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GeoPowering the West: Geothermal Energy - A brief tour

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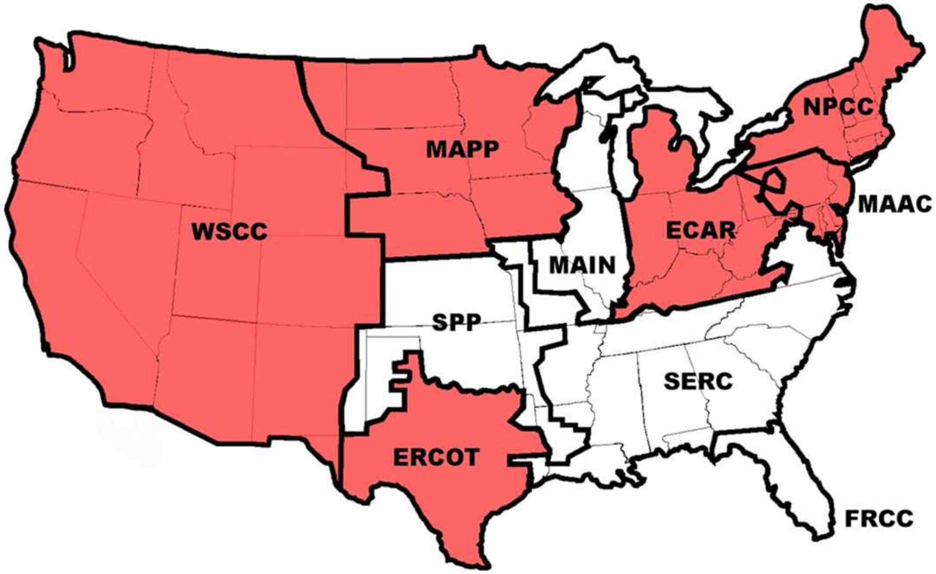
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

U.S. Energy Supply Challenges

"If the energy infrastructure of this country is inadequate or in some way excessively costly, it will undermine economic growth, and is therefore a major issue that must be addressed." *Alan Greenspan, January 26, 2001*

