Geothermal Electric Power

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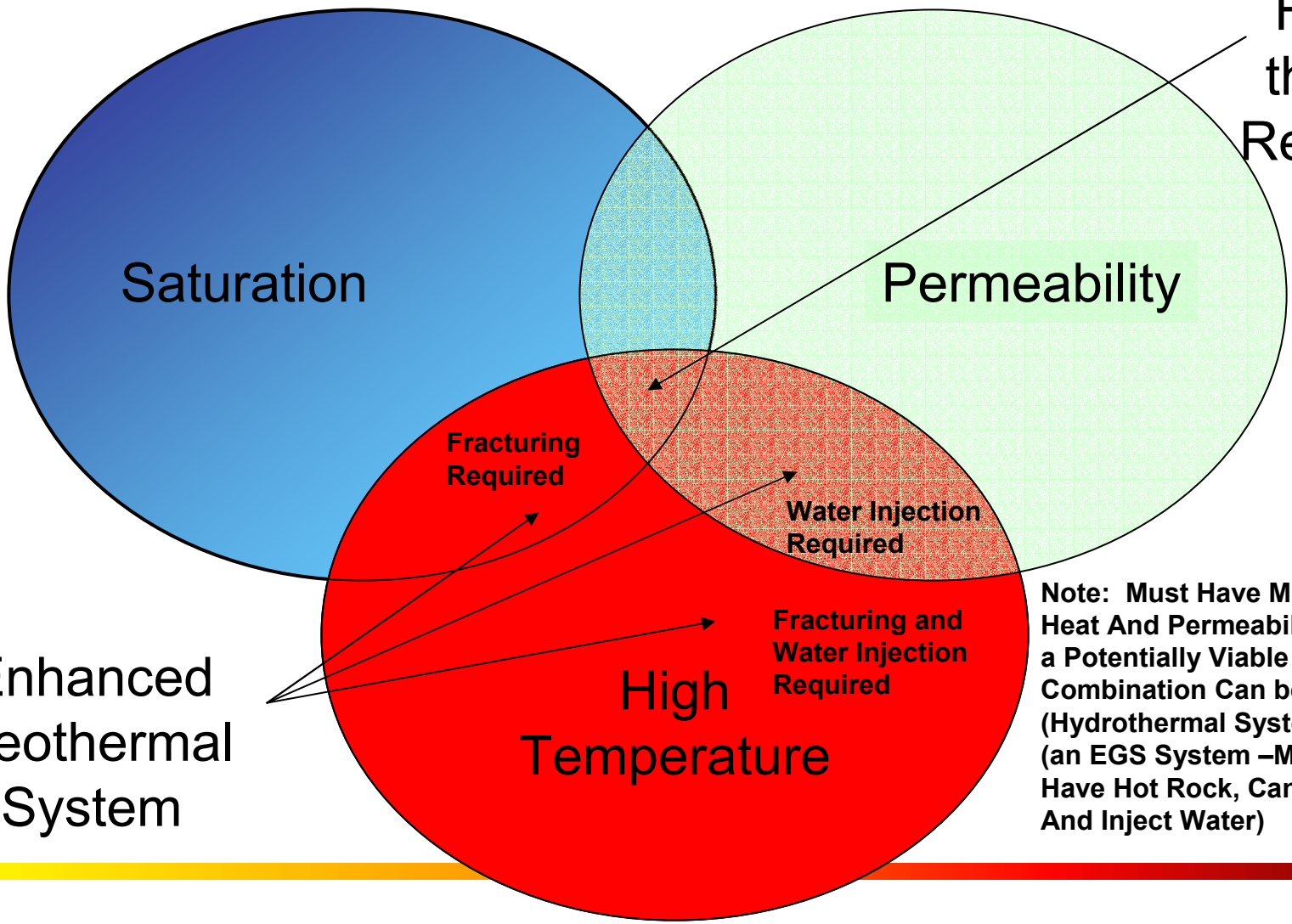
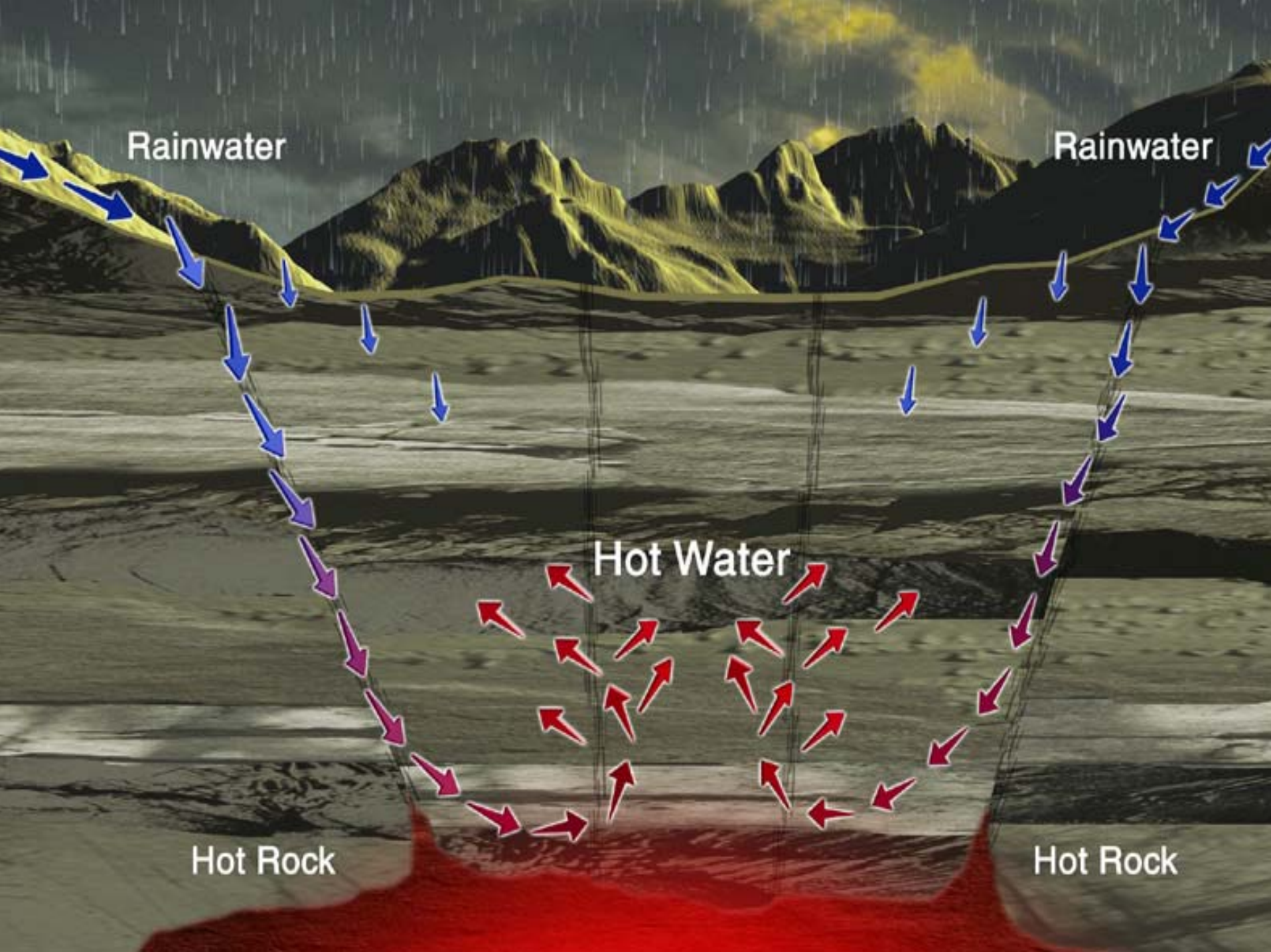
Advantages of Geothermal Energy

