FUTURE OF GEOTHERMAL ENERGY

by

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Enhanced Geothermal Systems (EGS) Web Seminar
Geothermal Resources Council

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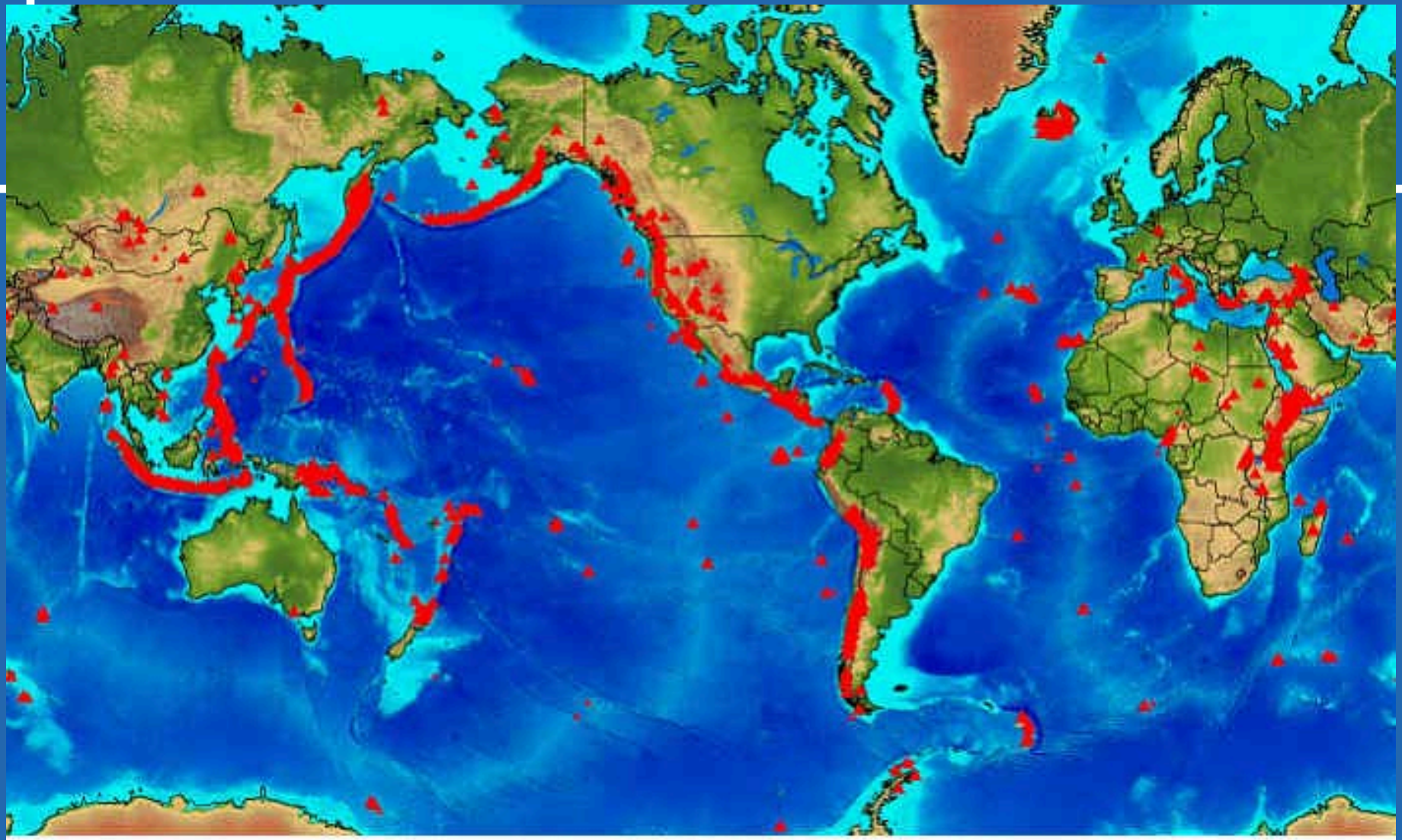
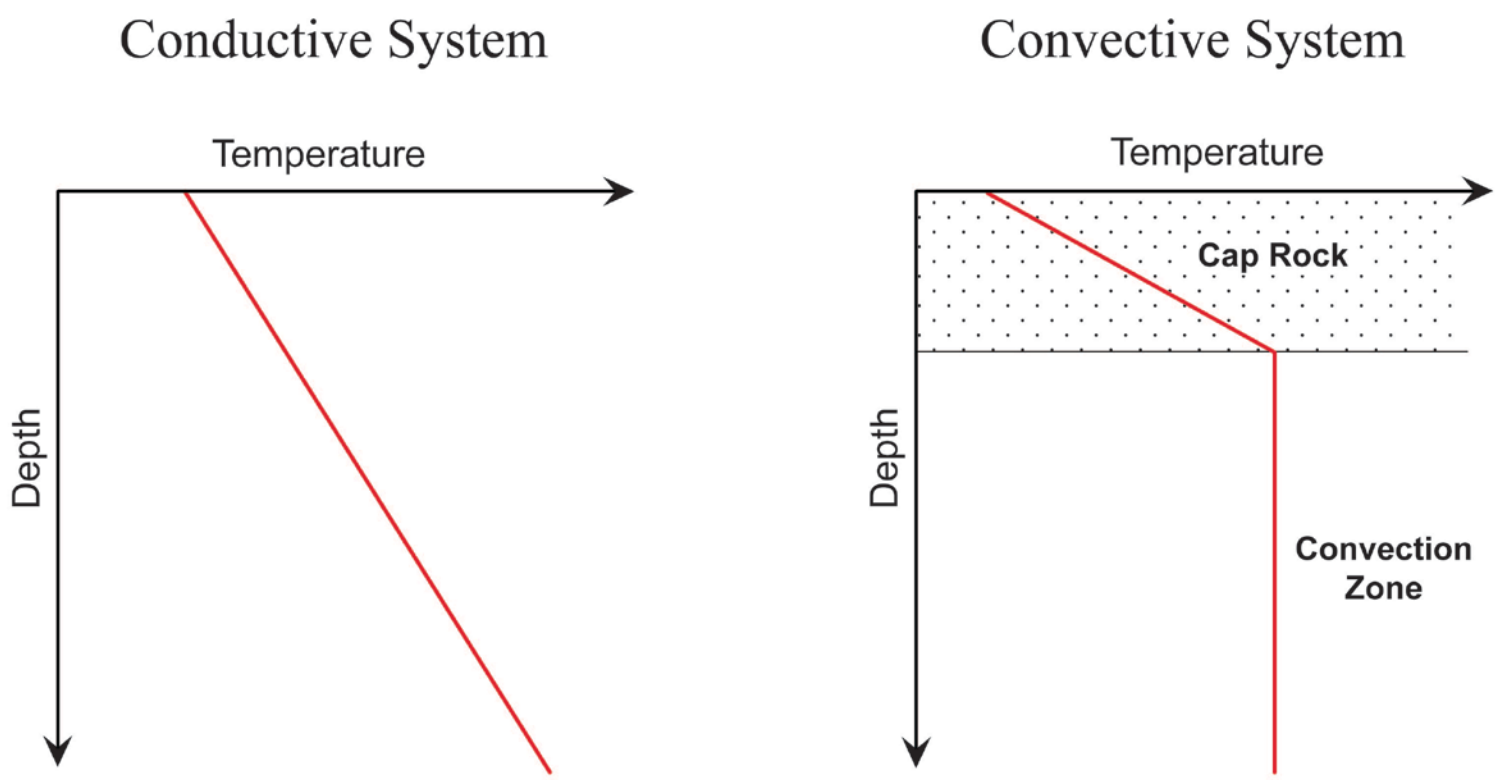


