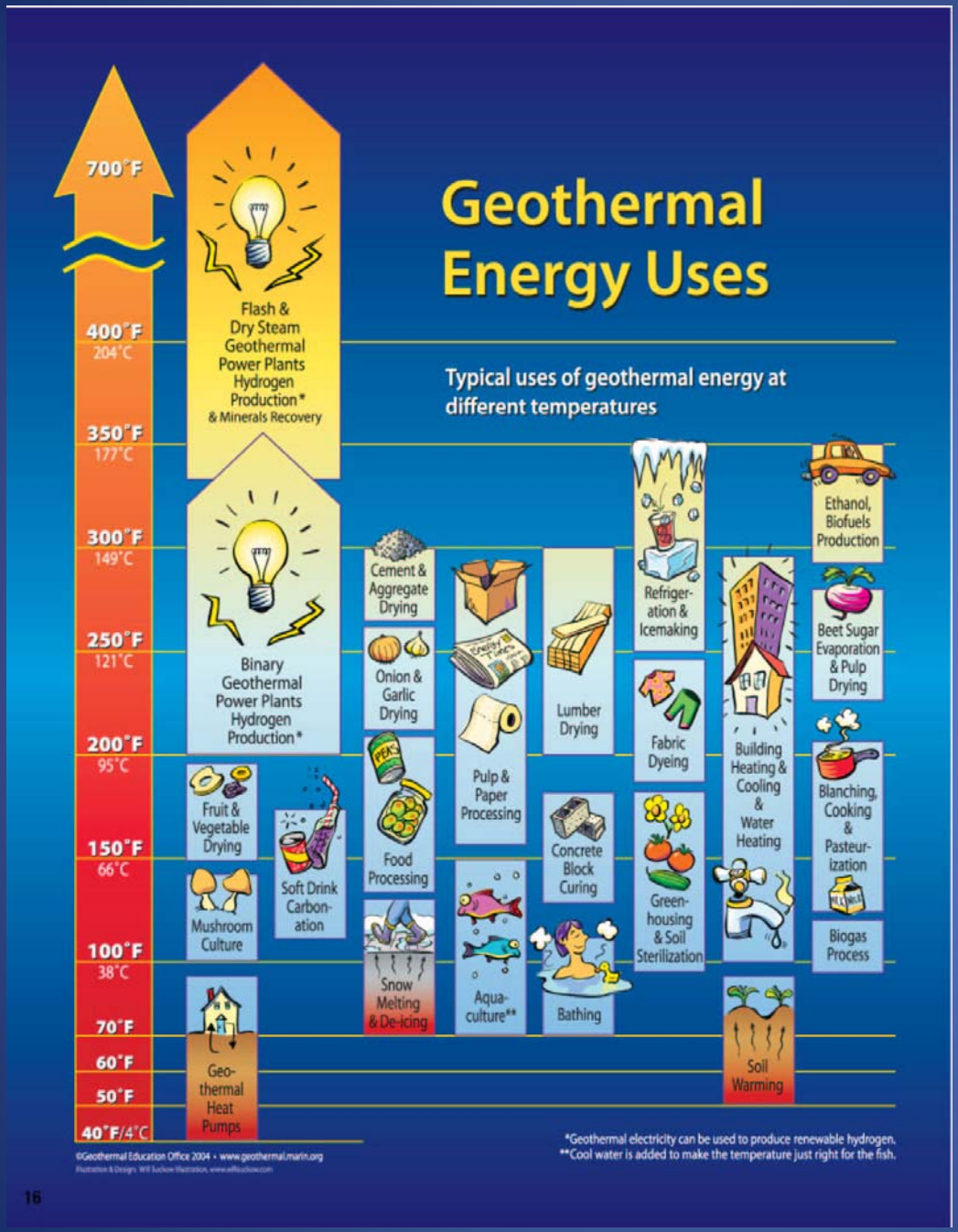
Geo-Heat Center

Oregon Institute of Technology

Klamath Falls, Oregon, USA



High Temperature Geothermal Provinces



- **Electric power generation**
- **Direct use**
- **Heat pumps**

SUMMARY CAPACITY & USE

Use	Installed Power (MW)	Energy Use (GWh/yr)	Capacity Factor
Electric	11,000	68,000	0.72
Direct-use	50,000	120,000	0.28

ELECTRIC POWER HISTORY

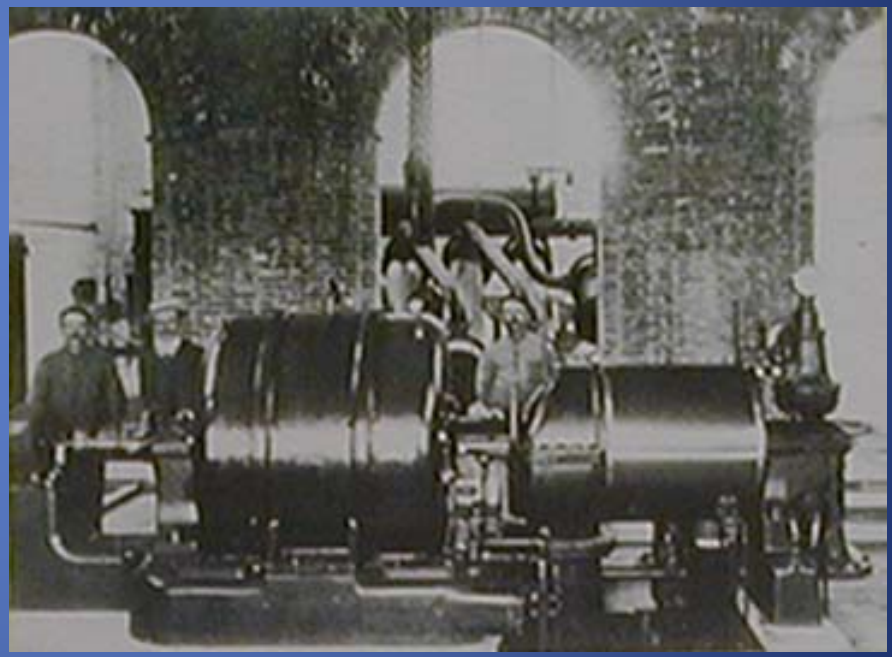
- Original country – first 50 years: Italy – 350 MWe
- Next 20 years: New Zealand, Mexico, USA, Japan, Russia (1958-1973) - 1,000 MWe
- 1973-1990: 9 more countries – 5,800 MWe
- Growth over the last 20 year (1990-2010):
  - 3.1 %/year (compounded)
  - Increase by about 5,000 MWe
  - New countries: Austria, Australia, Costa Rica, Ethiopia, Germany, Guatemala, Papua New Guinea, Portugal.
  - Argentina, Greece and Taiwan have shut down plants
  - Now at 11,000 MWe