- Environmentally sound
- Resources last the life of the plant
- High plant availability (over 95%)
- Provides steady base load power
- Relatively low cost (4 to 8 cents per kWh)

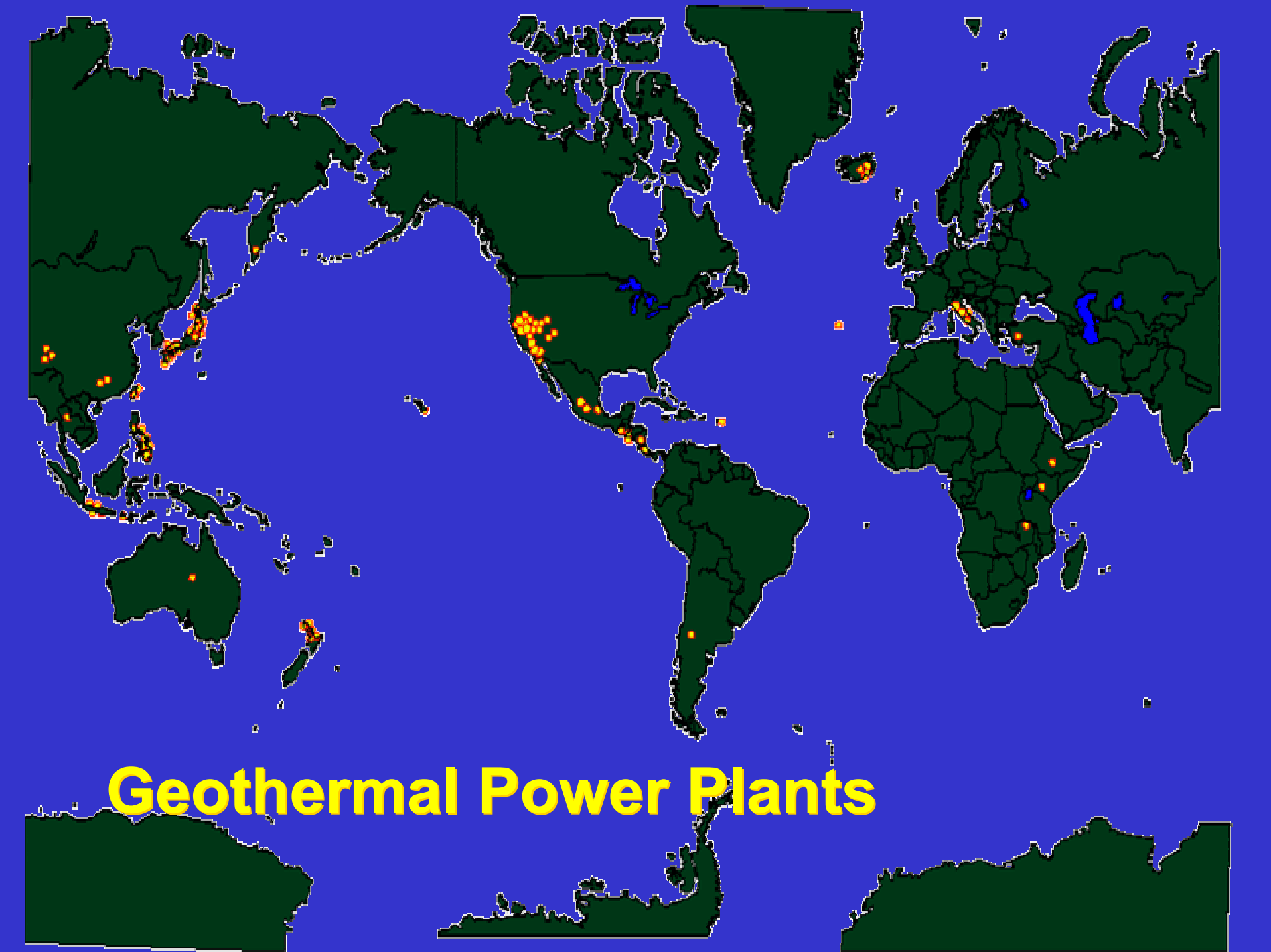
Geothermal Domains



Note: Must Have Mobile water, Heat And Permeability To Have a Potentially Viable System. This Combination Can be Natural (Hydrothermal System) or Created (an EGS System –Must always Have Hot Rock, Can Then Fracture And Inject Water)