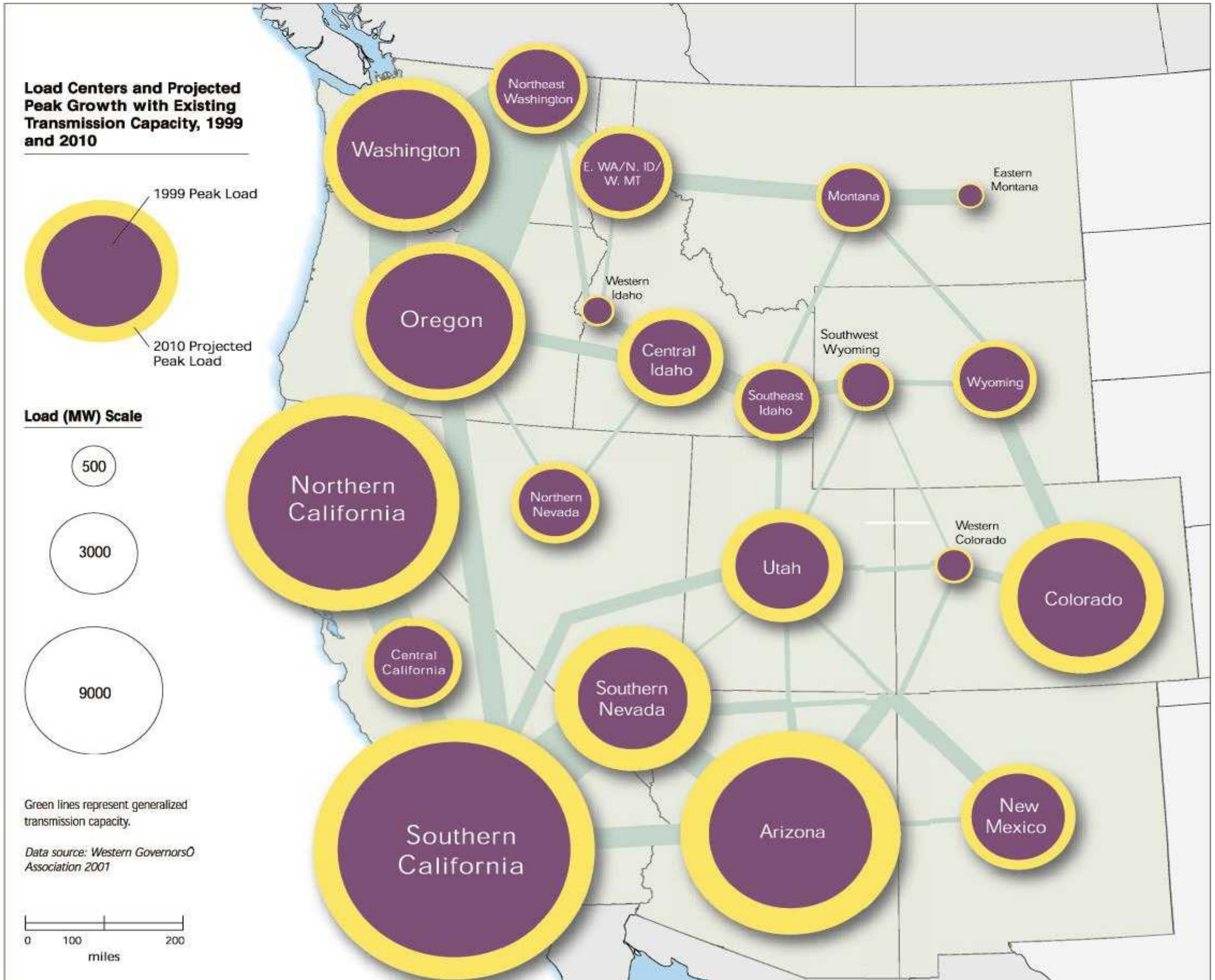
2009 Projection



Energy supply regions with capacity margins less than ten percent

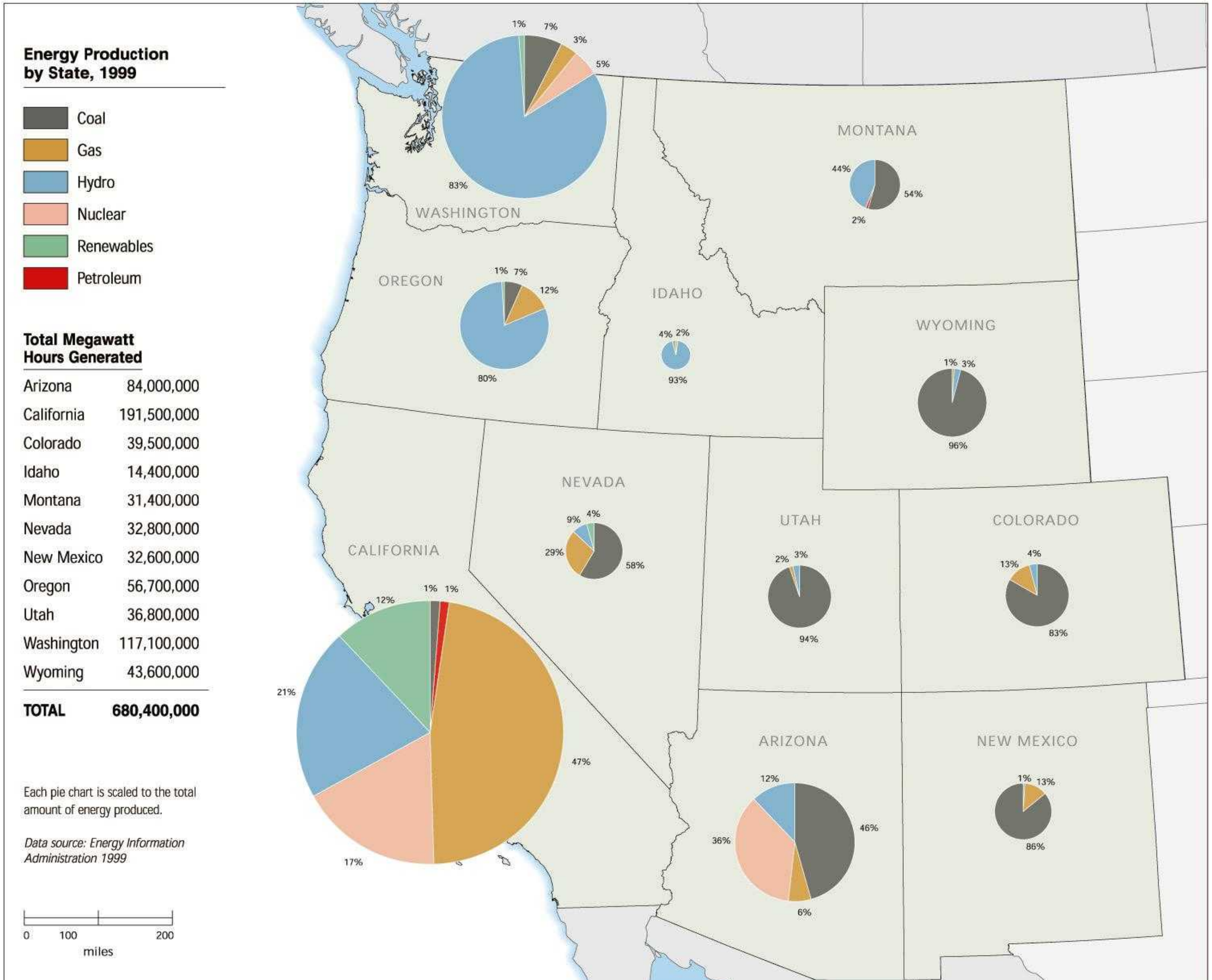
Source: North American Electricity Reliability Council, 2000