EARLY DEVELOPMENT

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

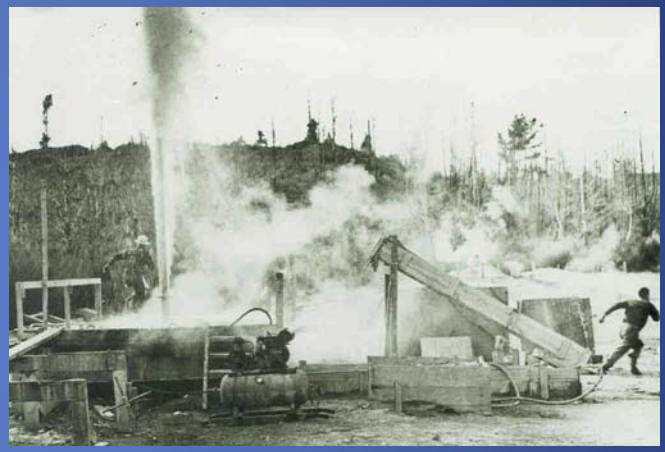
EARLY DEVELOPMENT II

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



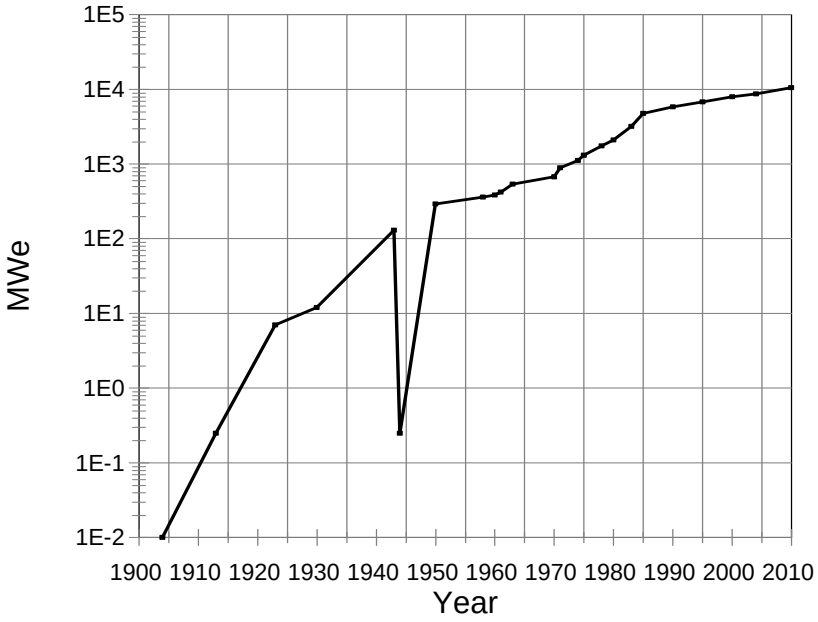
EARLY DEVELOPMENT
New Zealand

- 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

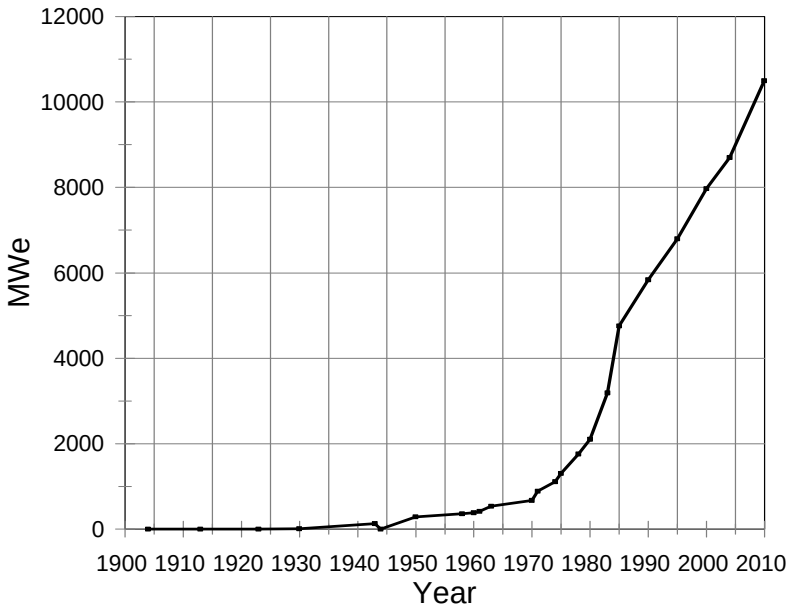


EARLY DEVELOPMENT
North America

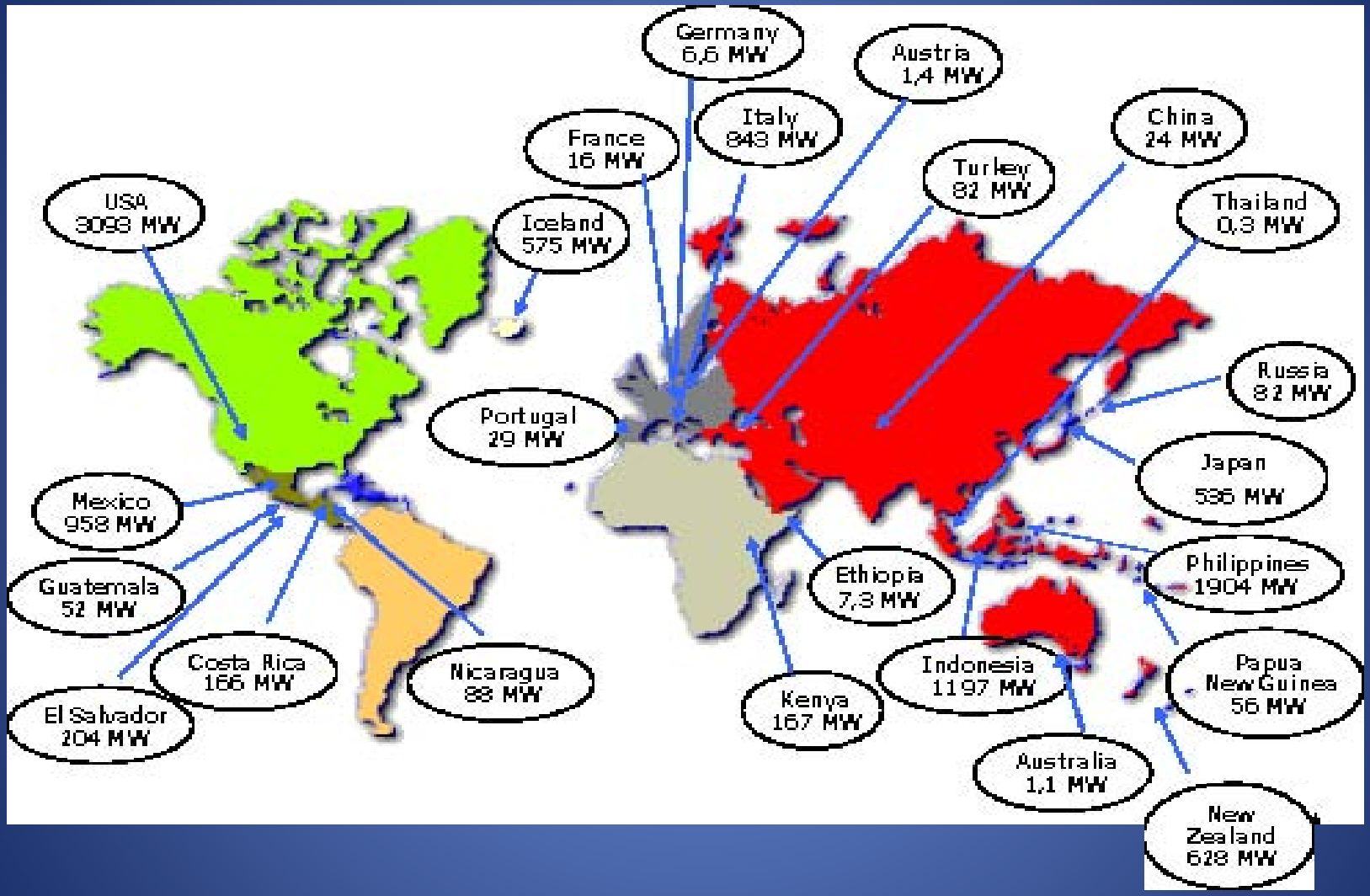
- 1934- first geothermal power plant at The Geysers – 35 kWe - 152ºC
- 1959 – first geothermal power plant in Mexico– Pathé – 3.5 MWe - >250ºC
- 1960 – first modern US plant on line at The Geysers in northern California – 12 MWe - 230ºC
- All are “dry steam” plants



Worldwide Geothermal power production 1904-2012



Production from 1904-1958 entirely from Italian fields

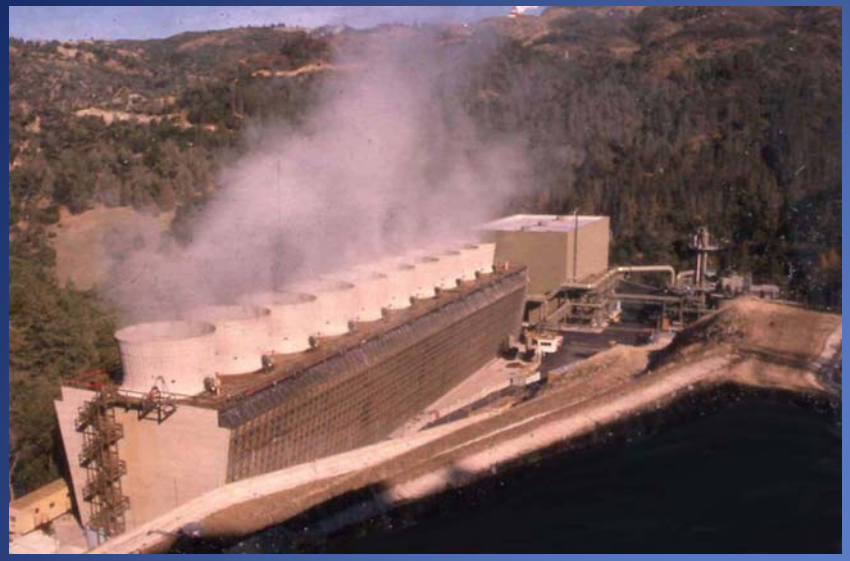


Worldwide Installed Capacity 2010 = 10,715 MWe

SUMMARY BY REGION

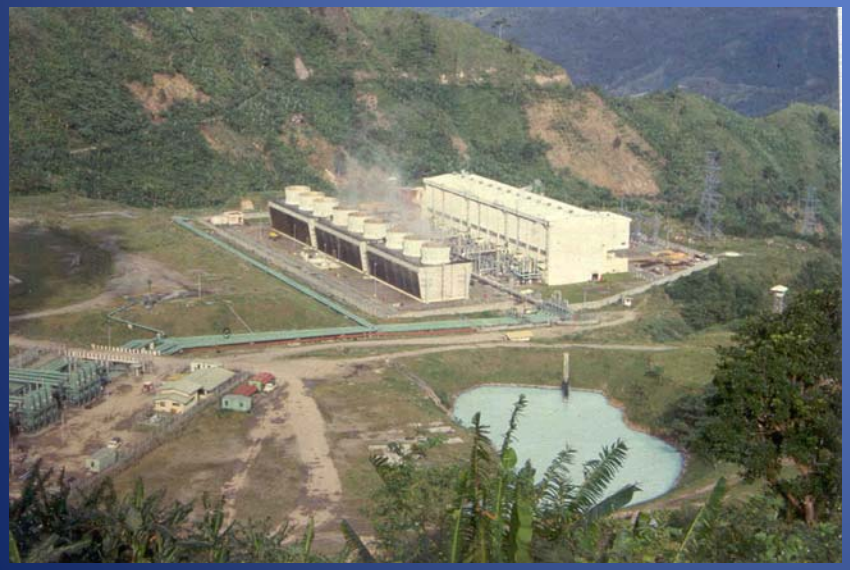
	Electric Power		
Region	%MWe	%GWh/yr	Countries
Africa	1.6	2.1	2
Americas	42.6	39.9	6
Asia	34.9	35.1	6
Europe	14.5	16.2	7
Oceania	6.4	6.7	3