Ring of Fire

A MATTER OF DEFINITION



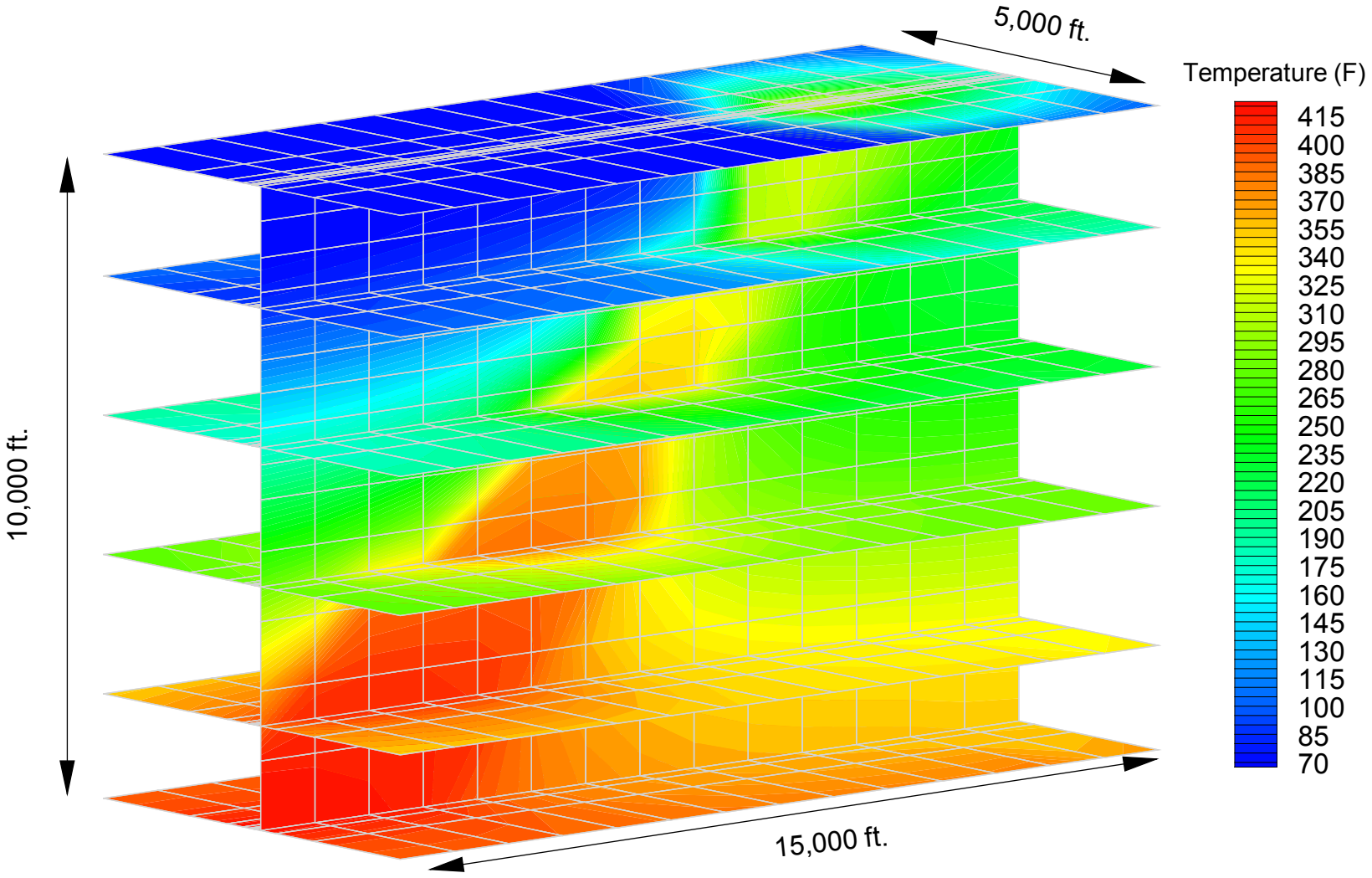
TYPES OF GEOTHERMAL ENERGY

- Convective ("Hydrothermal") systems
- Enhanced geothermal systems ("EGS")
- Conductive sedimentary systems
- Produced water from oil & gas fields
- Geopressured systems
- Magma energy

1. CONVECTIVE ("HYDROTHERMAL") SYSTEMS

- Limited distribution worldwide
- Decades of commercial exploitation history
- Two basic types
  - Volcanic
  - Non-volcanic
- Current generation capacity: worldwide 9,000 MW and in the U.S. 3,000 MW
- Estimated reserves in the U.S.: 10,000 to 30,000 MW.