Rainwater
Rainwater
Hot Water
Hot Rock
Hot Rock

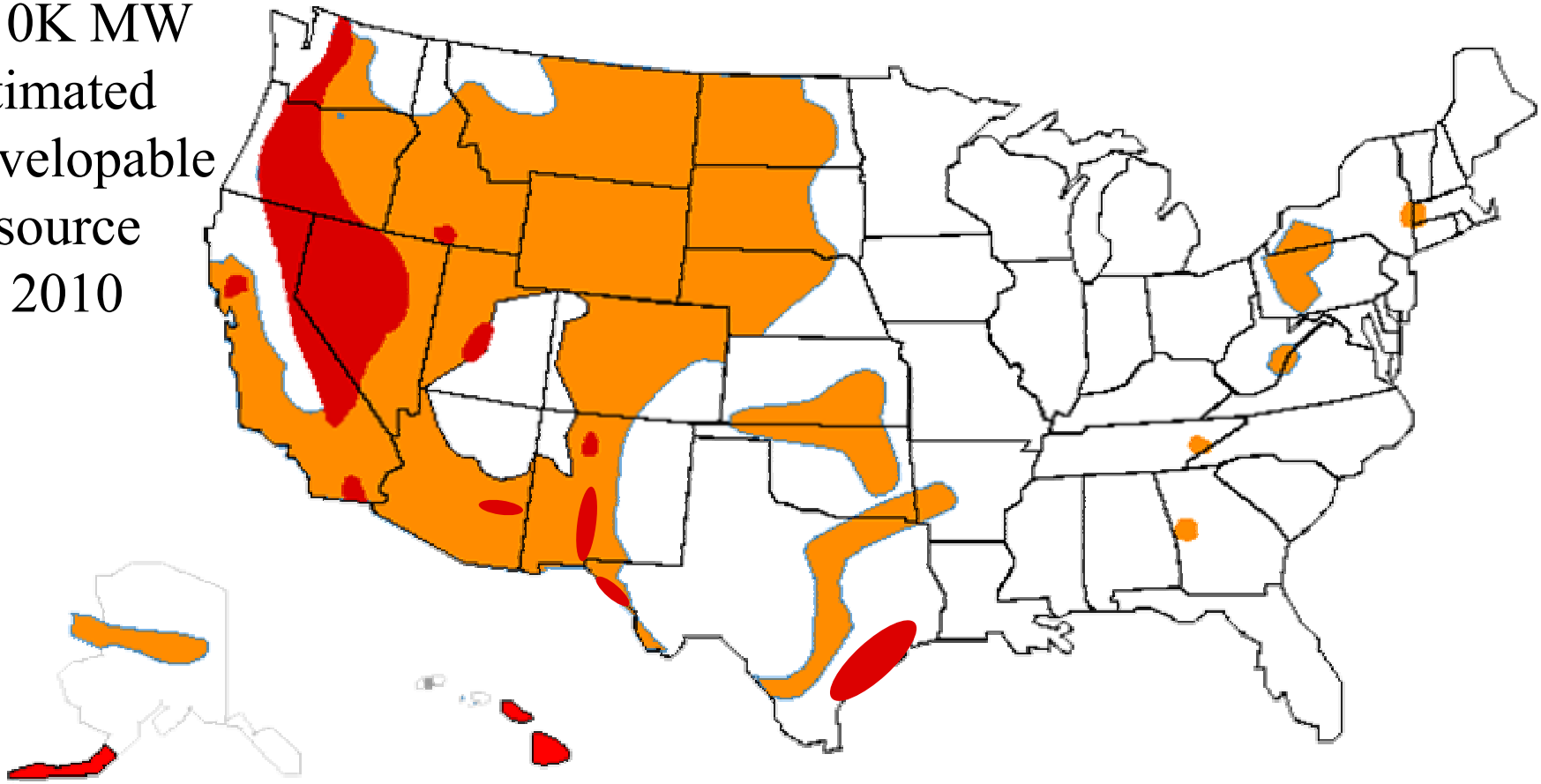

Hottest Known Geothermal Regions


Geothermal Power Plants

Today's Plants

- 8,000 MWe being generated in 21 countries
- 22 plants in U.S. (mostly California and Nevada) providing 2,200 MWe
- Hydrothermal resources could provide additional 20,000 MWe in U.S., 75,000 MWe in developing nations; hot dry rock resource is immense

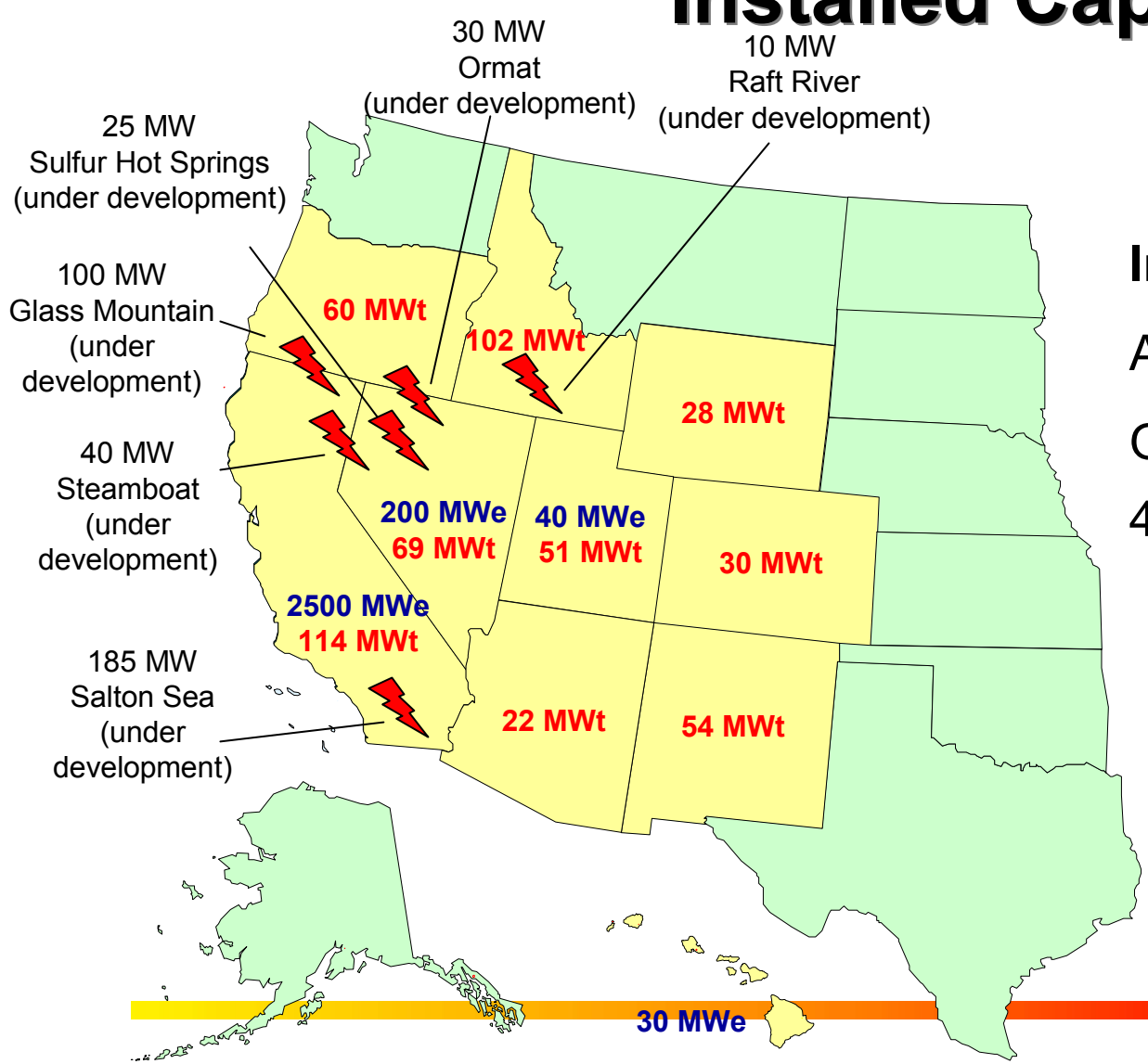
5-10K MW
Estimated
Developable
Resource
By 2010



Power Production

Direct
Uses

Installed Capacity



Installed:

About 2800 MW (electric)

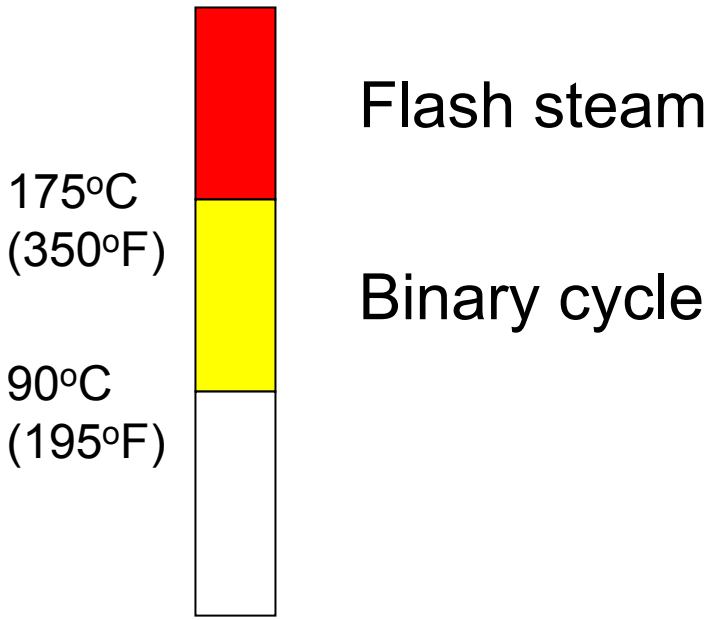
Over 600 MW (heat)