Geothermal Electric Power Generation



The Geysers, California, USA

Larderello, Italy



Binary (ORC) Geothermal Power Plants

Kenya

Austria

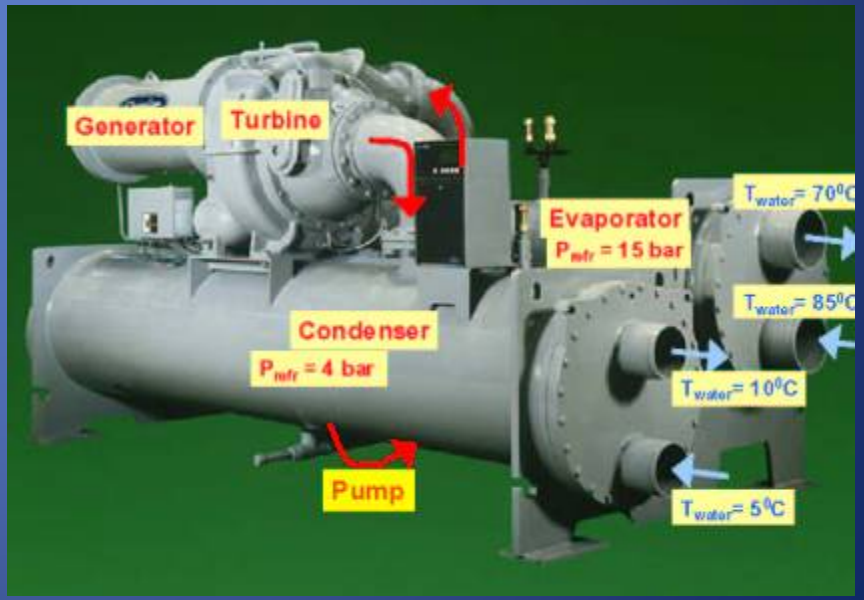
Nevada

California

CHENA HOT SPRINGS, ALASKA

United Technologies Corporation

200 kWe Carrier converted vapor-compression cycle chiller to a Rankin cycle that uses R-134a refrigerant



Installed in July of 2006

Lowest temperature geothermal use for power generation in the world

74°C resource and
5°C cooling water

DISTRIBUTION OF PLANT TYPES

Plant type	%*	GWh/unit	MW/unit
• Dry Steam:	2	260	46
• Single Flash:	41	199	31
• Double Flash:	20	236	34
• Binary/ combined cycle/ hybrid:	11	27	5
• Back Pressure:	2	26	4

*527 units total with average = 20 MWe

LEADING COUNTRIES >500 MWe

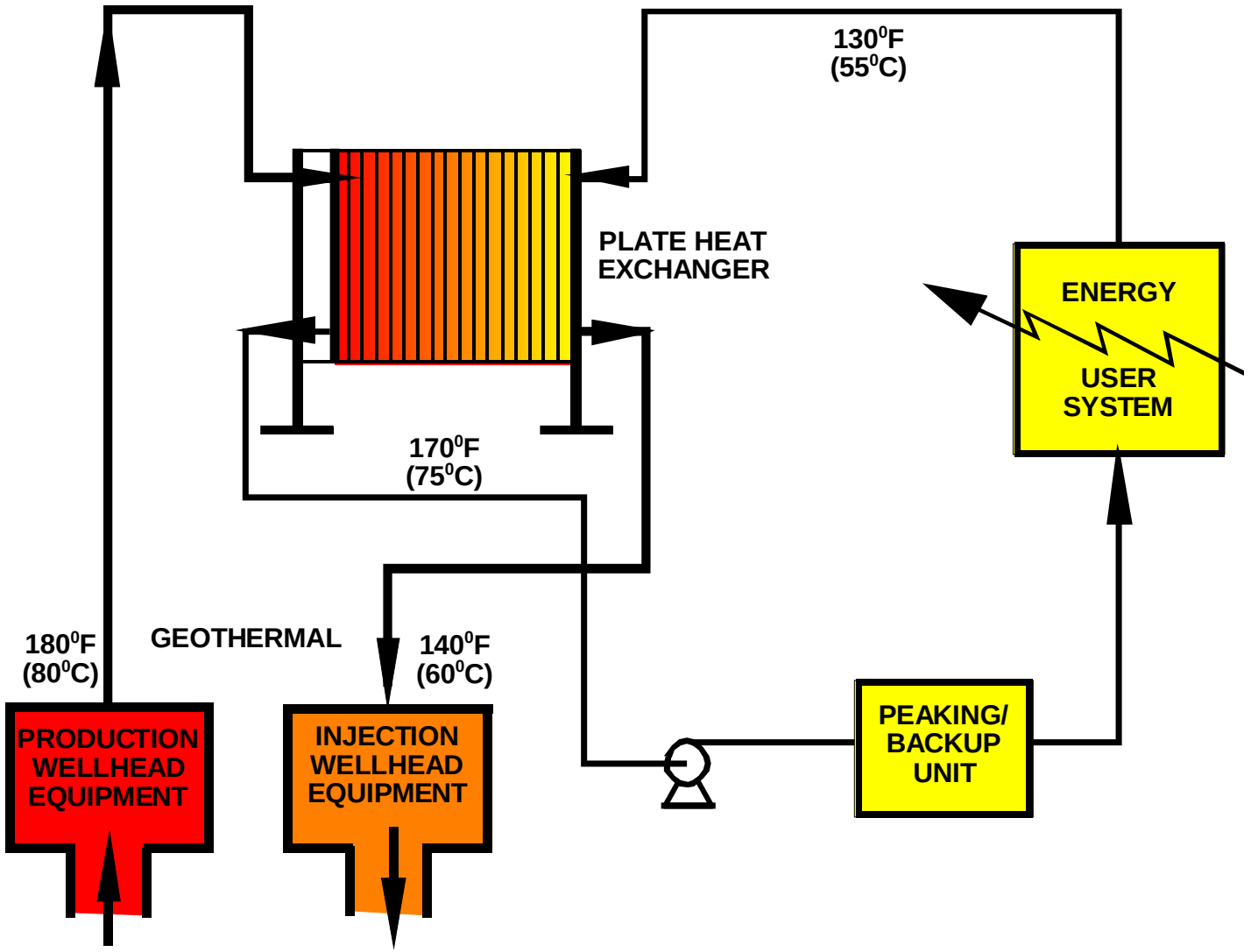
	Installed MWe	Running MWe	Capacity Factor	Number Units
United States	3093	2024	0.94	209
Philippines	1904	1774	0.66	56
Indonesia	1197	1197	0.92	22
Mexico	958	958	0.84	37
Italy	843	843	0.75	33
New Zealand	628	628	0.74	43
Iceland	575	575	0.91	25
Japan	536	422	0.83	20

GEOTHERMAL POWER CONTRIBUTIONS

Country or Region	% of National or Regional Capacity (%MWe)	% of National or Regional Energy (%GWh/yr)
Tibet	30	30
Tuscany (Italy)	25	25
Iceland	22	27
El Salvador	15	26
Kenya	12	17
Philippines	12	17
Hawaii (Big Island)	11	11
Nicaragua	11	10
Guadeloupe (Caribbean)	9	9
Costa Rica	8	12
New Zealand	6	10
California	4	7

WHAT IS DIRECT-USE: HEATING AND COOLING

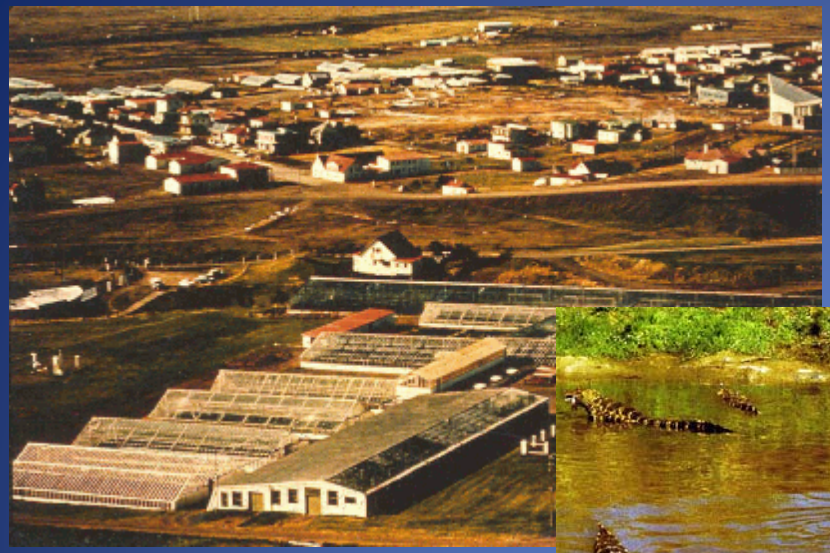
- Swimming, bathing and balneology
- Space heating and cooling
  - Including district (heating/cooling) systems
- Agriculture applications
  - Greenhouse heating
- Aquaculture applications
  - Fish pond and raceway heating
- Industrial processes
  - Including food and grain drying
- Geothermal heat pumps