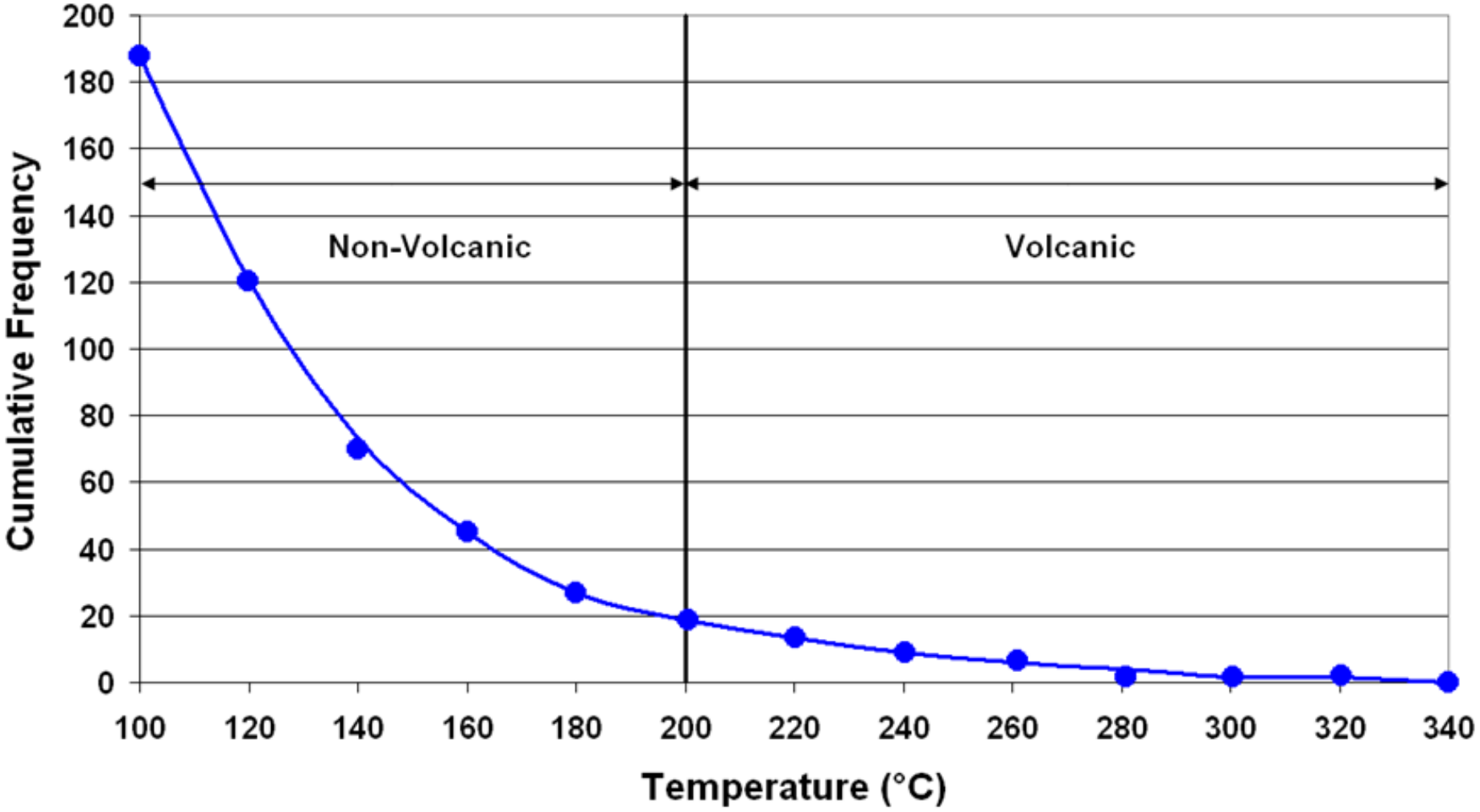
Beowawe Field - Initial-State Temperature Distribution



NUMBER OF ACTIVE VOLCANOES AND GEOTHERMAL RESOURCE BASE

COUNTRY	NO. OF ACTIVE VOLCANOES	GEOTHERMAL RESOURCE BASE (MW)
U.S.A	133	23,000
Japan	100	20,000
Indonesia	126	16,000
Philippines	53	6,000
Mexico	35	6,000
Iceland	33	5,800
Nicaragua	20	4,350
New Zealand	19	3,650