Western US: Load Growth



Source: Renewable Energy Atlas

Electricity Generation

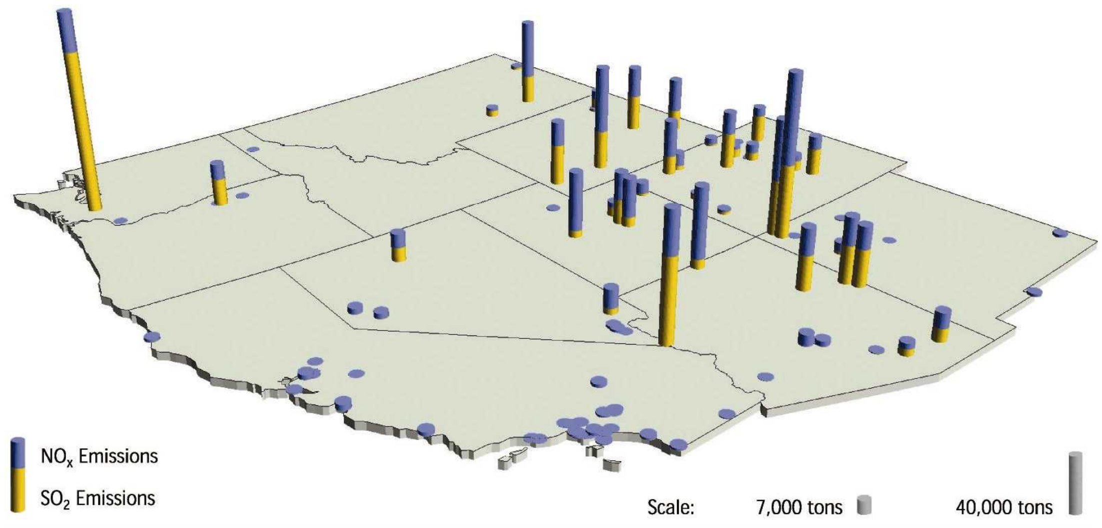


Source: Renewable Energy Atlas

Regional Power Plant Emissions

Power Plant Emissions, 2000

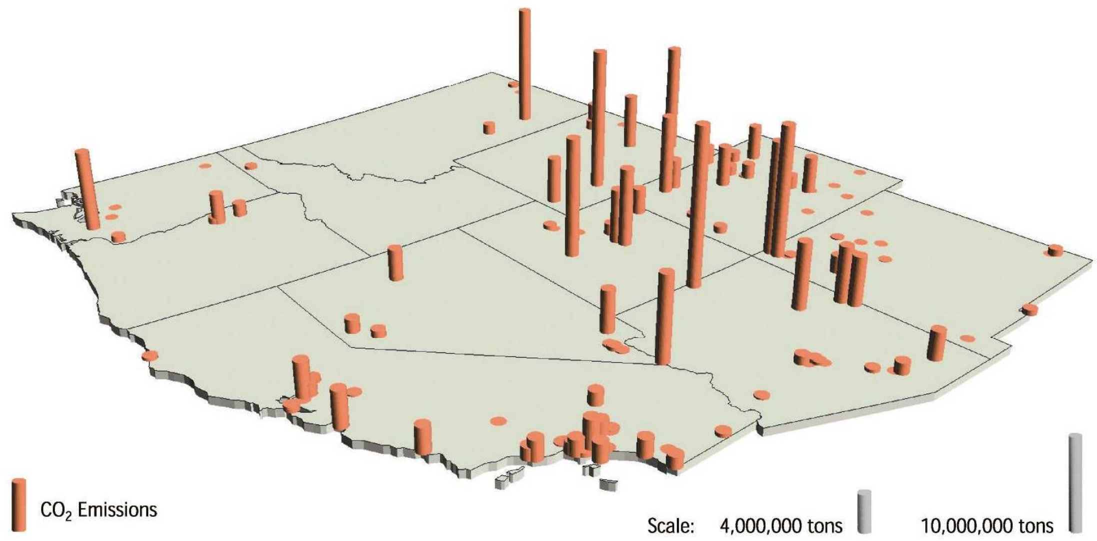
Each bar represents the location of a power plant regulated under the EPAÕ Acid Rain Program (Title IV). The height of the bars is scaled to reßect the emissions levels for each plant. Because CO_2 emissions are so much higher than either SO_2 or NO_x, different scaling factors were used to determine the height of the bars.