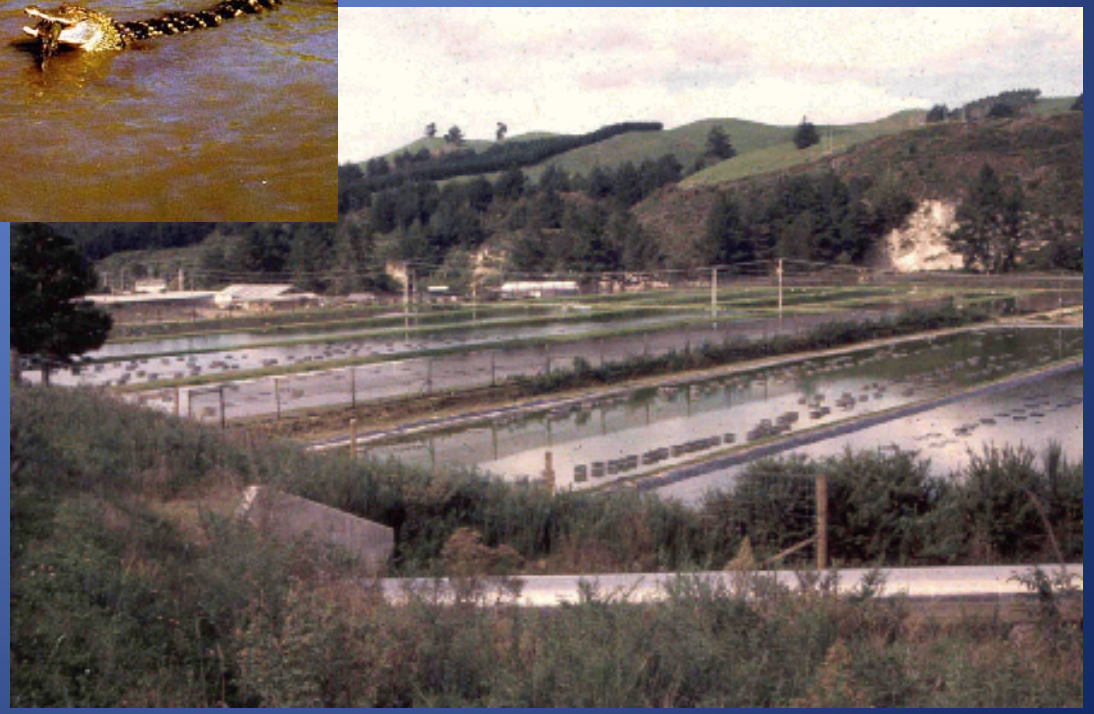


TYPICAL DIRECT-USE HEATING SYSTEM

Soaking and swimming in geothermal waters

AGRIBUSINESS APPLICATIONS





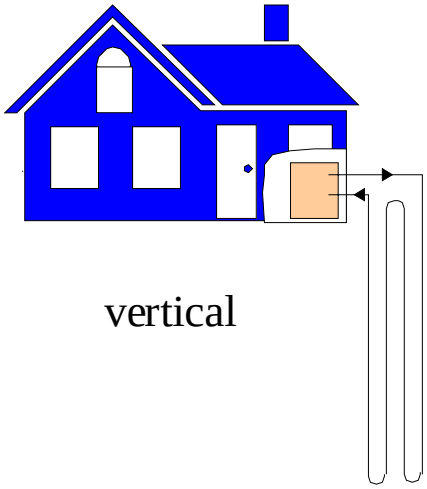
SPACE HEATING AND COOLING

REYKJAVIK, ICELAND

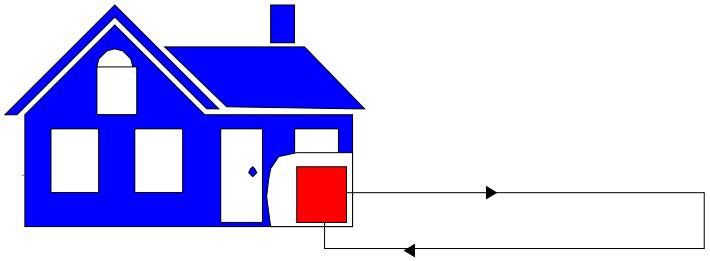
INDUSTRIAL APPLICATION EXAMPLES

HEAT PUMPS

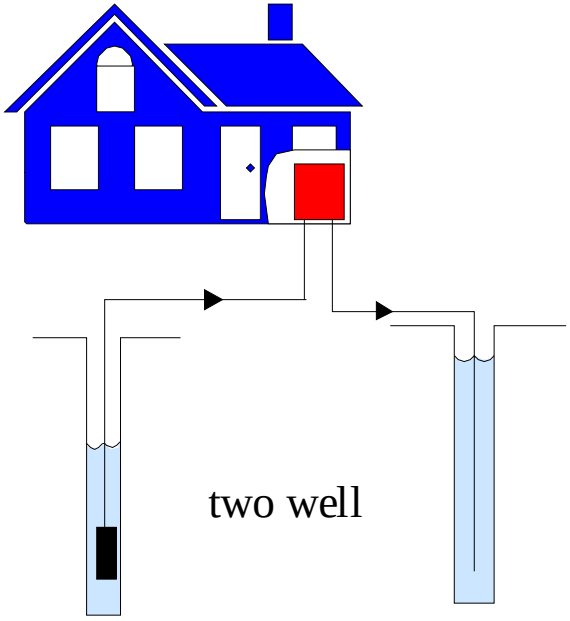
- Ground source and geothermal heat pumps (GSHP or GHP) – uses 5 to 30°C ground temperature – COP = 4
- 50 to 100% more efficient than air source, since uses constant temperature resource
- Ground coupled
  - Horizontal in trenches 1 – 3 m deep
  - Vertical in 10-cm diameter 50 – 100 m deep drill holes
  - Coils (“Slinky”)
- Ground water
  - Using well water or lake water