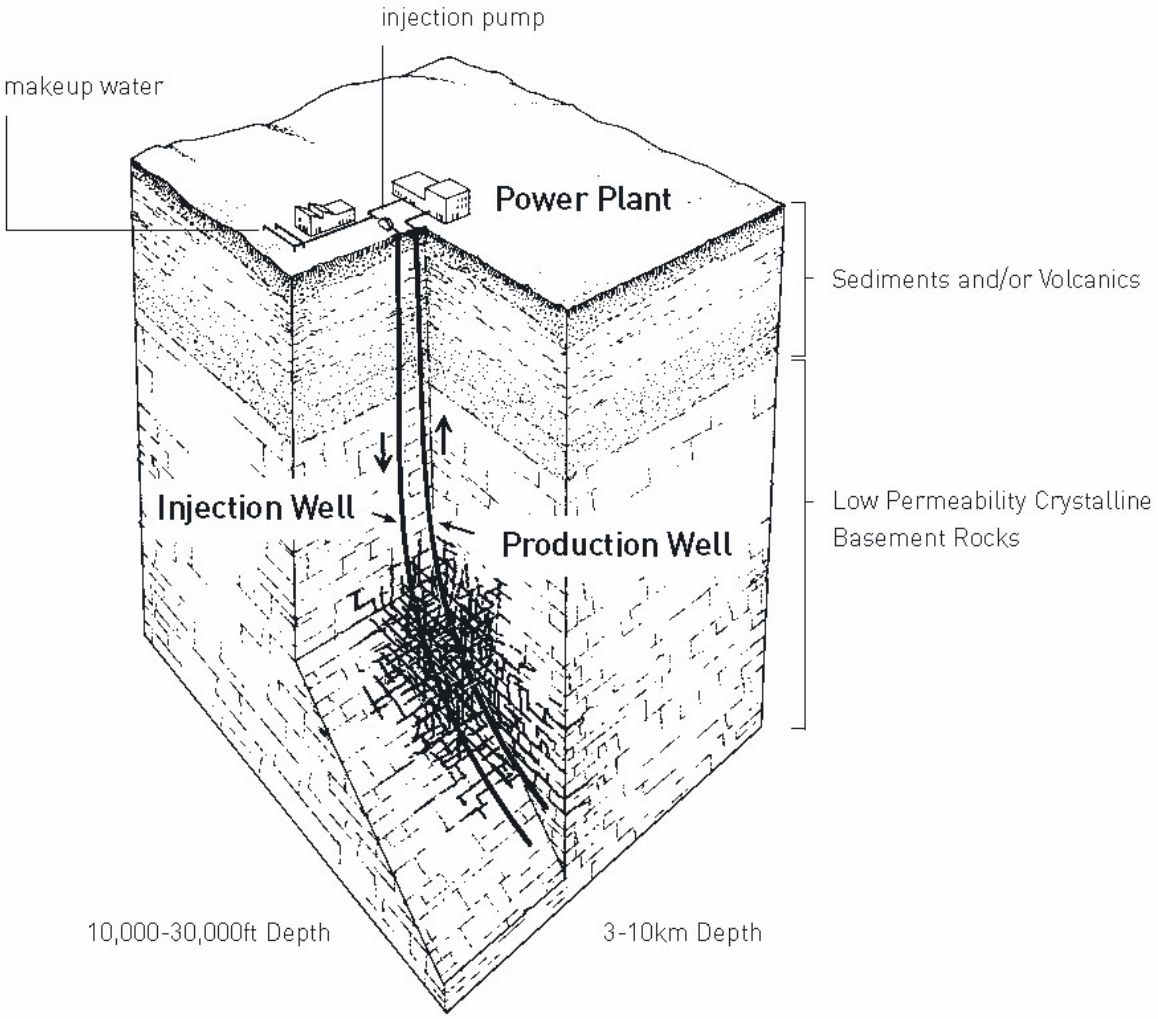
Cumulative Frequency versus Temperature of Identified Geothermal Fields in The United States (as of 1978)



2. ENHANCED GEOTHERMAL SYSTEMS

- Conductive system
- Worldwide distribution
- Still experimental
- Basic challenges:

  - Creating a pervasively fractured large rock volume
  - Securing commercial well productivity
  - Minimizing cooling
  - Minimizing water loss

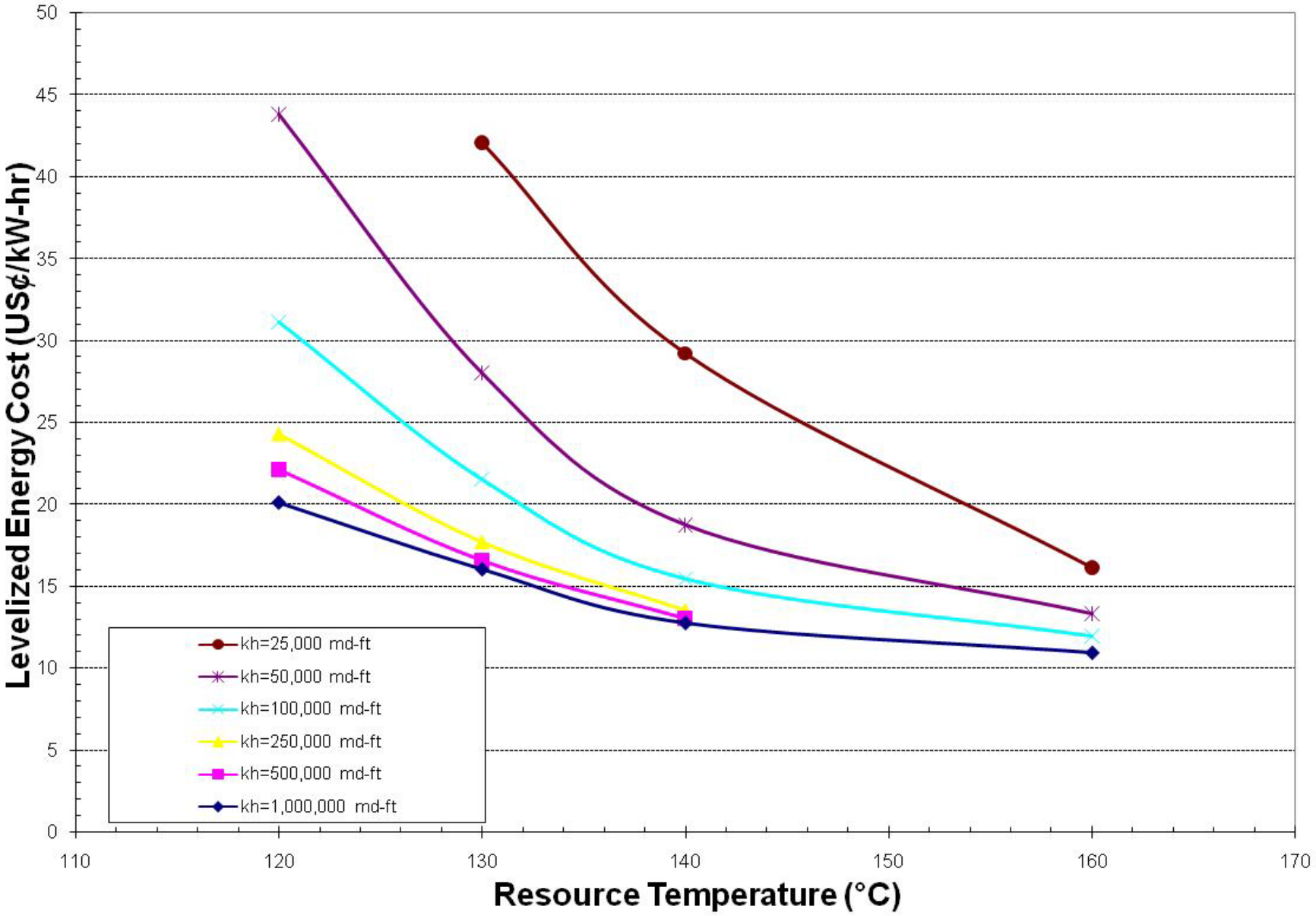


SCHEMATIC OF AN EGS SYSTEM (FROM M.I.T., 2006)