Total Emissions in Region from Title IV Plants, 2000

	tons
Sulfur Dioxide (SO_2)	506,662
Nitrogen Oxide (NO_X)	547,754
Carbon Dioxide (CO_2)	316,774,136

Data source: EPA Acid Rain Program (Title IV) Emissions Scorecard, 2000



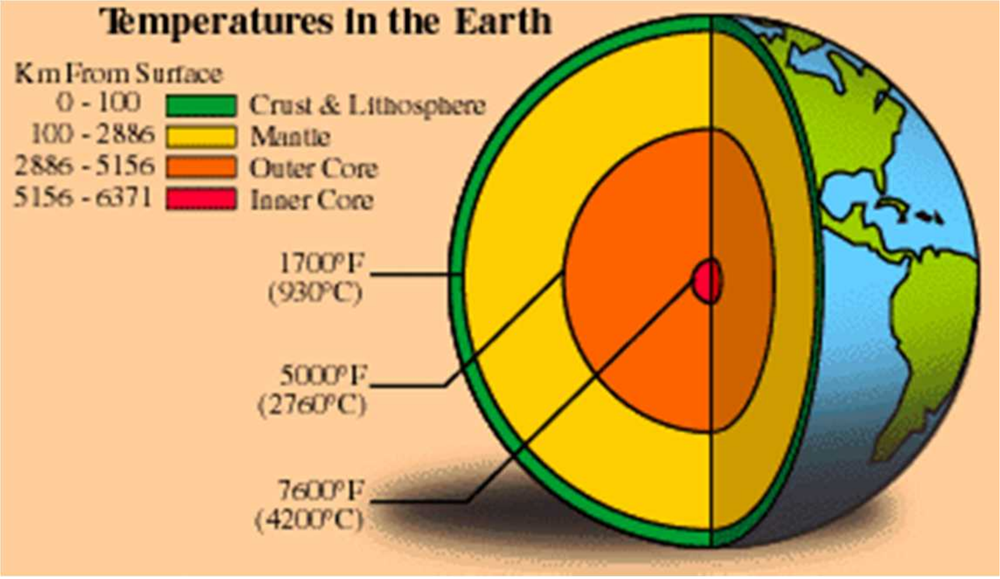
Source:
Renewable Energy Atlas

al
tories

Geothermal Energy

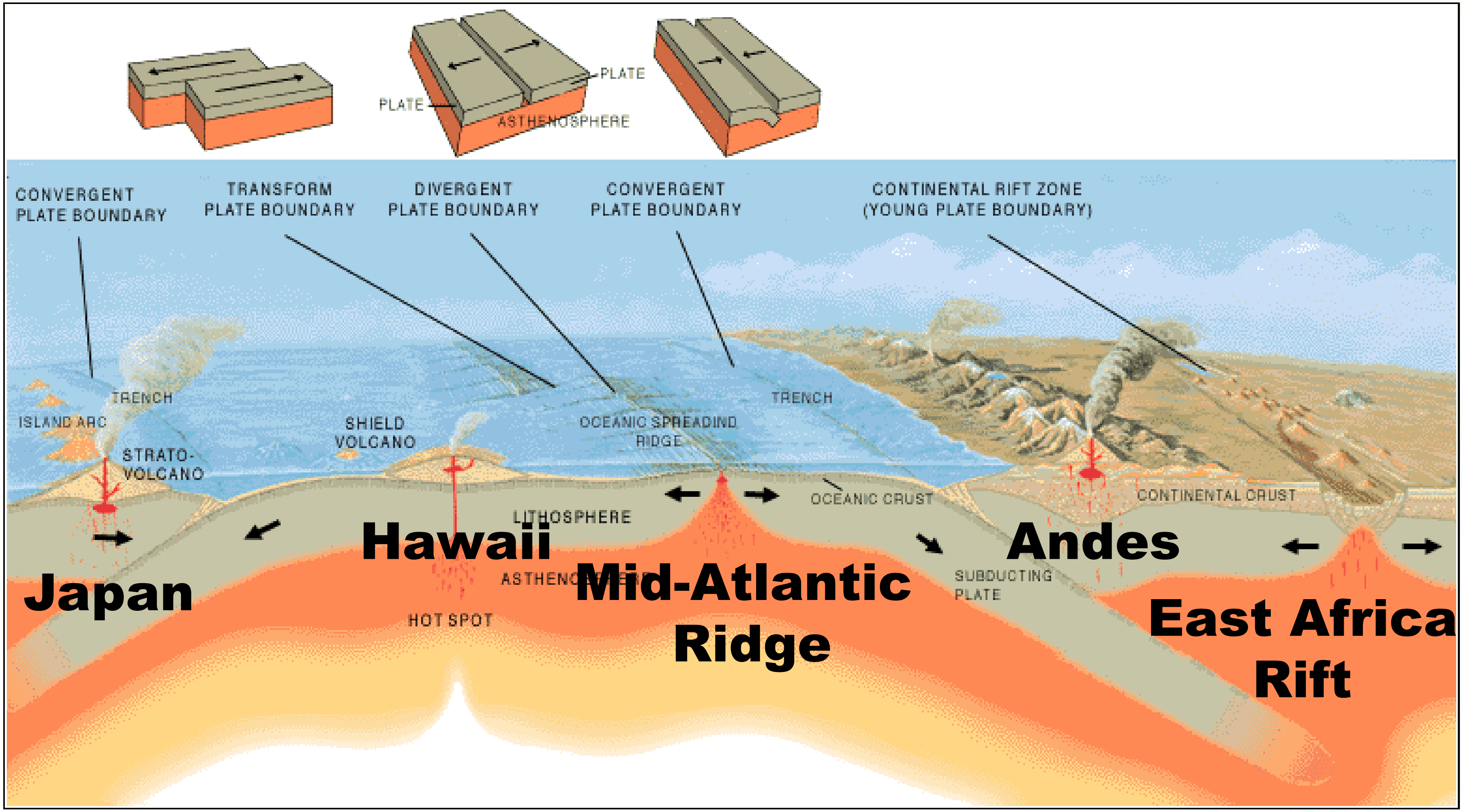
Uses the Earth's natural heat for:

- **Agricultural and industrial processes**
- **Electricity generation**
- **Space and hot water heating**



Hot rock is everywhere, but there are only a few places where it is hot enough (220° F) near the surface for extracting energy to be economical.

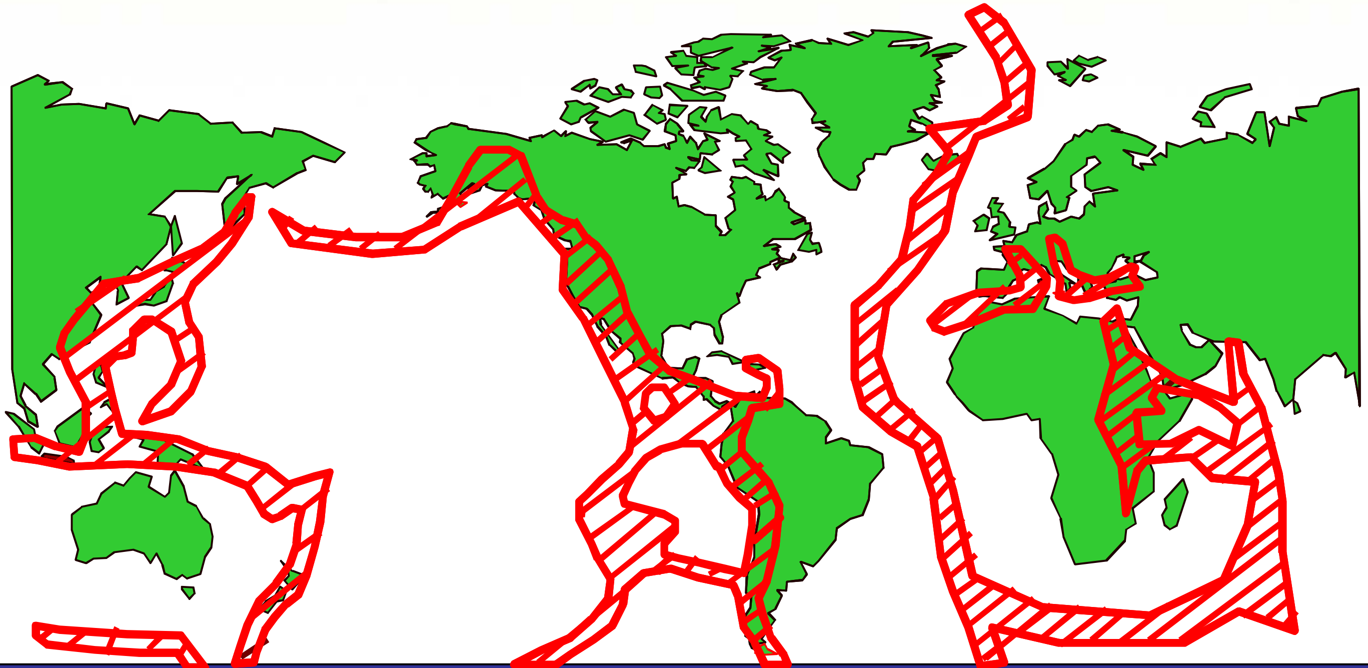
Tectonic Plate Boundaries



Source: Fraser

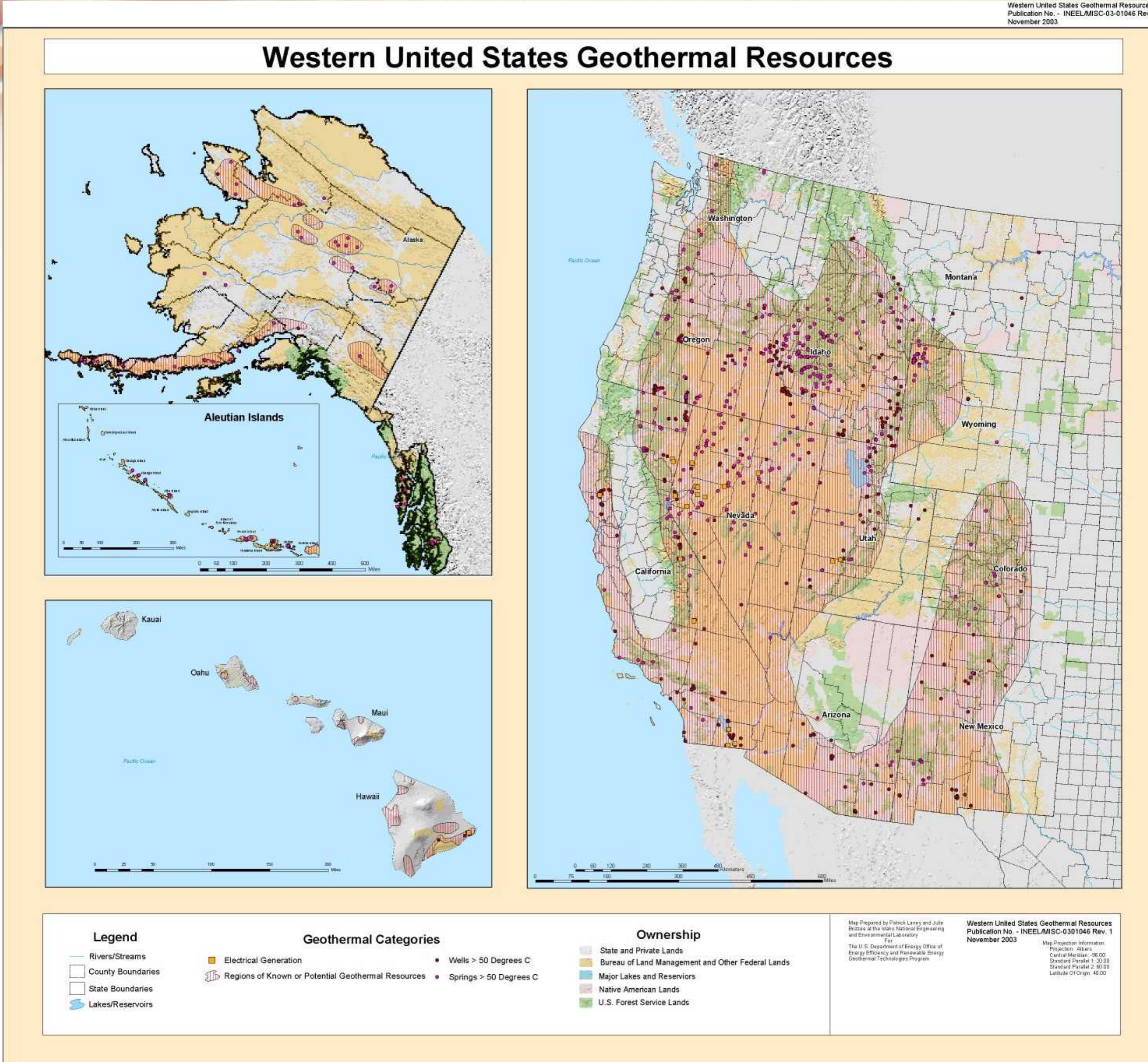
World Resource Map

Worldwide Geothermal Electric Potential



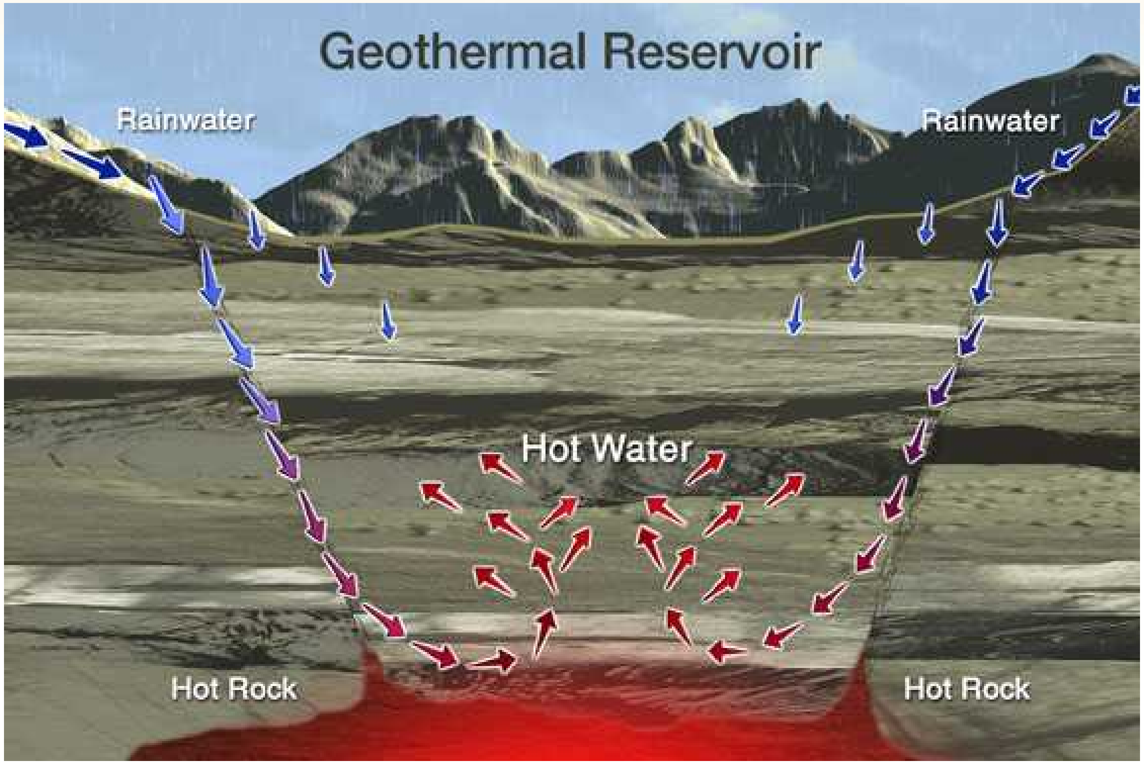
Countries with Potential of 1,000 MW or More