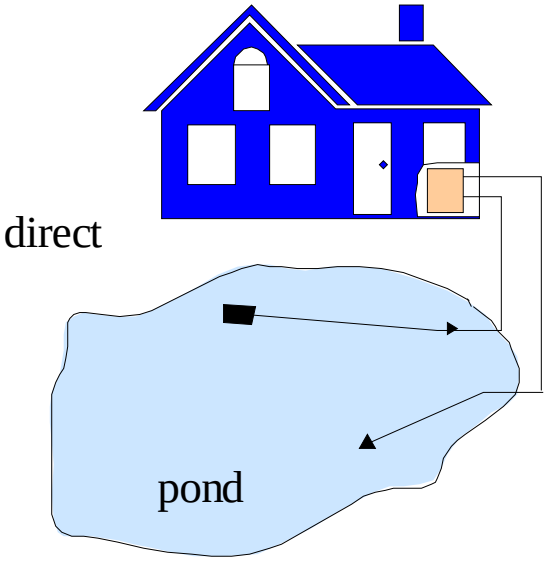
vertical



horizontal

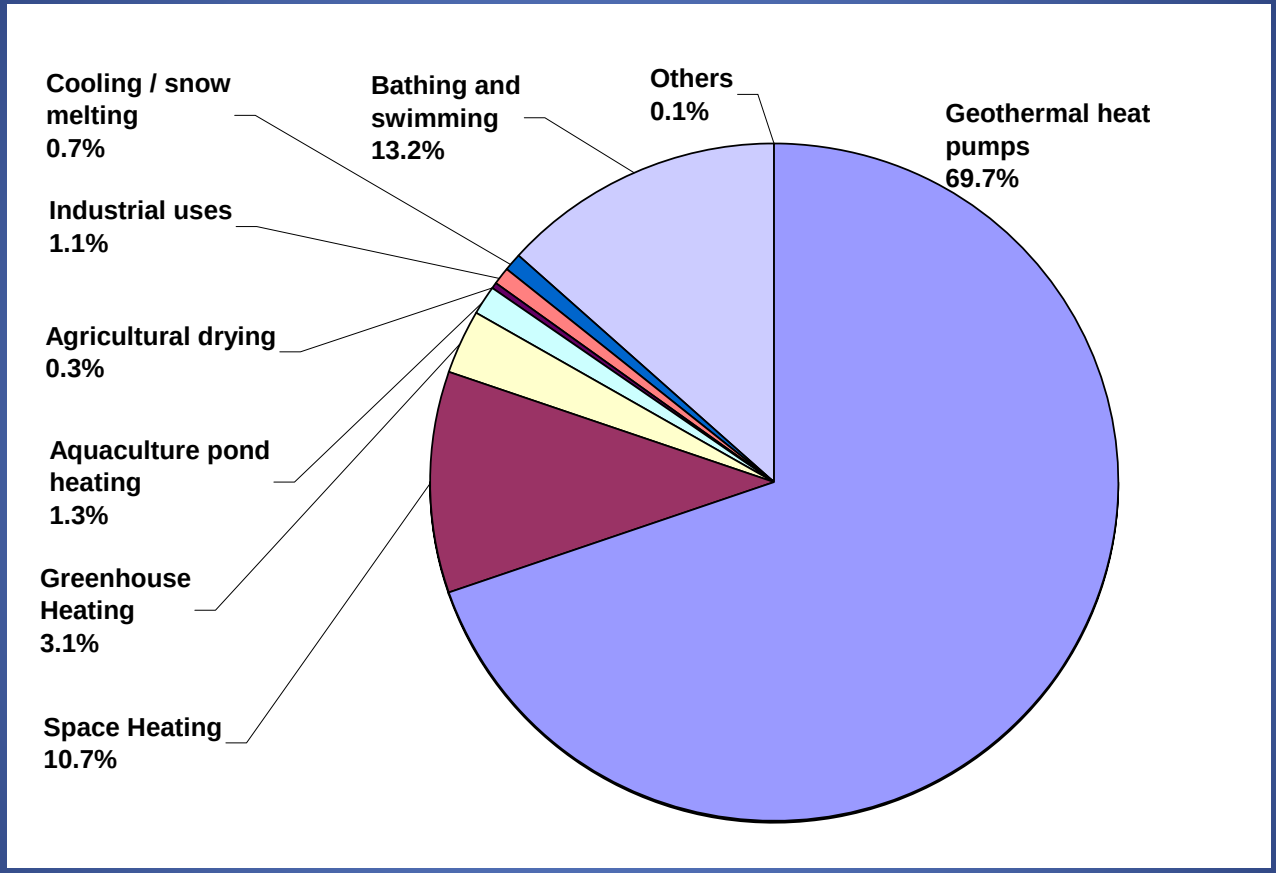


two well

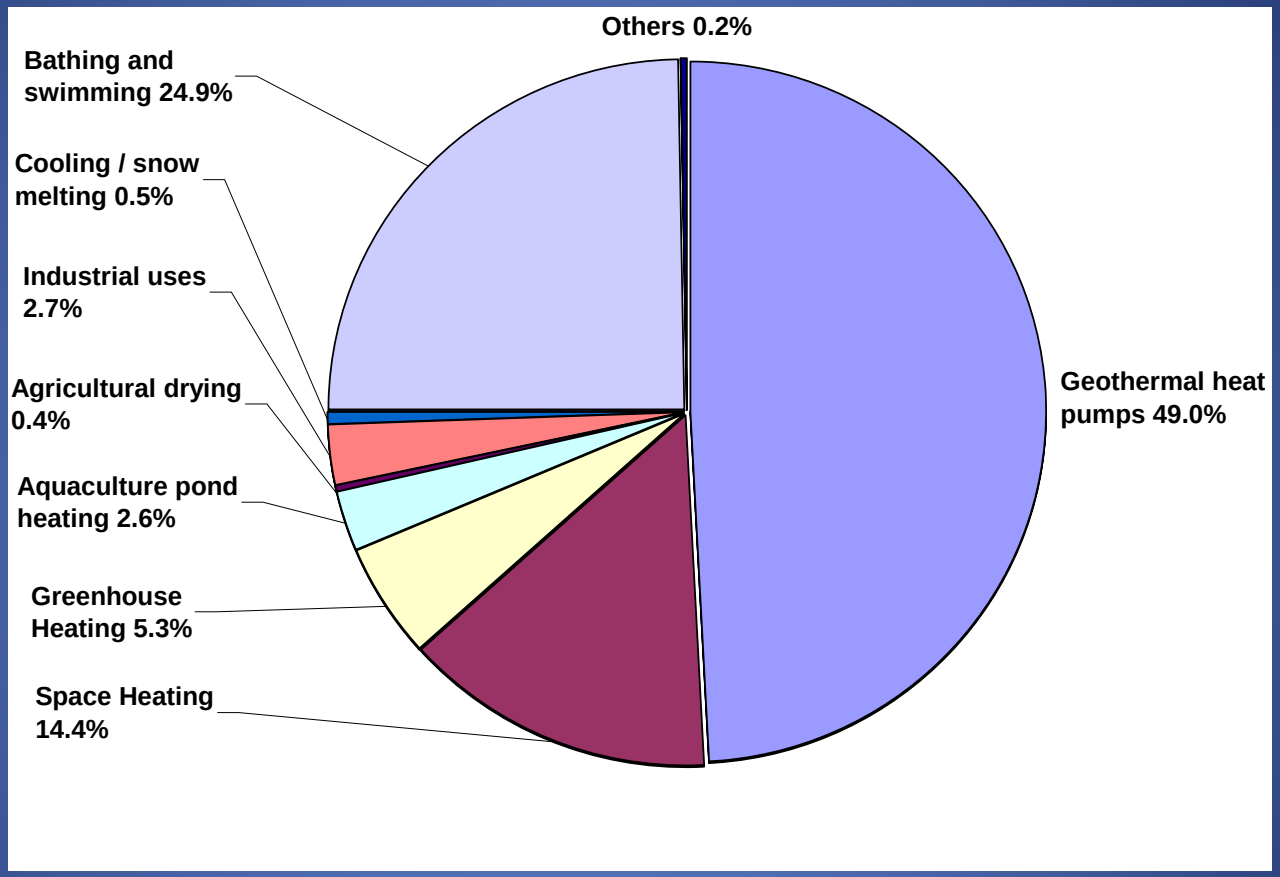


direct

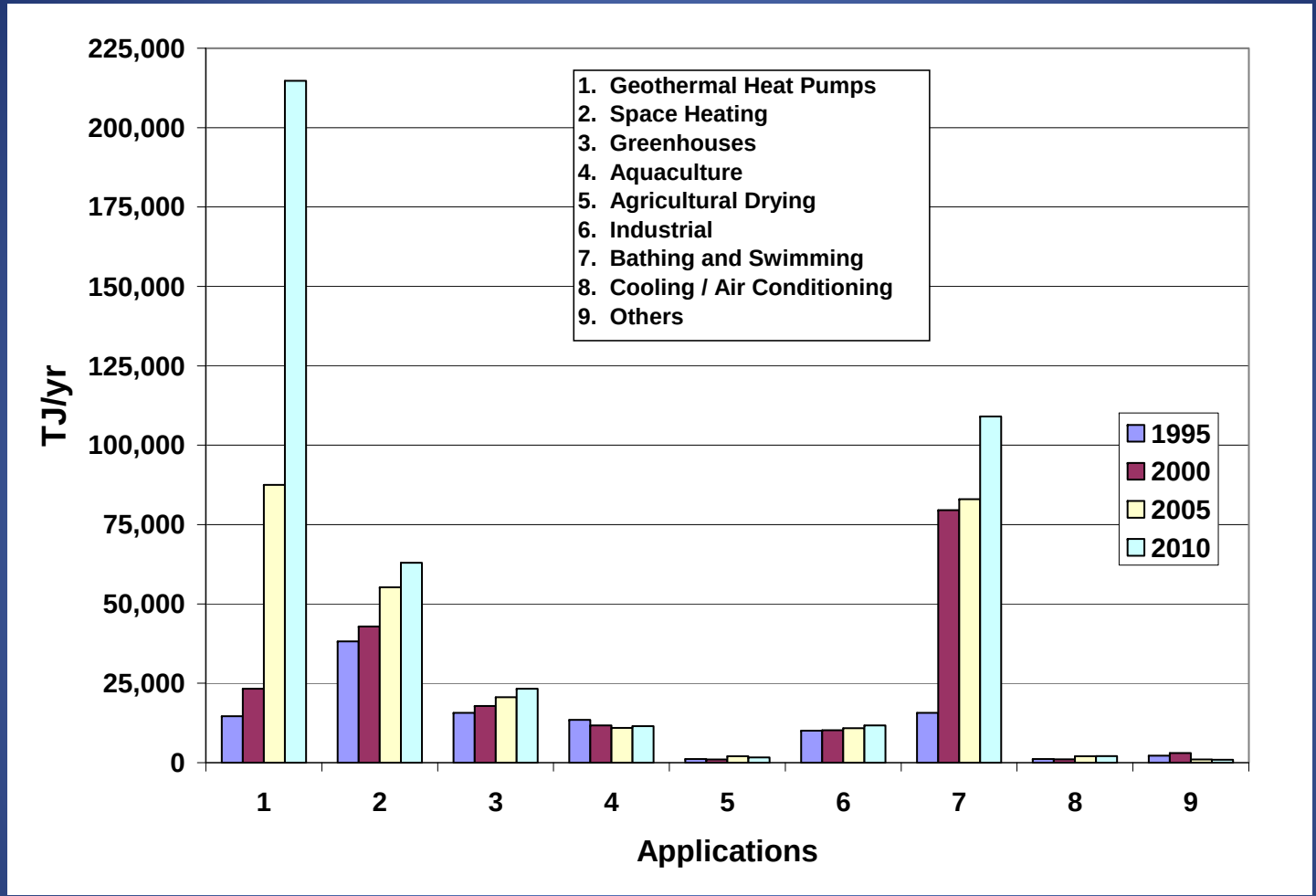
pond



Worldwide direct-use installed capacity (MWt)- 2010



Worldwide direct-use annual use (TJ/yr)- 2010



Comparison of worldwide energy in TJ/yr for 1995, 2000, 2005 and 2010.

LEADING COUNTRIES >1,000 MWt

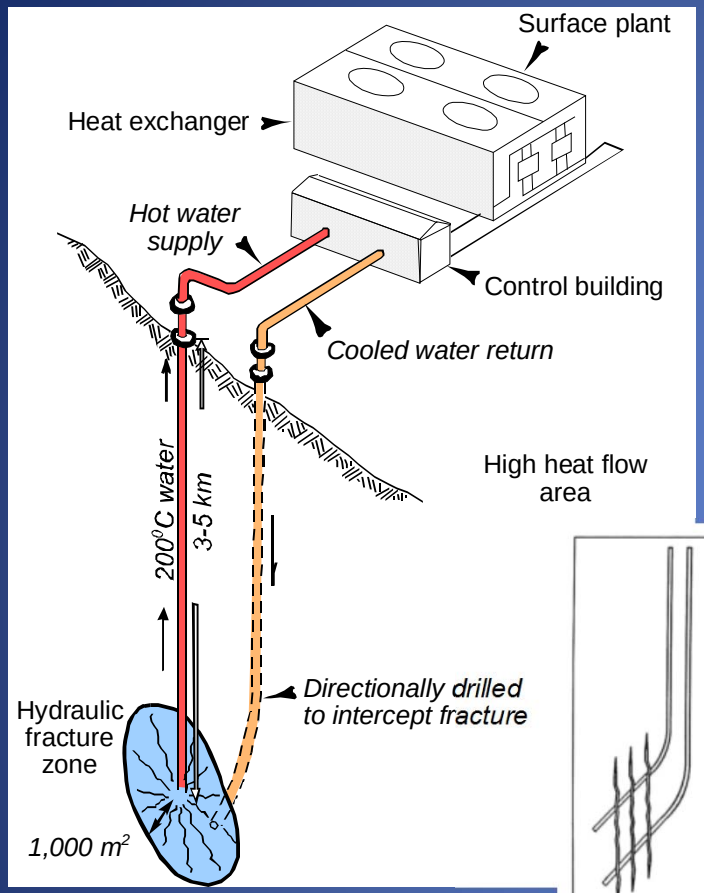
Country	GWh/yr	MWt	Main Use
China	20,932	8,898	bathing/dist. heating
USA	15,710	12,611	GHP
Sweden	12,585	4,460	GHP
Turkey	10,247	2,084	district heating
Japan	7,139	2,100	bathing (onsens)
Iceland	6,768	1,826	district heating
France	3,592	1,345	district heating
Germany	3,546	2,485	bathing/dist. heating
Norway	3,000	1,000	GHP
Netherlands	2,972	1,410	GHP
Canada	2,465	1,126	GHP
Switzerland	2,143	1,061	GHP