400 MW under development (electric)

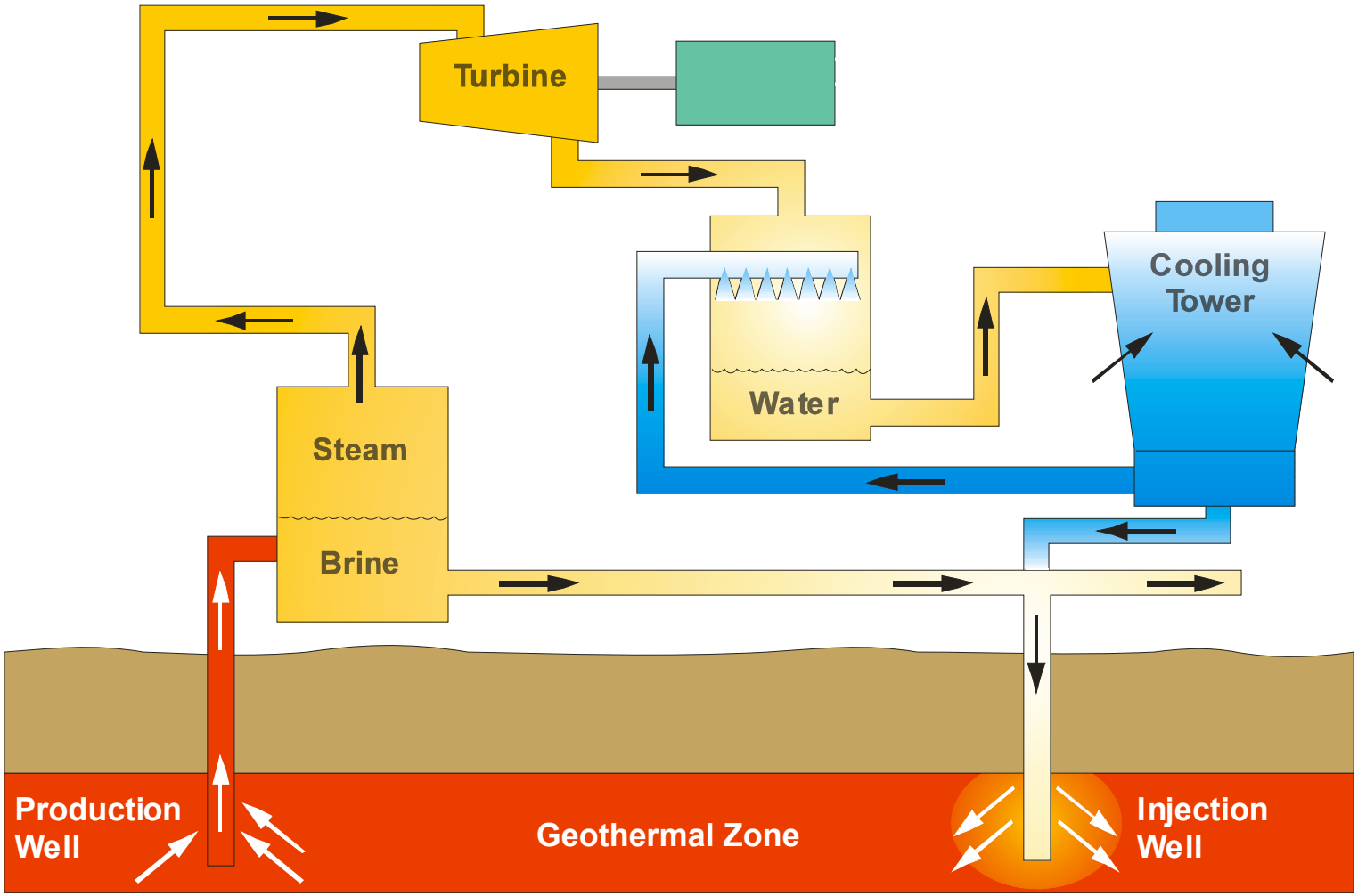
Greater Than 20 MW

Less than 20 MW

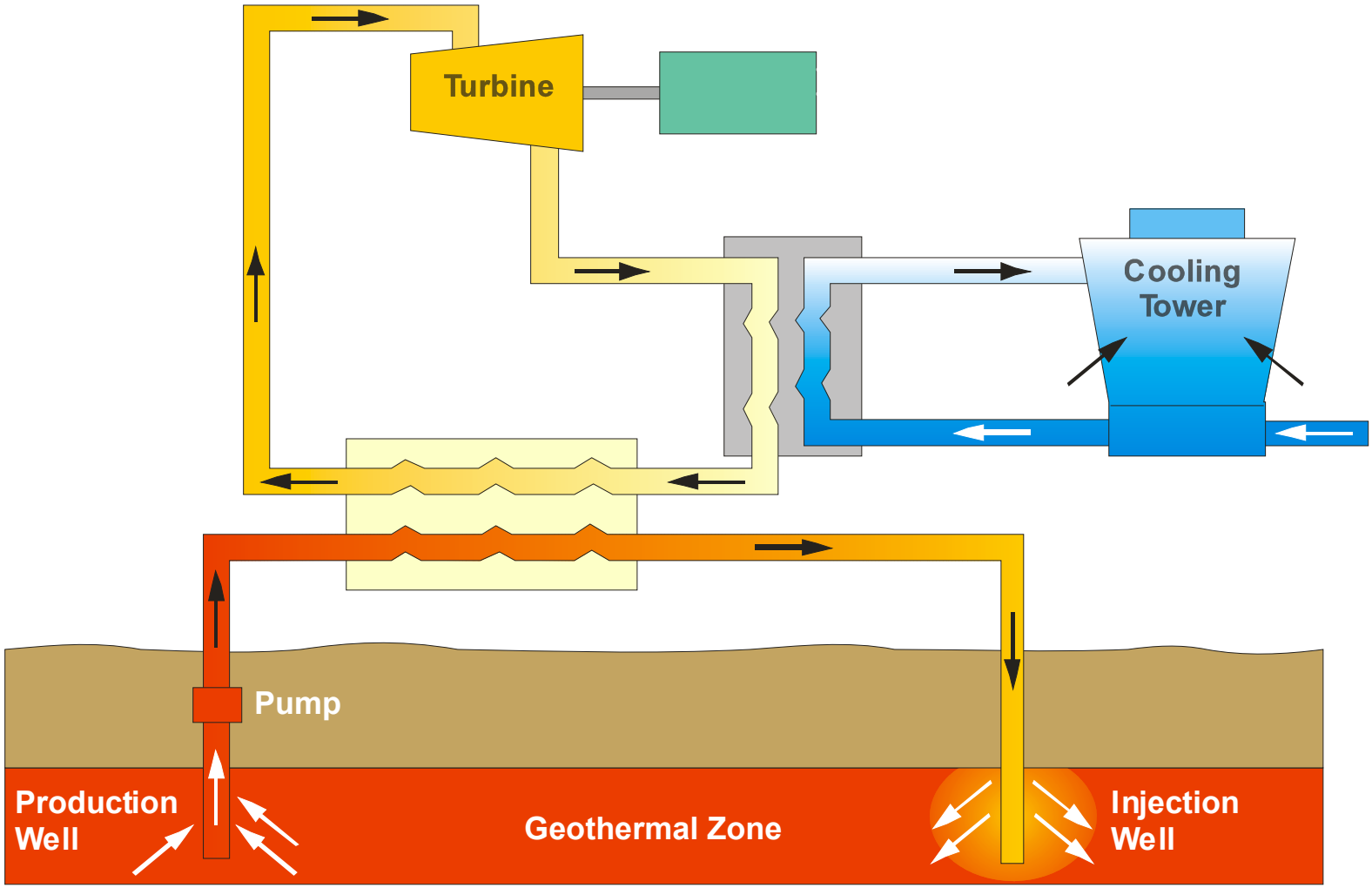
Plant Type vs. Temperature



Flash Steam Power Plant



Binary Cycle Power Plant



Plant Costs

	Flash ($/kW)	Binary ($/kW)
Exp./drilling	700	500
Equip.	750	1600
TOTAL	1,450	2,100

DOE Role

- R&D and deployment activities to enable US industry to expand geothermal energy use
- Priorities are exploration and drilling to reduce risks and up-front costs. Immediate gains anticipated from enhanced conversion technology
- Goal is 20,000 MW_e hydrothermal and 20,000 MW_e enhanced geothermal plants by 2020