3. CONDUCTIVE SEDIMENTARY SYSTEM

- In sedimentary basins with high heat flow
- No fracturing needed but deep wells required.
- Not yet commercially proven but should be feasible if reservoir flow capacity and temperature are high enough

Levelized Energy Cost versus kh and Temperature



4. OIL & GAS FIELD WATERS

- From deep oil or gas field
- Hot water produced with oil or gas or from depleted oil/gas wells
- No technical challenge but power cost may not always be attractive

5. GEOPRESSURED SYSTEMS

- Very restricted distribution
- Reservoir pressure higher than hydrostatic
- Kinetic energy, thermal energy and energy from dissolved methane
- No commercial project to date; one demonstration of technical feasibility
- Several technical challenges to making power cost commercial

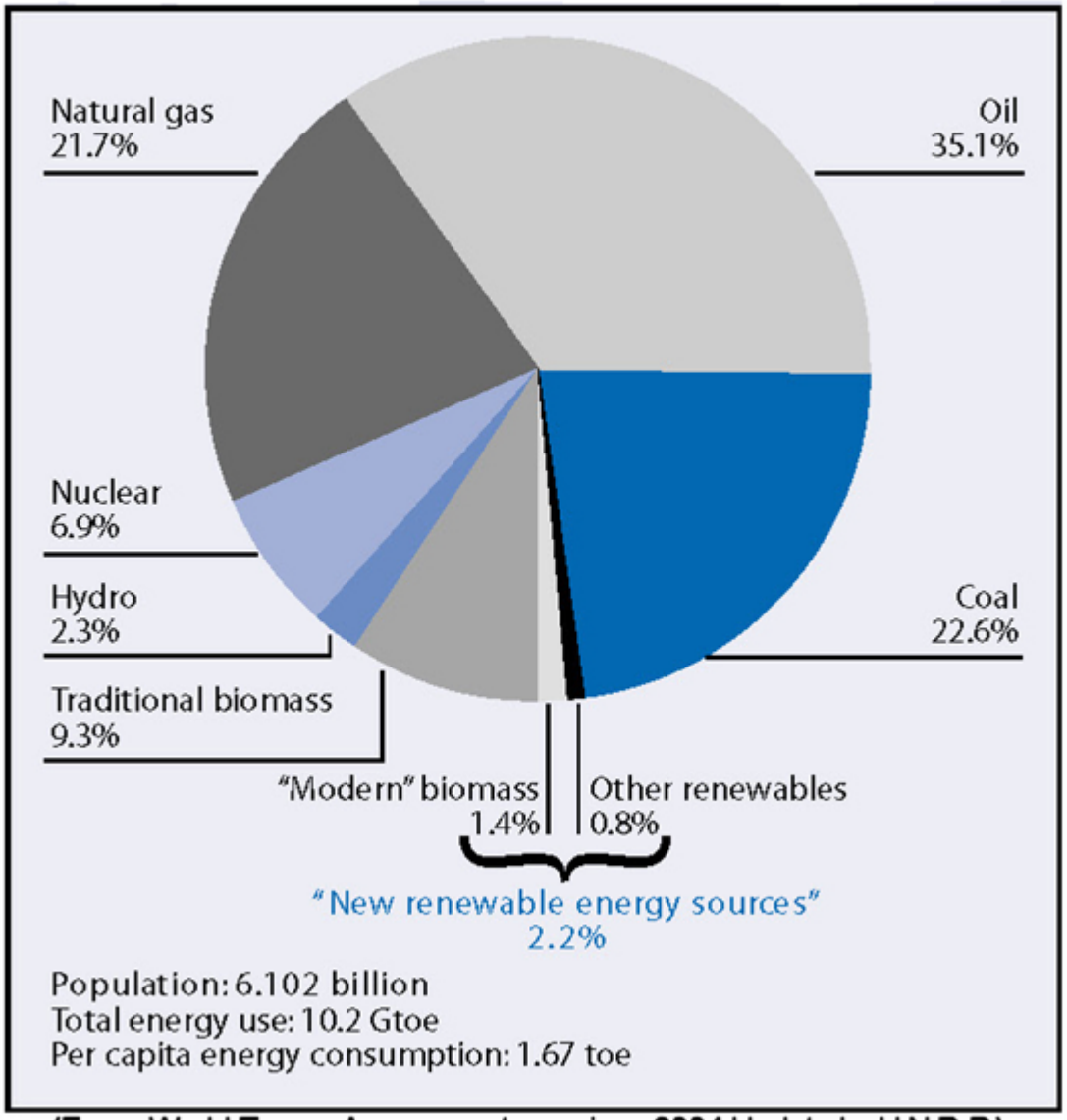
MAGMA ENERGY

- Extremely localized
- Many technical challenges

FUTURE OF GEOTHERMAL ENERGY

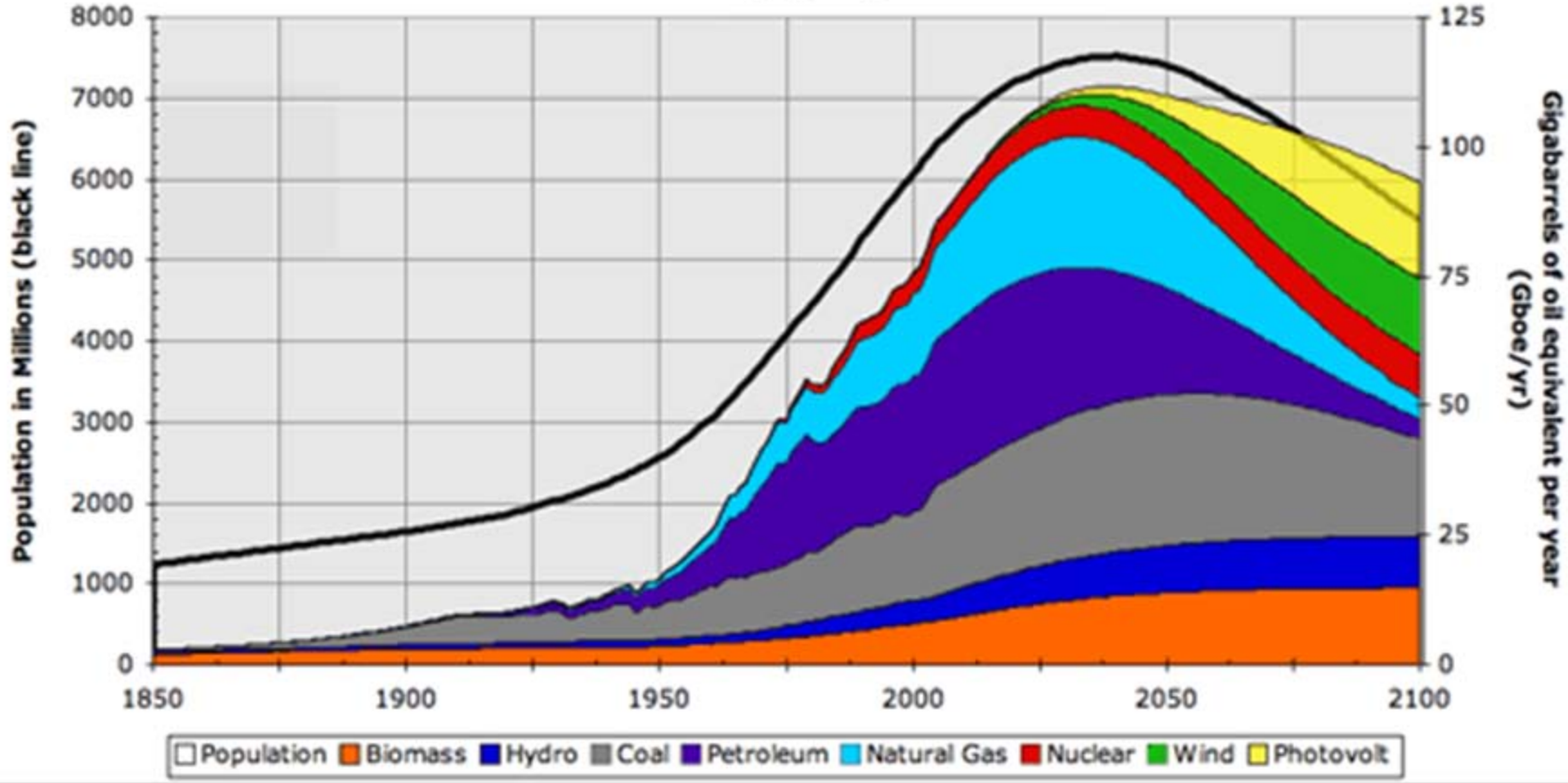
- Population and energy consumption forecast
- Potential contribution from various geothermal energy sources
- Reduction in geothermal power cost through technical innovation

World primary energy use, by energy source, 2001 (share of 10.2 GTOE)



(From: World Energy Assessment overview: 2004 Update by U.N.D.P.)