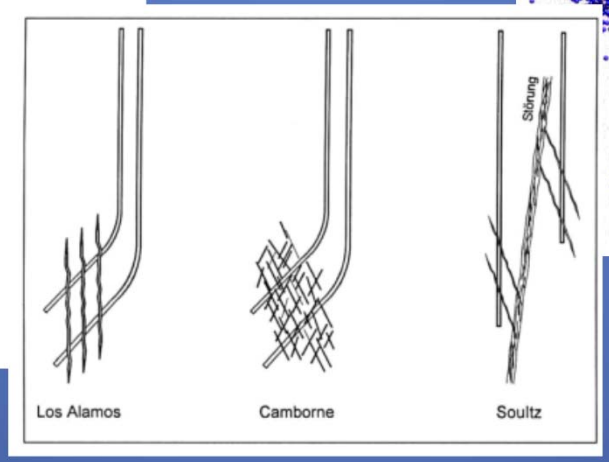
DIRECT-USE SUMMARY BY REGION

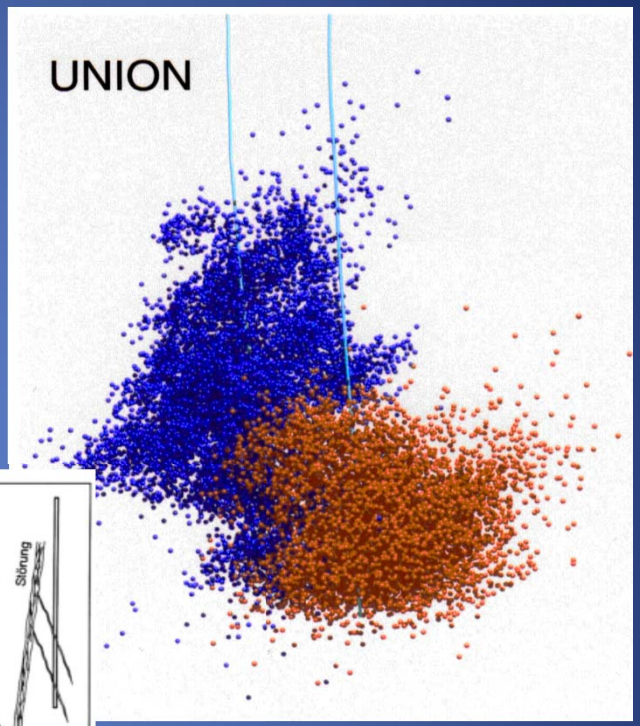
Region	%MWt	%GWh/yr	Countries
Africa	0.3	0.7	7
Americas	30.1	19.0	15
Asia	28.7	34.9	16
Europe	40.0	43.1	37
Oceania	0.9	2.3	3

NATION DIRECT-USE CONTRIBUTIONS

- Iceland: 89% of space heating
- Turkey: space heating approaching 30%
- Tunisia: 200 ha of greenhouses
- Japan: 2,000 onsens; 5,000 public baths;
  1,500 hotels – 15 million guests/yr
- Switzerland: 60,000 GHP (≈1/km²)
- United States: 1 million GHP – 12.5% growth/yr
- Sweden: 12% of space heating/thermal storage







Soultz-sous-Forêt

HOT DRY ROCKS (ENHANCED GEOTHERMAL SYSTEM) : >200˚C
HYDRO-FACTURED ROCK – 3 TO 6 KM DEEP

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 1.5 MWe by 2010**
- **Suitable European sites**

  potential = 110 000 MWe

Hot Fractured Rock (HFR)

Australia's Cooper Basin

(source: Geodynamics Ltd.)