	Potential	Installed		Potential	Installed		Potential	Installed
Indonesia	19,650	144	El Salvador	2,000	105	Colombia	1,000	0
Philippines	8,000	888	Guatemala	2,000	0	Ecuador	1,000	0
Ethiopia	5,000	0	Nicaragua	2,000	70	Peru	1,000	0
Mexico	5,000	752	Kenya	1,700	45	Venezuela	1,000	0
Papua New Guinea	3,000	0	Argentina	1,000	0.6	Russia	1,000	11
Costa Rica	2,000	55	Chile	1,000	0	U.S.	20,000+	2733



Western United States Geothermal Resources
Publication No. - INEEL/MISC-03-01046 Rev. 1
November 2003
Western United States Geothermal Resources
Alaska
Aleutian Islands
Kauai
Oahu
Maui
Hawaii
Pacific Ocean
Washington
Oregon
Idaho
Montana
Wyoming
Nevada
Utah
California
Colorado
Arizona
New Mexico
Legend
Rivers/Streams
County Boundaries
State Boundaries
Lakes/Reservoirs
Geothermal Categories
Electrical Generation
Regions of Known or Potential Geothermal Resources
Wells > 50 Degrees C
Springs > 50 Degrees C
Ownership
State and Private Lands
Bureau of Land Management and Other Federal Lands
Major Lakes and Reserviors
Native American Lands
U.S. Forest Service Lands
Map Prepared by Patrick Laney and Julie Brizzee at the Idaho National Engineering and Environmental Laboratory
For
The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Geothermal Technologies Program
Western United States Geothermal Resources
Publication No. - INEEL/MISC-0301046 Rev. 1
November 2003
Map Projection Information:
Projection: Albers
Central Meridian: -96.00
Standard Parallel 1: 20.00
Standard Parallel 2: 60.00
Latitude Of Origin: 40.00