World energy production

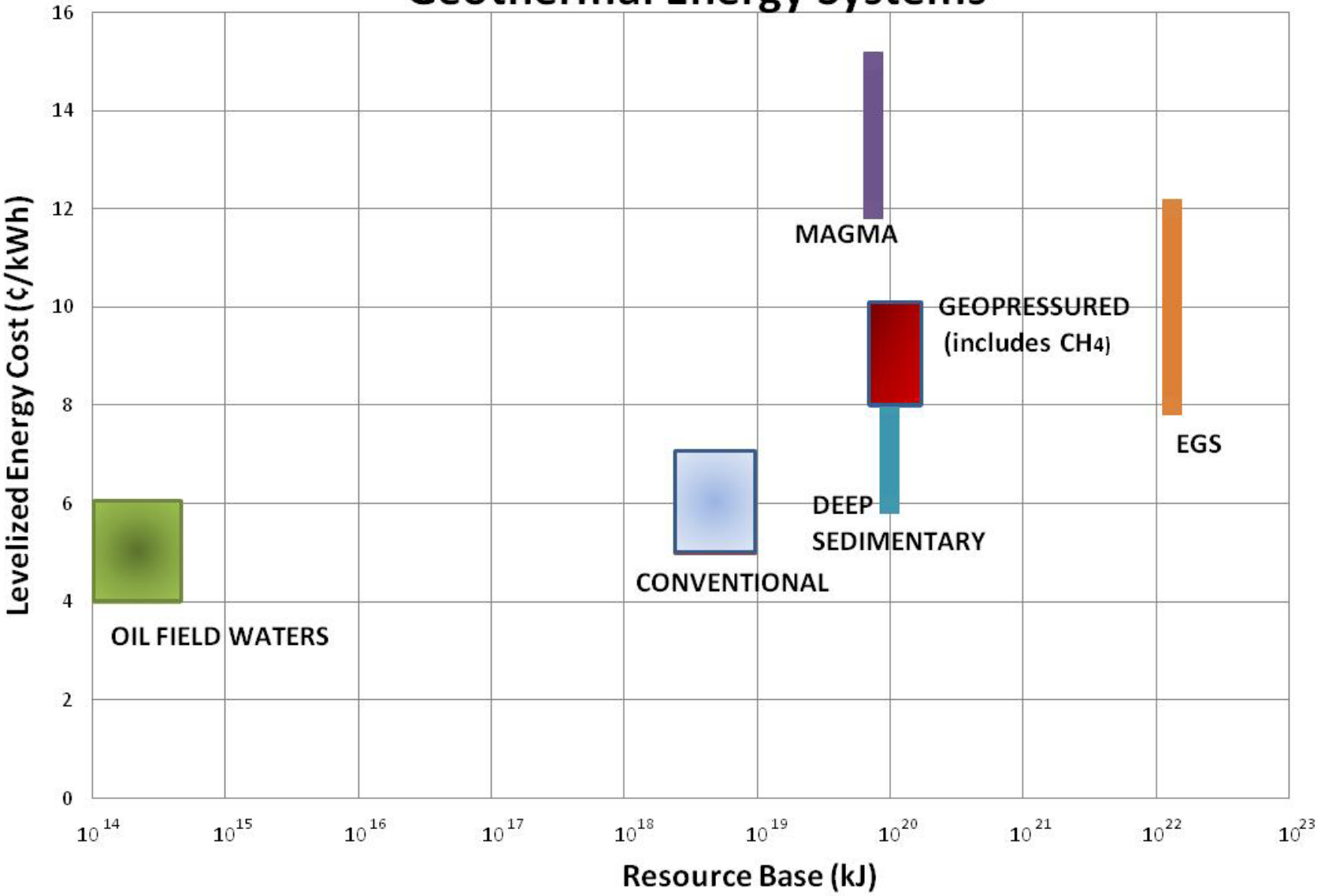


(From: The Quaker Economist, Vol. 7, No. 155 March 2007)

U.S. GEOTHERMAL RESOURCE BASE (M.I.T., 2006)

Resource Type	Resource Base up to 10 km (J)	No. of Years of Potential Reserves
Convective	2.4E21 to 9.6 E21	~1
EGS	1.4E25	1,400
Conductive Sedimentary	1.0E23	10
Oil/Gas Field Waters	1.0E17 to 4.5E17	< 1
Geopressured	7.1E22 to 1.7E23	7 to 17
Magma Energy	7.4E22	7

Resource Base and Power Cost of the Various Geothermal Energy Systems



Is Geothermal Energy Renewable?

- Geothermal energy would be instantly renewable if the energy extraction rate does not exceed the natural heat loss rate from the earth's surface, which is of the same order of magnitude (about 10^{20}J per year) as the worldwide energy consumption rate today.

Is Geothermal Energy Renewable? (Cont'd)