Two wells drilled: 4900 & 4572 m

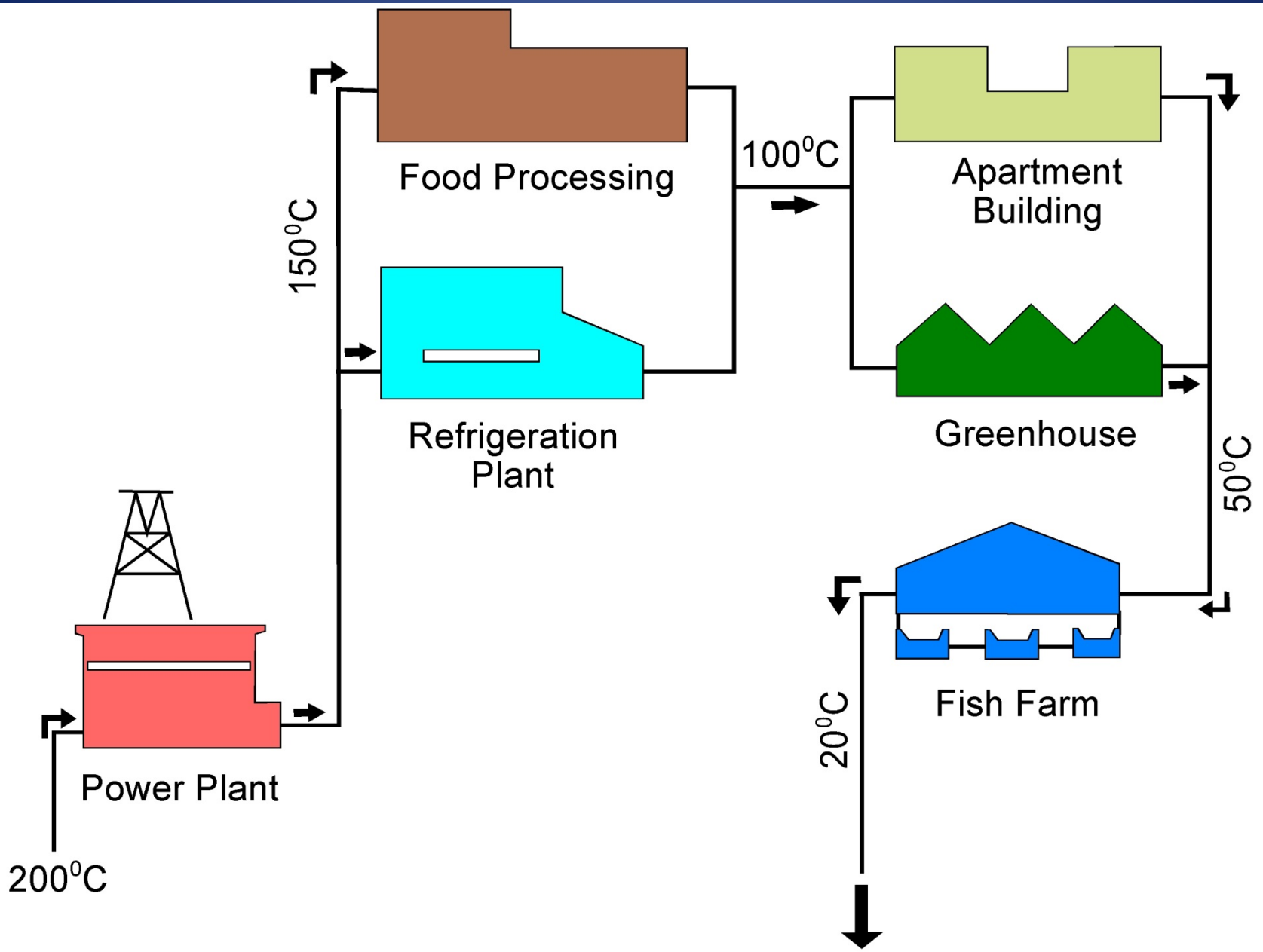
270 and 250^{o}C into granite rock

2013: 3-5 MWe binary plant

275 kV powerline – 60 million €

NEW TRENDS

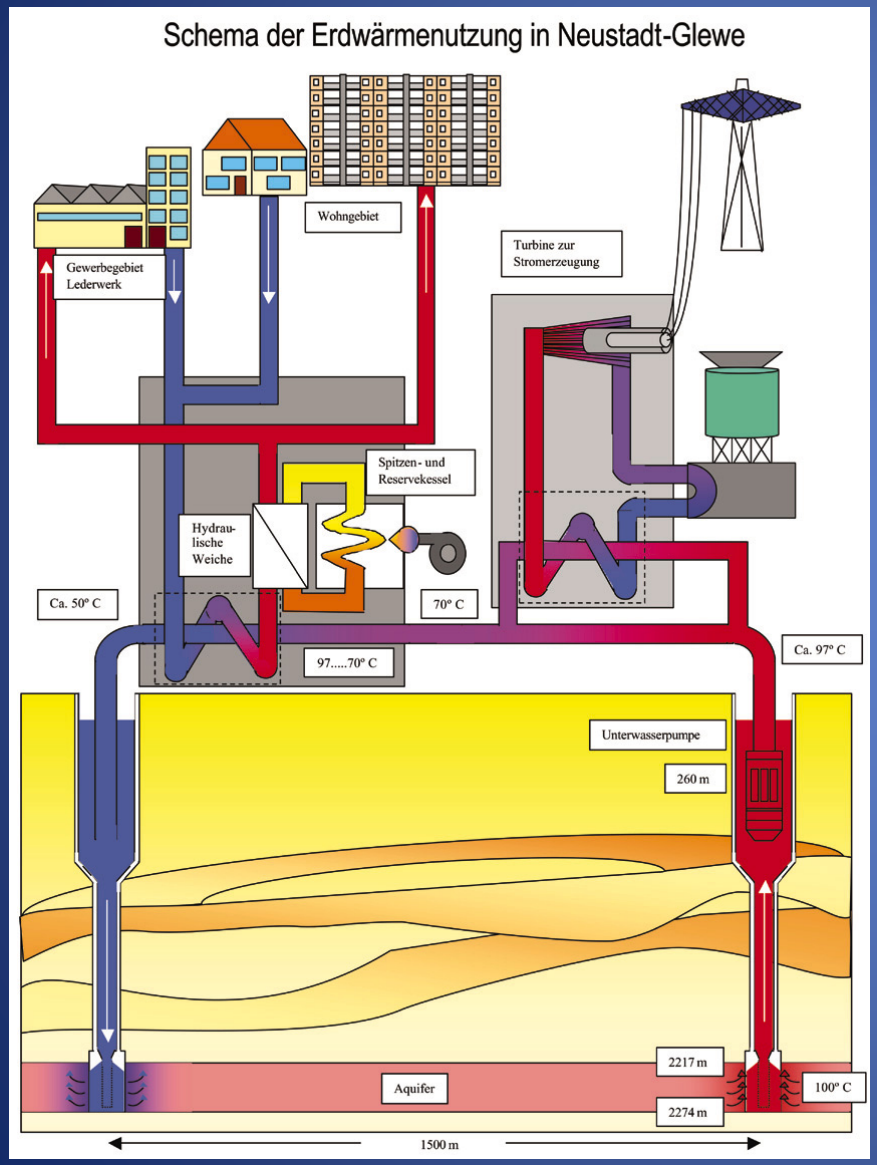
- **COMBINED HEAT AND POWER PLANTS**
  - **Low temperature resources used for binary power production and cascaded for direct use**
  - **Temperatures as low as 98^{o}C are being used**
  - **Makes efficient use of the resources**
  - **Improves economics**
  - **Increases employment**



Cascading to maximize use of geothermal energy

NEUSTADT GLEWE, GERMANY

combined heat and power plant

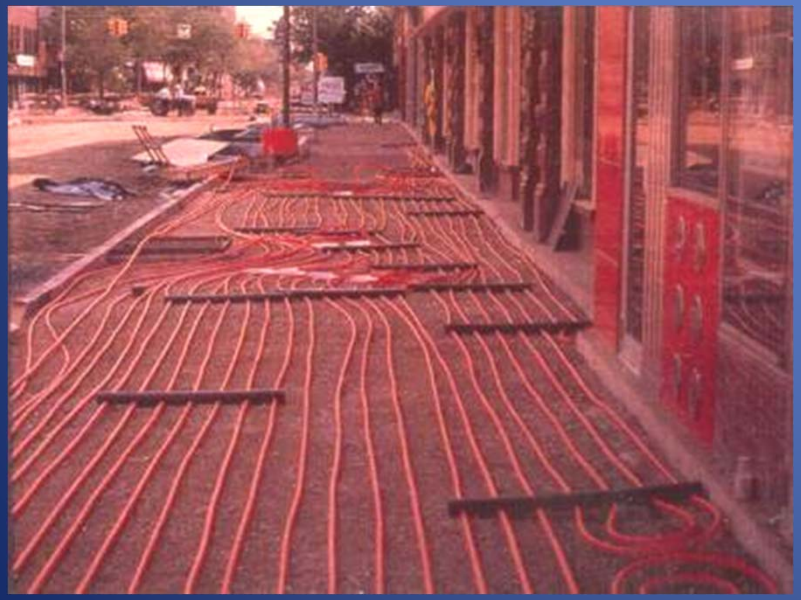


98°C – 1,700 L/s
210 kWe & 6 MWt

KLAMATH FALLS

- 600± geothermal wells
- 30 to 600 m deep
- 40 to 105°C
- Majority use downhole heat exchangers
- City district heating system – 24 buildings
- Pavement snow melting systems
- Oregon Institute of Technology
- 50 MWt capacity, 116 GWh/yr (418 TJ/yr)
- 50,000 bbl equivalent fuel oil saved per year