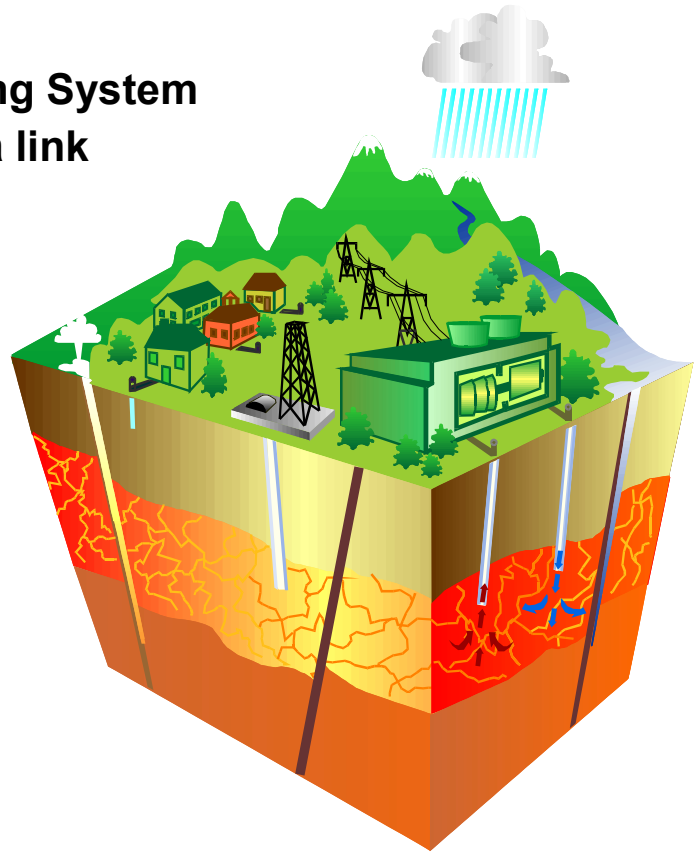
Geothermal Program Strategic Thrusts- 6 National Labs Involved

Drilling

- Advanced Drilling System
- High-speed data link

Exploration

- Integrated geophysical methods
- 3-D seismic analysis



Energy Conversion

- Small modular power systems
- Improved heat rejection
- Kalina cycle demonstration

Reservoir Engineering

- Enhanced Geothermal Systems
- Tracer injection experiments

NREL Energy Conversion Research

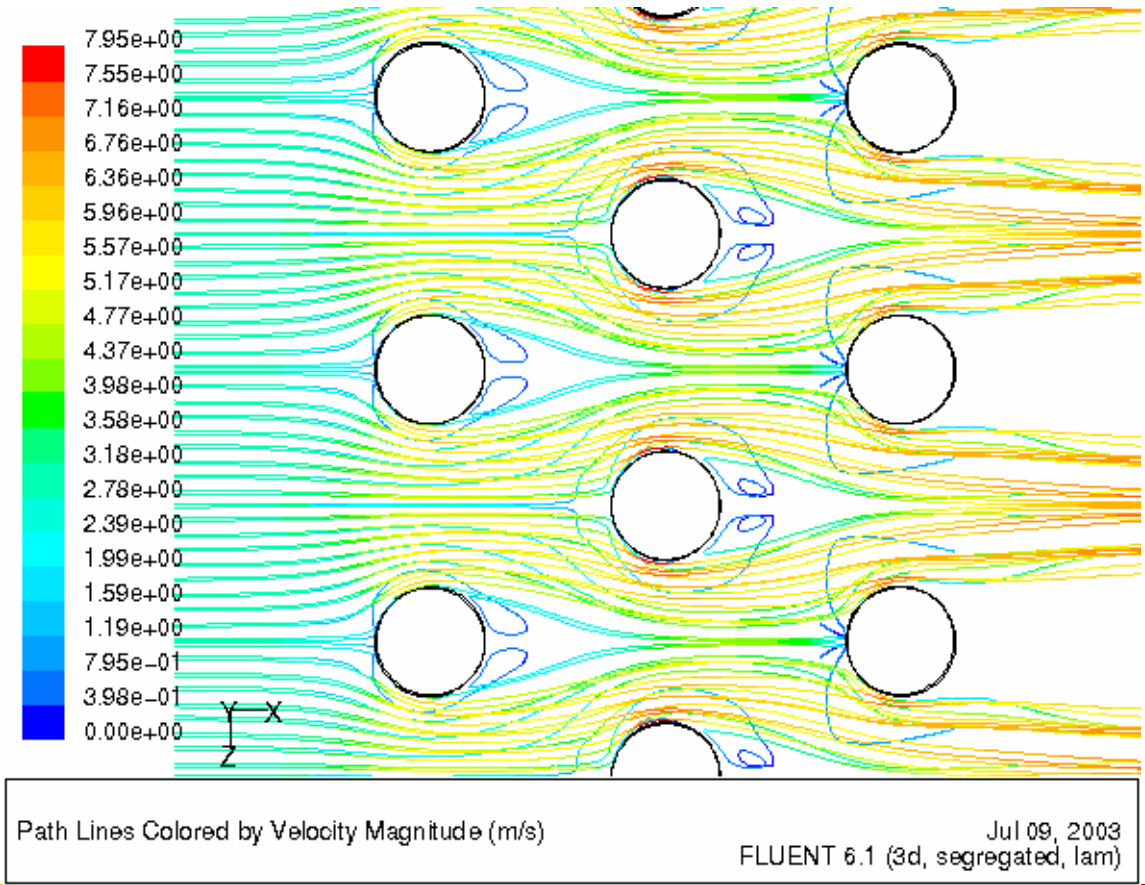
Potential Impacts of Power Plant R&D

Area	Improvement
Heat exchangers	**8% – 10%**
Cycle efficiency	**5% – 7%**
Off-design enhancement	**3% – 5%**
Reduced O&M	**2% – 3%**