- However, natural heat loss rate per unit area of the earth's surface (on the order of 50 KW per square km) is so low that commercial geothermal energy extraction is primarily "heat mining."
- The 6 types of geothermal energy sources considered before are various heat mining schemes, each with a minor contribution from renewable heat flow from the earth's core.

How Long Can Geothermal Energy Supply the World?

- Total stored heat energy up to a depth 5 km worldwide = 1.46×10^{26}J (Los Alamos Scientific Laboratory, 1981); on the order of 1% of this resource base is minable, implying a worldwide recoverable resource base on the order of 1.46×10^{24}J.

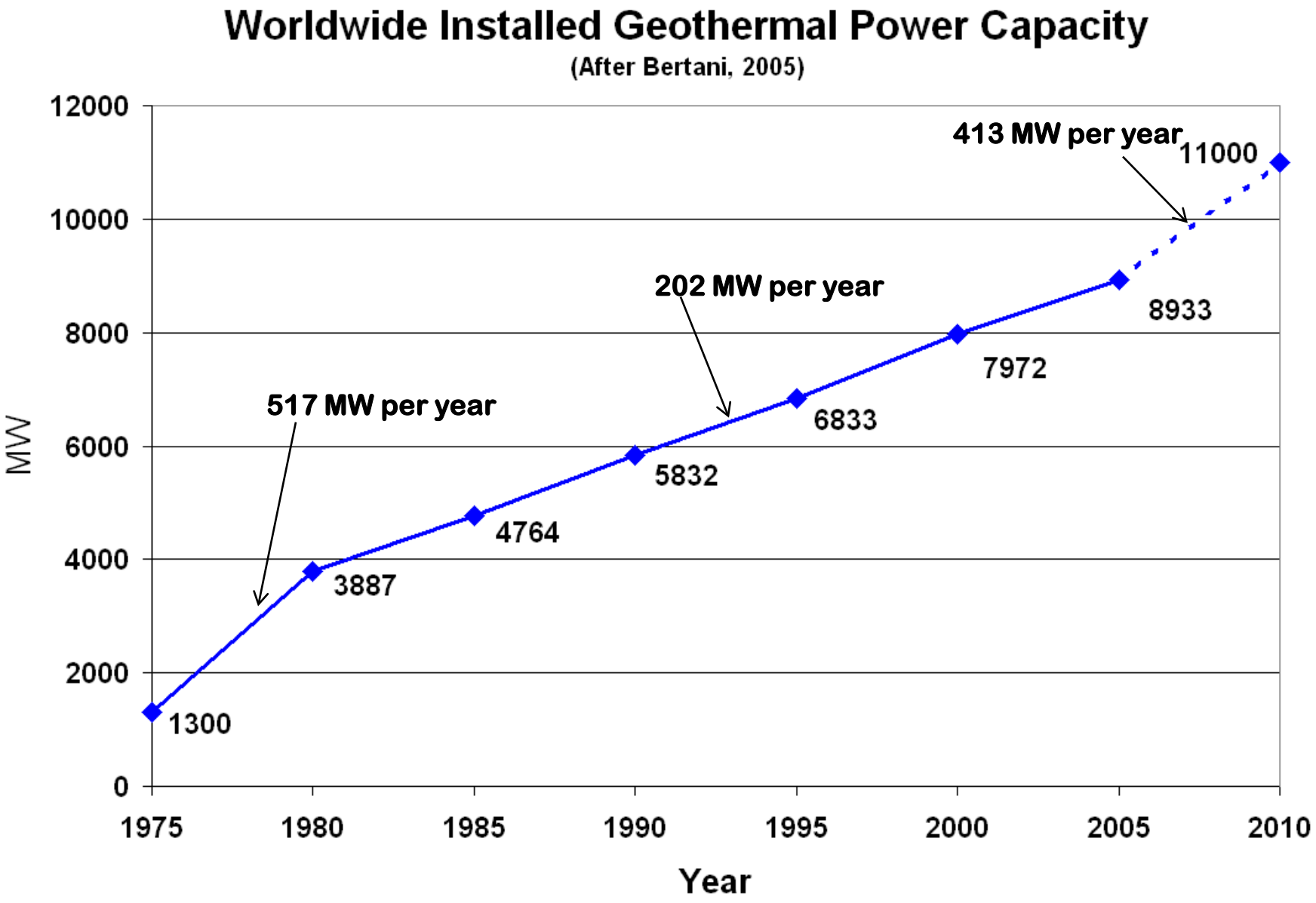
How Long Can Geothermal Energy Supply the World? (Cont'd)

- At the current annual worldwide energy consumption rate of 4.18×10^{20} J (UN World Energy Assessment, 2001), heat mining up to a depth of only 5 km can theoretically supply the world's energy need for about 3,500 years.