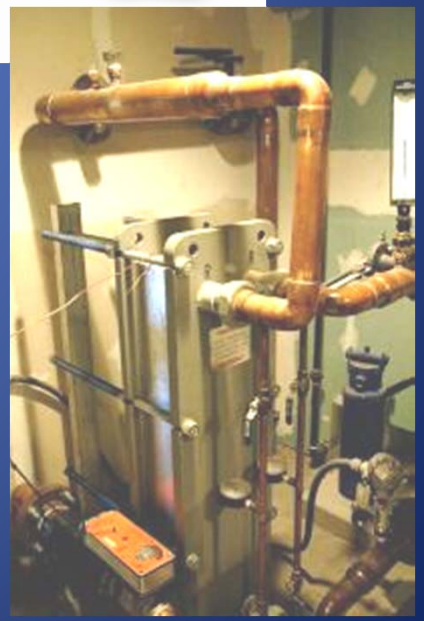
Klamath Falls snow melting system



KLAMATH FALLS GEOTHERMAL USES ON THE DISTRICT HEATING SYSTEM

IFA Nursery – 1.6 ha
– commercial trees seedlings

KLAMATH BASIN BREWING COMPANY
Klamath Falls, Oregon



“Gone Fishing” – African Cichlids

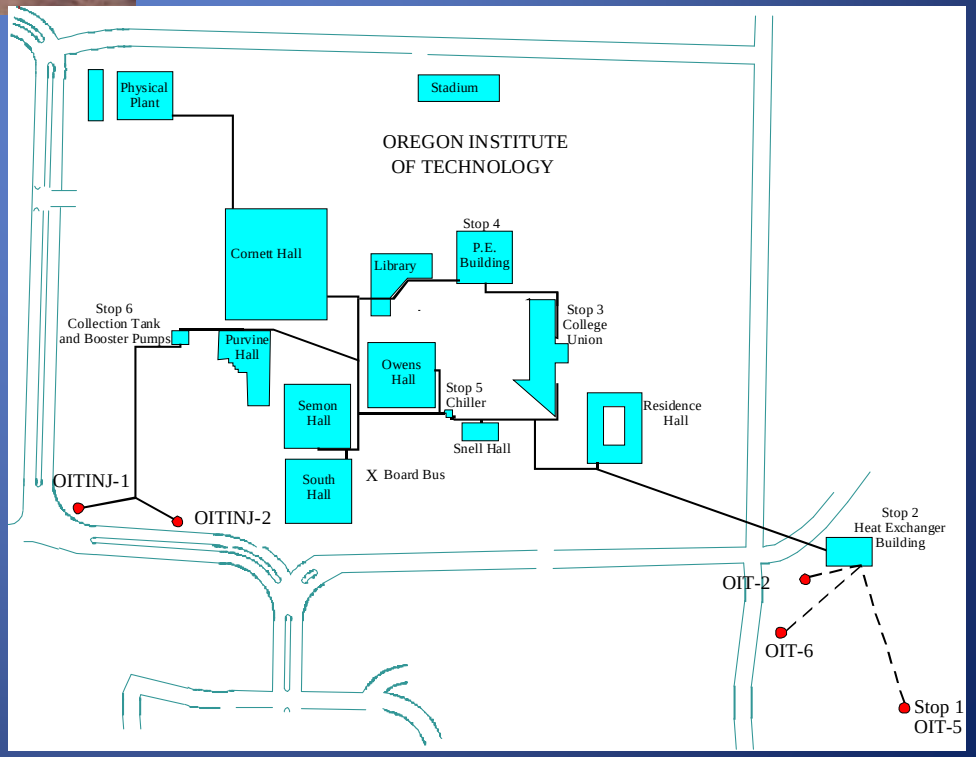
91°C water

3 wells: 400 – 600 m

6 MWt – 14 GWh/yr

Saving $1mil/yr

Oregon Institute of Technology



OREGON INSTITUTE OF TECHNOLOGY SMALL SCALE POWER PLANT

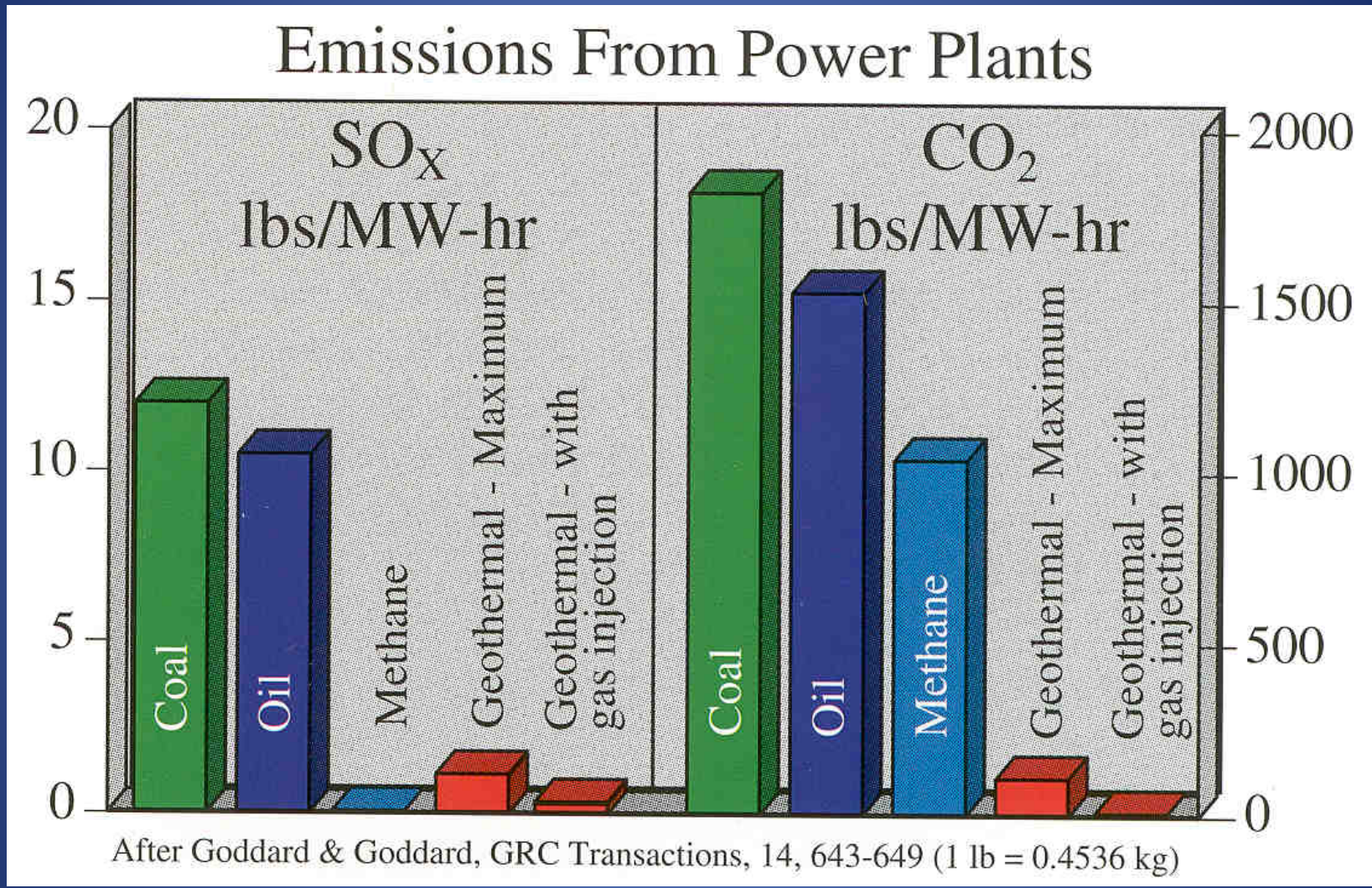
- Uses existing wells at 91°C
- 280 kWe
- Uses 38 l/s
- Taking 17°C off the top
- Remainder used to heat campus
- Started operation in February 2010
- Supplies 10% of campus electric needs and provides energy to pump wells on campus

WORLDWIDE ENERGY SAVINGS

Compared to fuel oil:

	10^6 Barrels	10^6 Tonnes	C 10^6t	CO_2 10^6t
Electric	114	17	15	49
Direct-use	125	19	17	53
Total	239	36	32	102

Savings: ≈ 3 days of world's consumption of oil


Emissions From Power Plants
SO_X lbs/MW-hr
CO_2 lbs/MW-hr
20
15
10
5
0
2000
1500
1000
500
0
Coal
Oil
Methane
Geothermal - Maximum
Geothermal - with gas injection
Coal
Oil
Methane
Geothermal - Maximum
Geothermal - with gas injection
After Goddard & Goddard, GRC Transactions, 14, 643-649 (1 lb = 0.4536 kg)

WORLDWIDE SUMMARY

- Electricity generation increased 11%/yr over the past 40 years; dropping to 3%/yr in last 10
- Direct-use remained steady at 10%/yr over the past 40 years.
- Majority of direct-use growth due to GHP at 24%/yr over the past 10 years.
- Only 10 countries reported geothermal use 40 years ago; 78 now; 10 more developing use

FUTURE PREDICTIONS

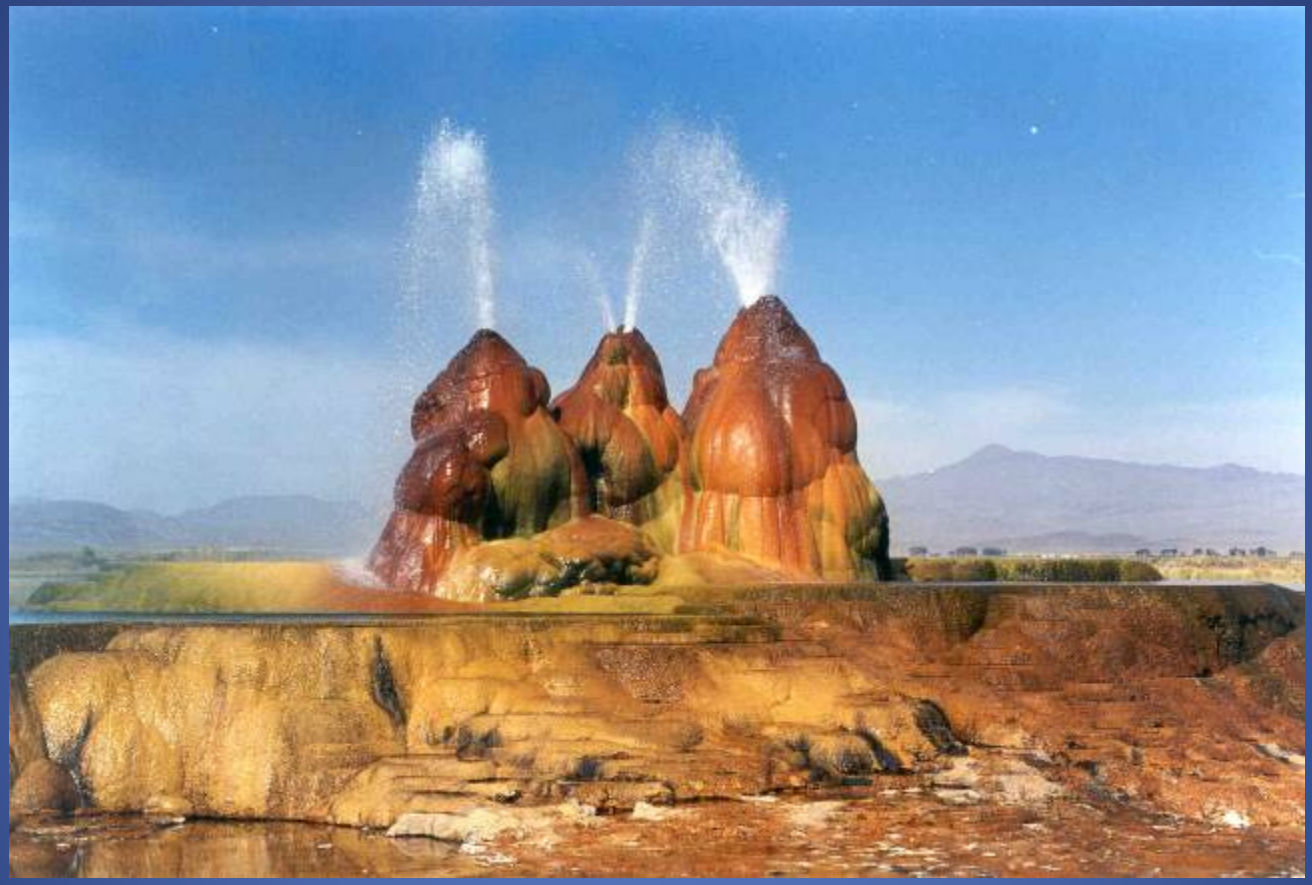
- Emphasis on combined heat and power plants such as those in Germany and Austria
- Low temperature, small scale binary power plants providing distributed power as at Chena Hot Springs in Alaska
- Agricultural crop drying especially in tropical climates
- Largest growth will be in geothermal heat pumps growing at a rate of 10 to 20%/year

FUTURE POWER GENERATION

- By 2015 new countries on line: Argentina, Canada, Chile, Greece, Honduras, Hungary, Netherlands, Nevis, Romania, Spain, Slovakia and Taiwan
- Total of 18,500 MWe (increase of 8,000 MWe)
- By 2050, 70,000 MWe (without EGS)
  - 4.8%/yr growth from 2010
  - 3.9%/yr growth from 2015

FUTURE DIRECT-USE

- By 2015 increasing direct-use from 78 to 100 countries and GHP from 43 to 60 countries
- Then by 2015 assuming an average increase of 7%/yr for direct-use and 22%/yr for GHP
  - Total: 111,000 MWt and 855,000 TJ/yr
- By 2050 assuming an average increase of 3.1%/yr for direct-use and 7.5%/yr for GHP
  - Total: 650,000 MWt and 4,370,000 TJ/yr



Thank you