PLANT OPTIMIZATION

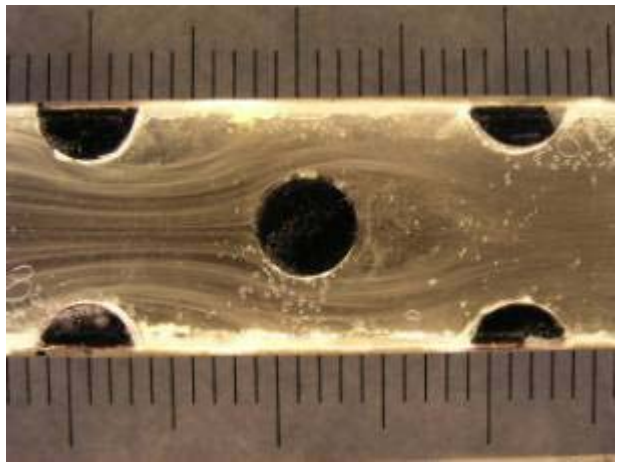
- **Conceived and developed the R&D-100 award winning Advanced Direct Contact Condenser**

Fluent Analysis: 3 Rows of Tubes

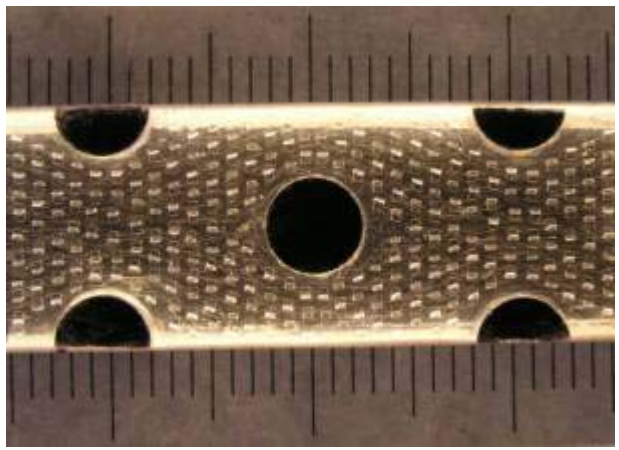


Flow Comparison: Plain Fins vs. Tabbed Fins

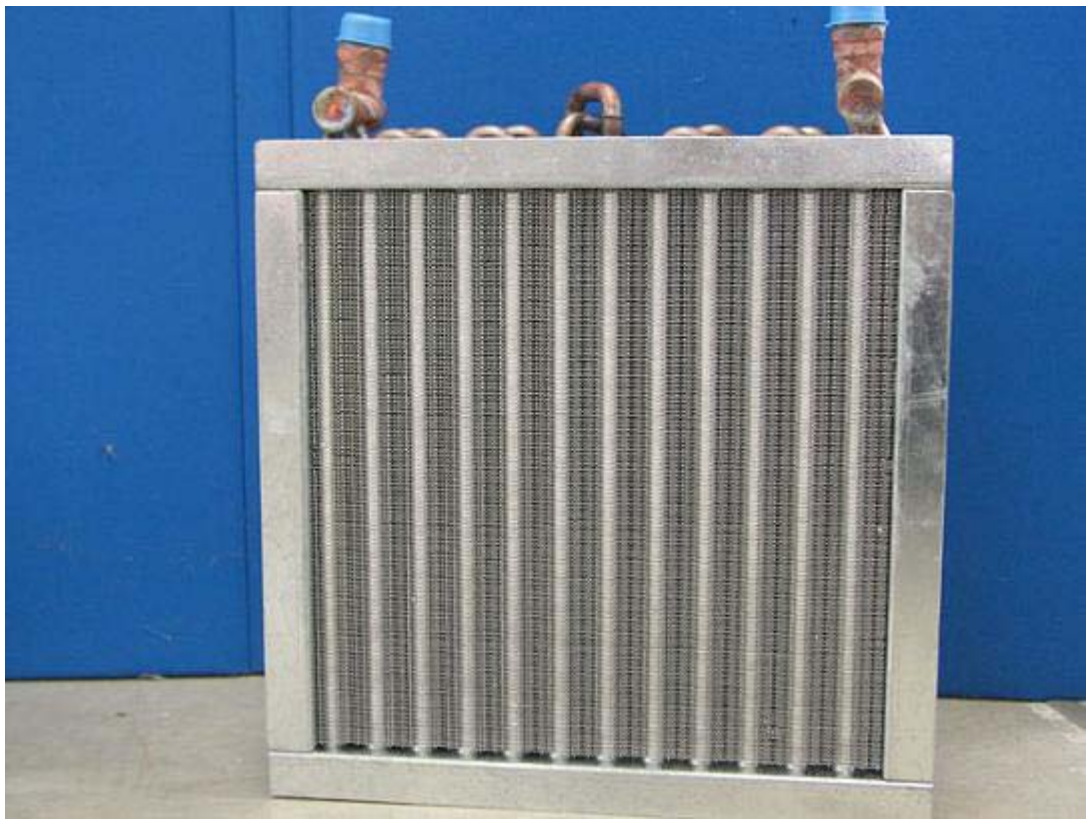
Plain



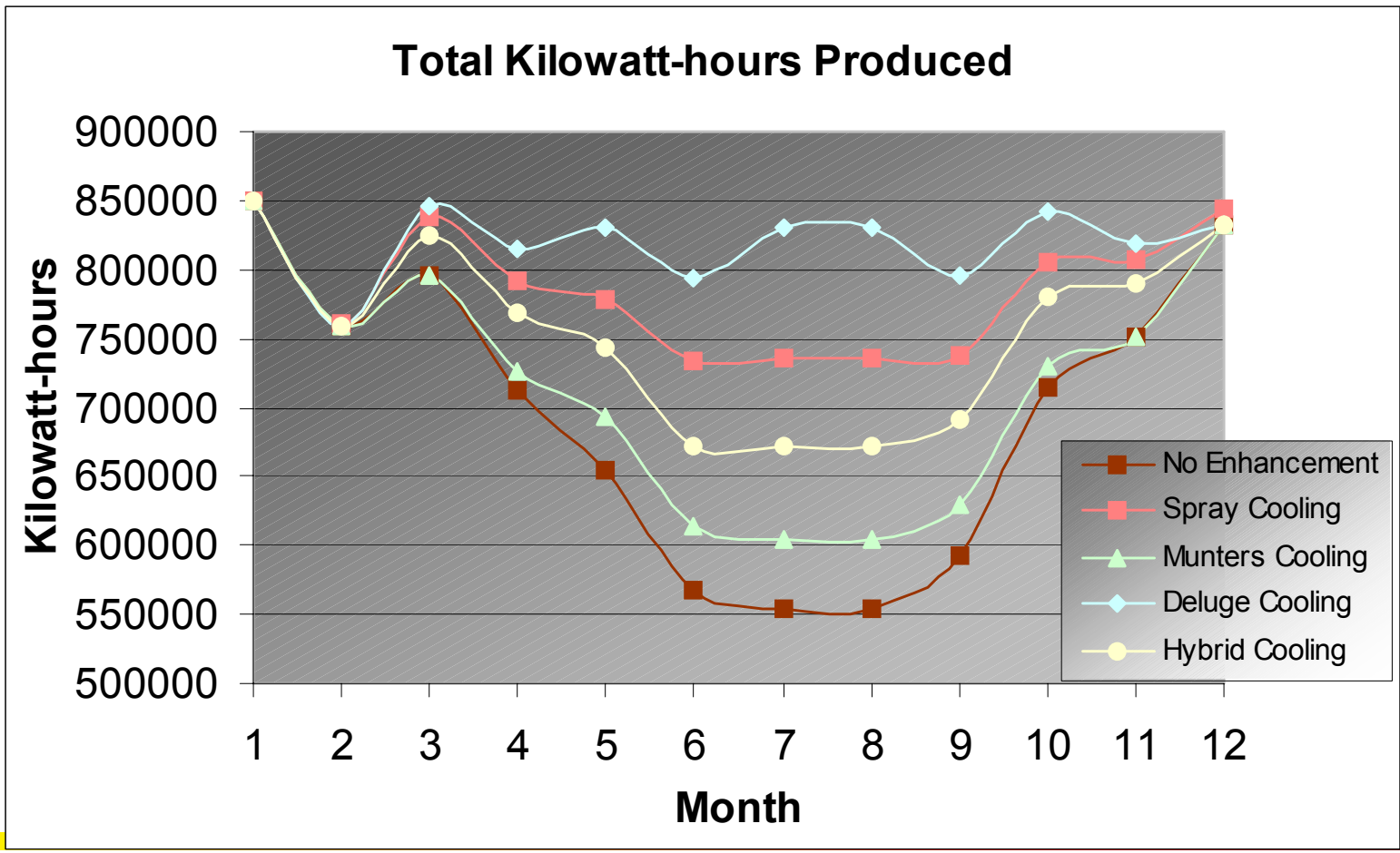
Tabbed



SRC Prototype High-Performance "t-fin"Heat Exchanger



Power Production with Evaporative Pre-cooling



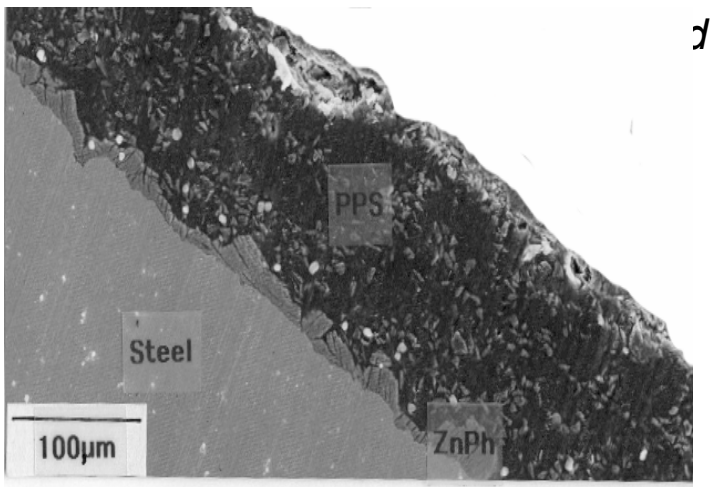
Field Measurements

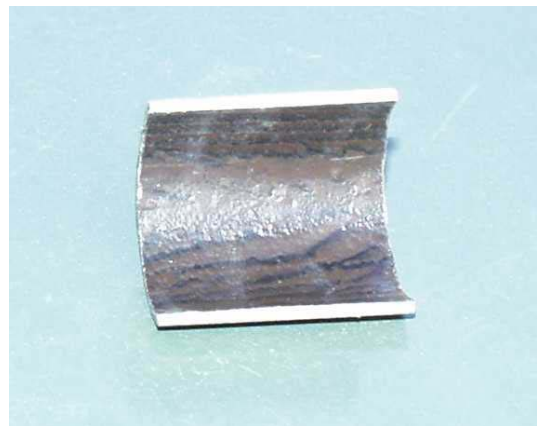
Munters system

Hybrid system

Heat Exchanger Coatings

- **NREL-BNL-industry partnerships**