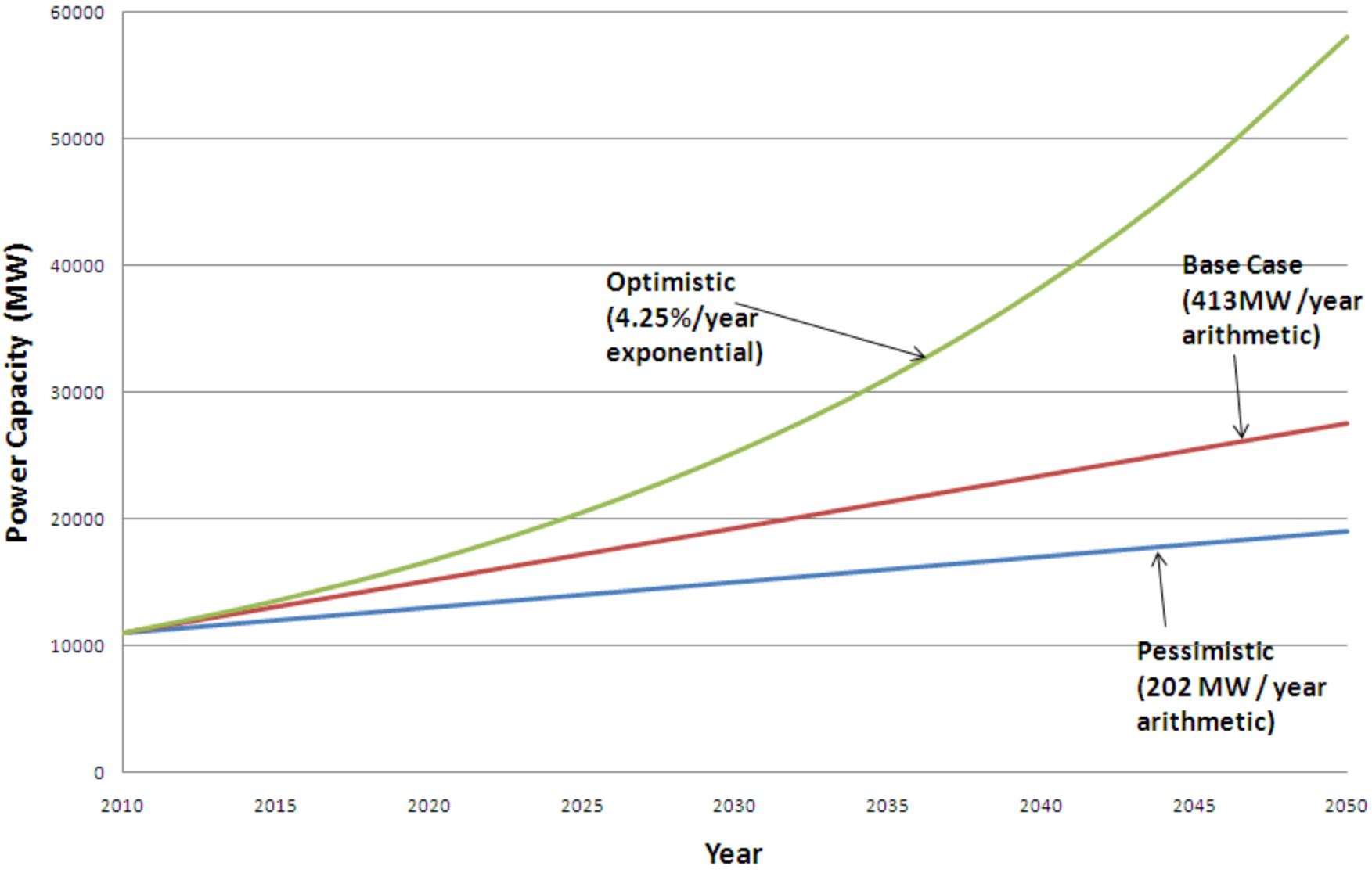
- Since drilling to a depth of at least 10 km is technically feasible today, geothermal heat mining can, in theory, supply the world for many millenia.

How Long Can Geothermal Energy Supply the World? (Cont'd)

- If a geothermal energy exploitation project is operated for its typical life of 30 years and then stopped, the resource world be naturally replenished in about a century, when it can be exploited again. With such an exploitation scheme, geothermal power can be considered truly renewable, and therefore, practically inexhaustible.


Worldwide Installed Geothermal Power Capacity
(After Bertani, 2005)
MW
Year
0
2000
4000
6000
8000
10000
12000
1975
1980
1985
1990
1995
2000
2005
2010
1300
3887
4764
5832
6833
7972
8933
11000
517 MW per year
202 MW per year
413 MW per year

Possible Growth Trends in Worldwide Geothermal Power Capacity



CONCLUSIONS

- Of the six basic types of geothermal energy, the resource base in U.S. enhanced geothermal systems is two orders of magnitude higher than in the other types combined; the same is likely to be true for the world.

CONCLUSIONS (Cont'd)

- Commercial geothermal energy exploitation is primarily a heat mining operation rather than tapping an instantly renewable energy source, such as, solar or wind energy.
- At the current annual energy consumption rate, geothermal heat mining can theoretically supply the world for several millenia.

CONCLUSIONS (Cont'd)

- If a commercial geothermal exploitation project is operated for a typical life of 30 years and then stopped, the resource would be naturally replenished and available for exploitation again in about a century; with such a scheme a geothermal project could be made entirely renewable, and therefore, practically inexhaustible.

CONCLUSIONS

- Between years 2010 and 2050, geothermal power capacity in the world would increase from 11,000 MW to perhaps as high as 58,000 MW.
- Rate of growth in power capacity can be much higher given adequate commercial incentives by governments and international agencies.