- **Cost-effective thermally conductive polymer coating (PPS composite liner with a zinc phosphate primer) protects carbon steel tubes**
- **Developed through lab and field tests**





PI: T. Sugama, BNL
PI: K. Gawlik, NREL

Innovative Cycles Research

- Aimed at lower temperature resources, especially suitable for enhanced geothermal systems
- Should exceed efficiency of simple binary cycles at lower cost
- Prefer robustness, simplicity, environmental friendly cycles
- Building 1.3 MW mixed hydrocarbon working fluid plant, analyzing other cycles

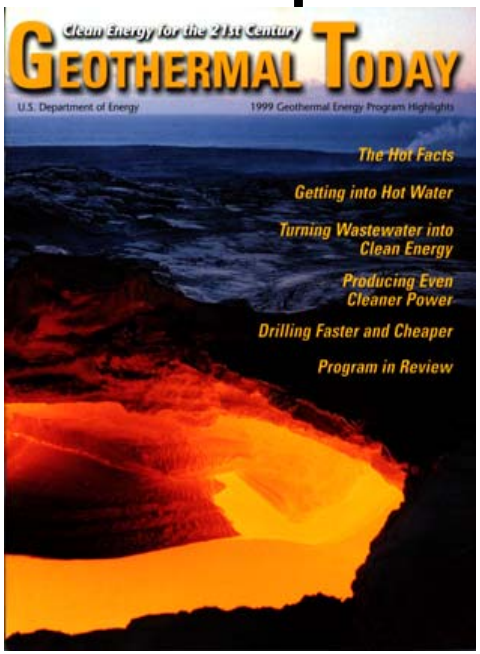
Analysis Support

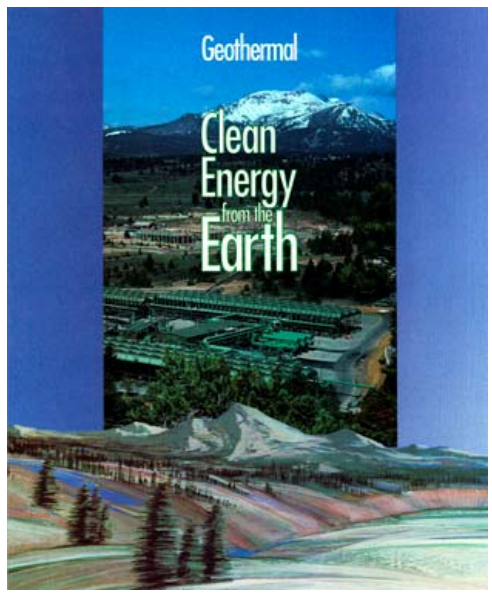
- Cost trends in geothermal
- Production tax credit report
- By-product value
- Program emphasis

PI: W. Short, L. Vimmerstedt, NREL

Promoting Geothermal Energy through Outreach Materials and Activities

Beautiful products for the Program





PI: B. Green, NREL

Technology Summary

- Clean, reliable base load power
- Large plants ~5 cents/kWh, small plants ~7 cents/kWh
- R&D underway to reduce risks and costs
- Expect renewed interest with production tax credit

Direct Uses and Geothermal Heat Pumps

Direct Uses

- Balneology (hot spring and spa bathing)
- Agriculture (greenhouse and soil warming)
- Aquaculture (fish, prawn, and alligator farming)
- Industrial Uses (product drying and warming)
- Residential and District Heating

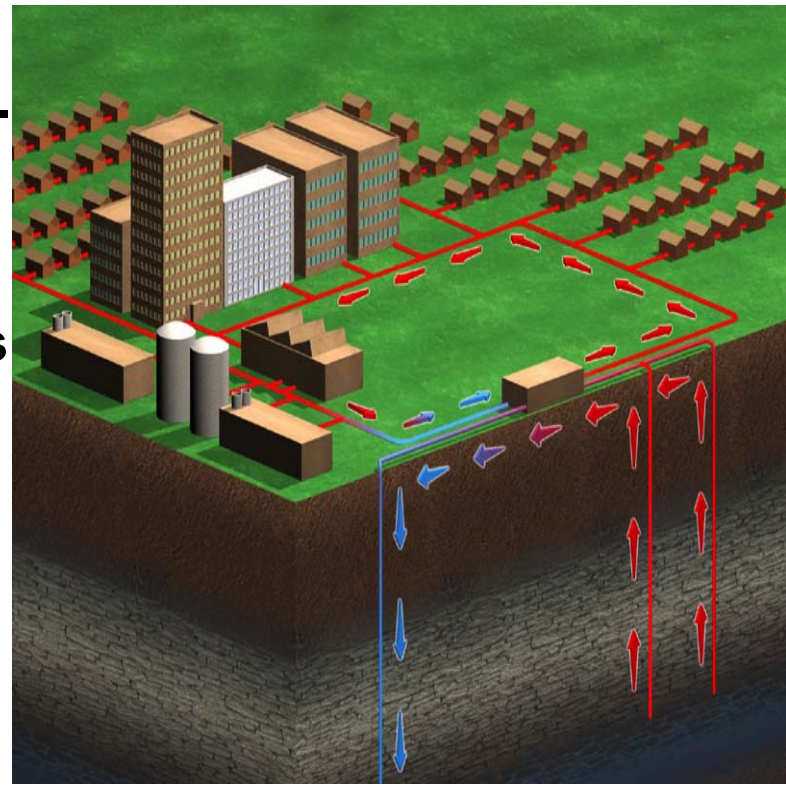
Worldwide Geothermal Direct Use

- Direct uses of geothermal water supply over 11,000 thermal megawatts in over 40 countries.

- Another 35 countries use natural hot springs for bathing but have not yet developed their geothermal reservoirs for commercial use.

District Heating in Western U.S.

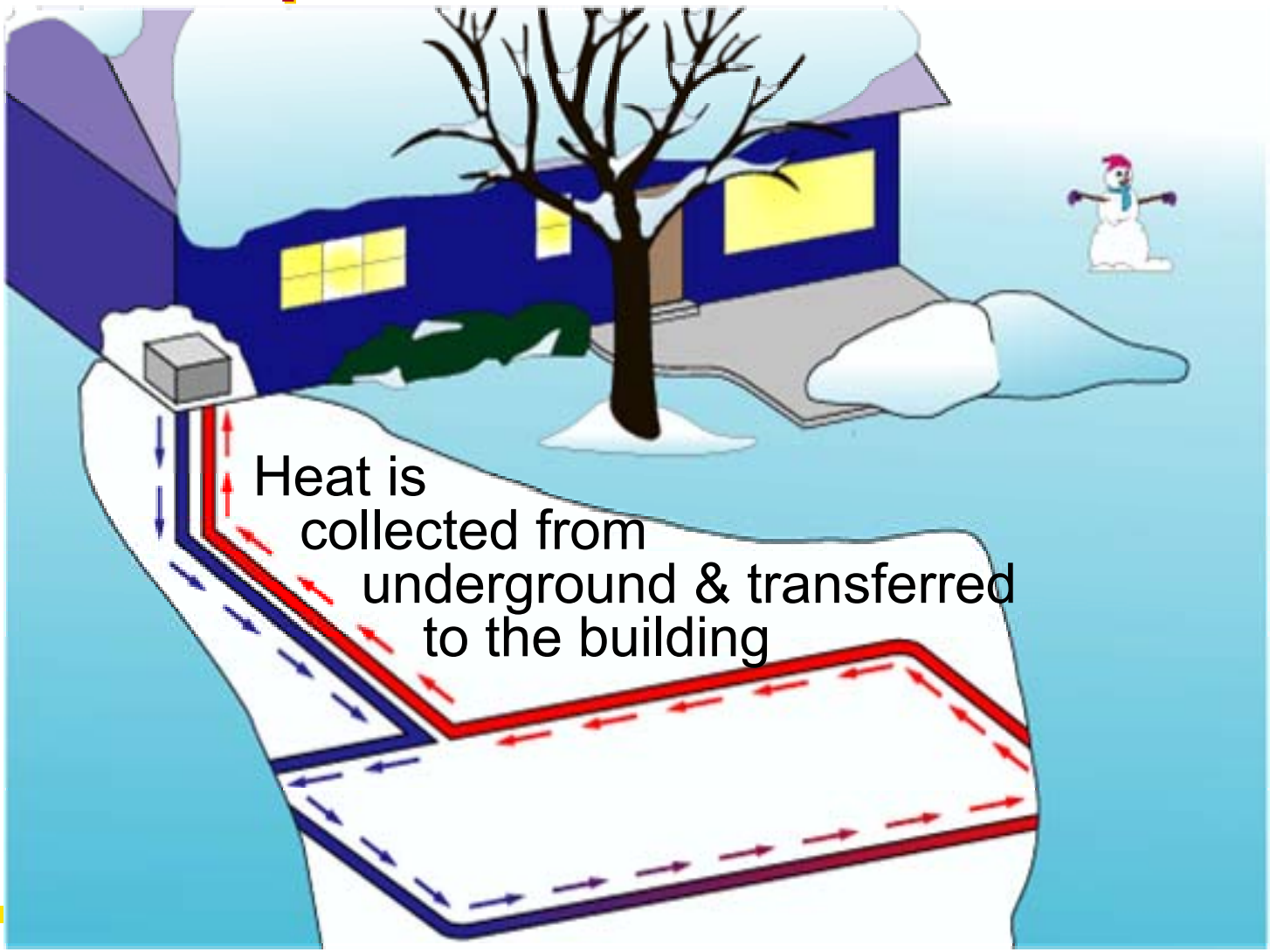
- There are 18 district heating systems operating in the western United States.
- Over 270 cities in the western U.S. are close enough to geothermal reservoirs to use district heating.



Geothermal Heat Pumps

- Use ground as source/sink for a heat pump instead of air
- $7,500 for 3-ton system compared to $4,000 conventional furnace/AC
- 2-10 year payback
- 500,000 systems in U.S. today

Heat Pump in Winter



Heat Pump in Summer