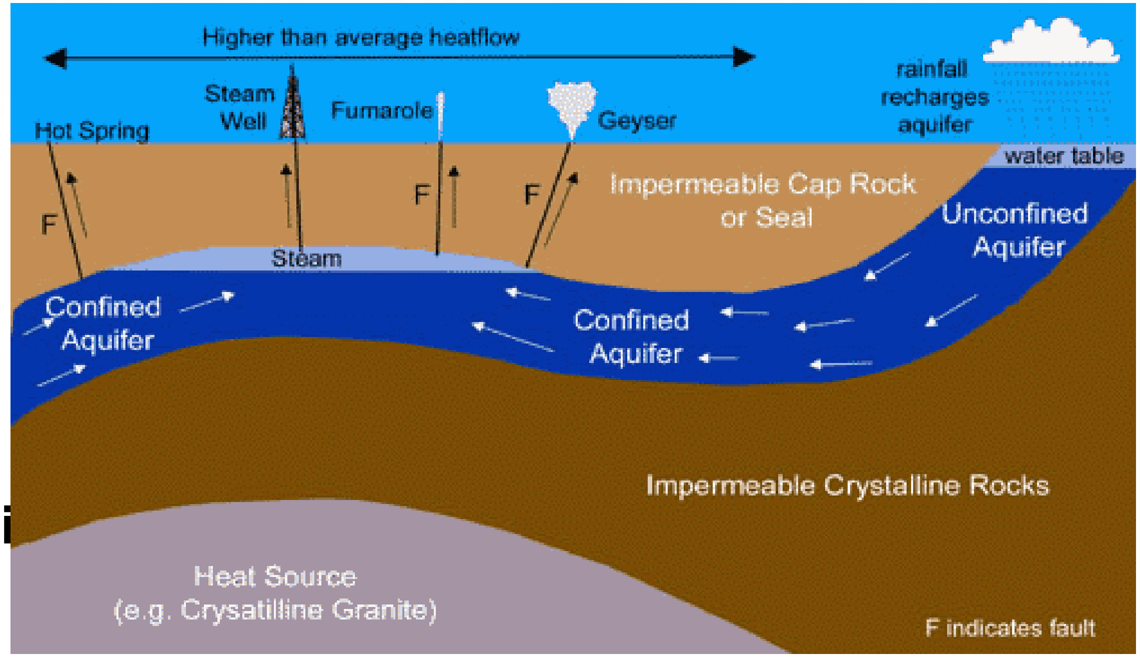
How Geothermal Sites Are Created



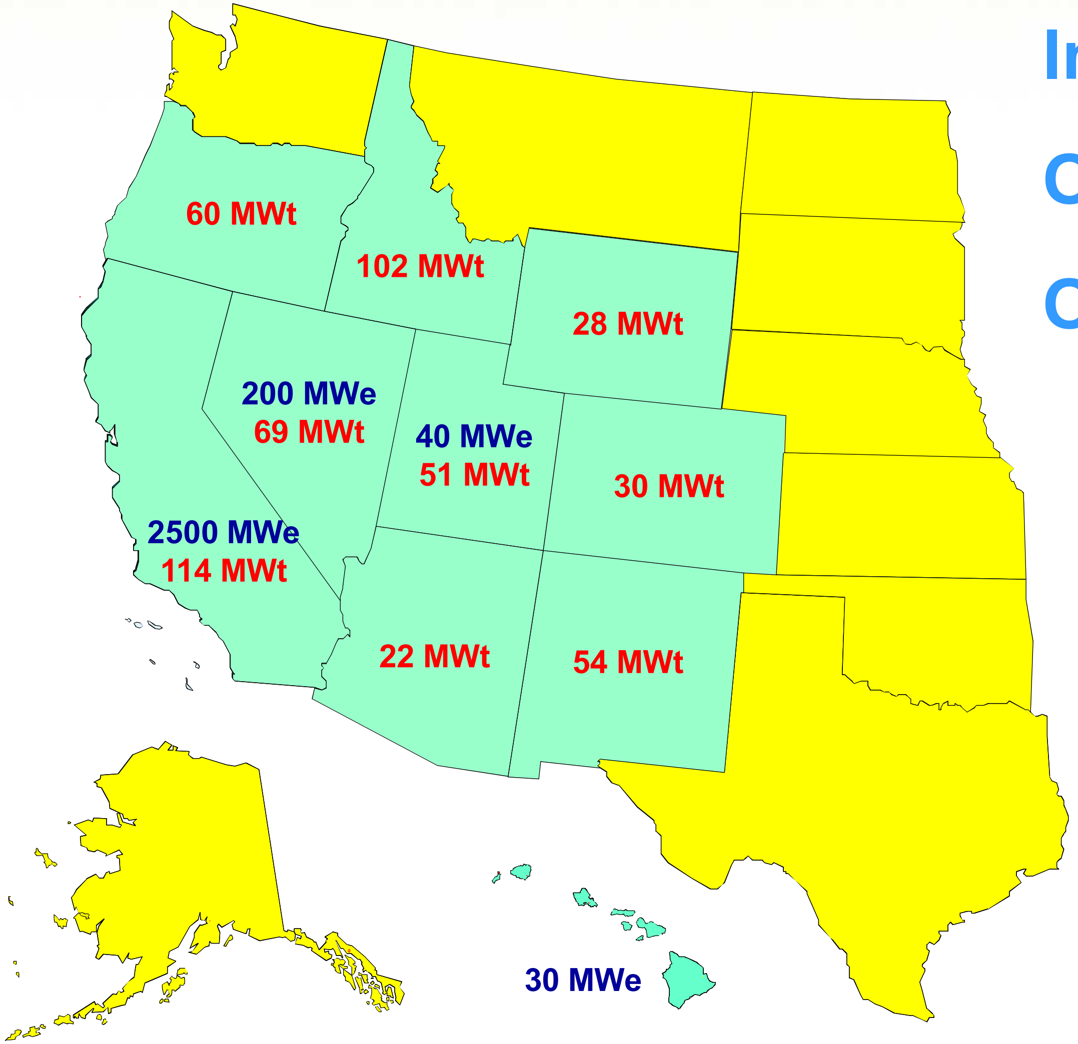
Geothermal resources are found where geological activity has brought hot rock near the surface. When hot water and steam is trapped under a layer of impermeable rock, it forms a geothermal reservoir.

Generic Geothermal Site

Geothermal resources are typically found where hot rock or magma has come near the surface through geologic activity. We gain access to the resource by drilling into i manifestation, such as a



Heat and Power for the 21st Century



Installed:

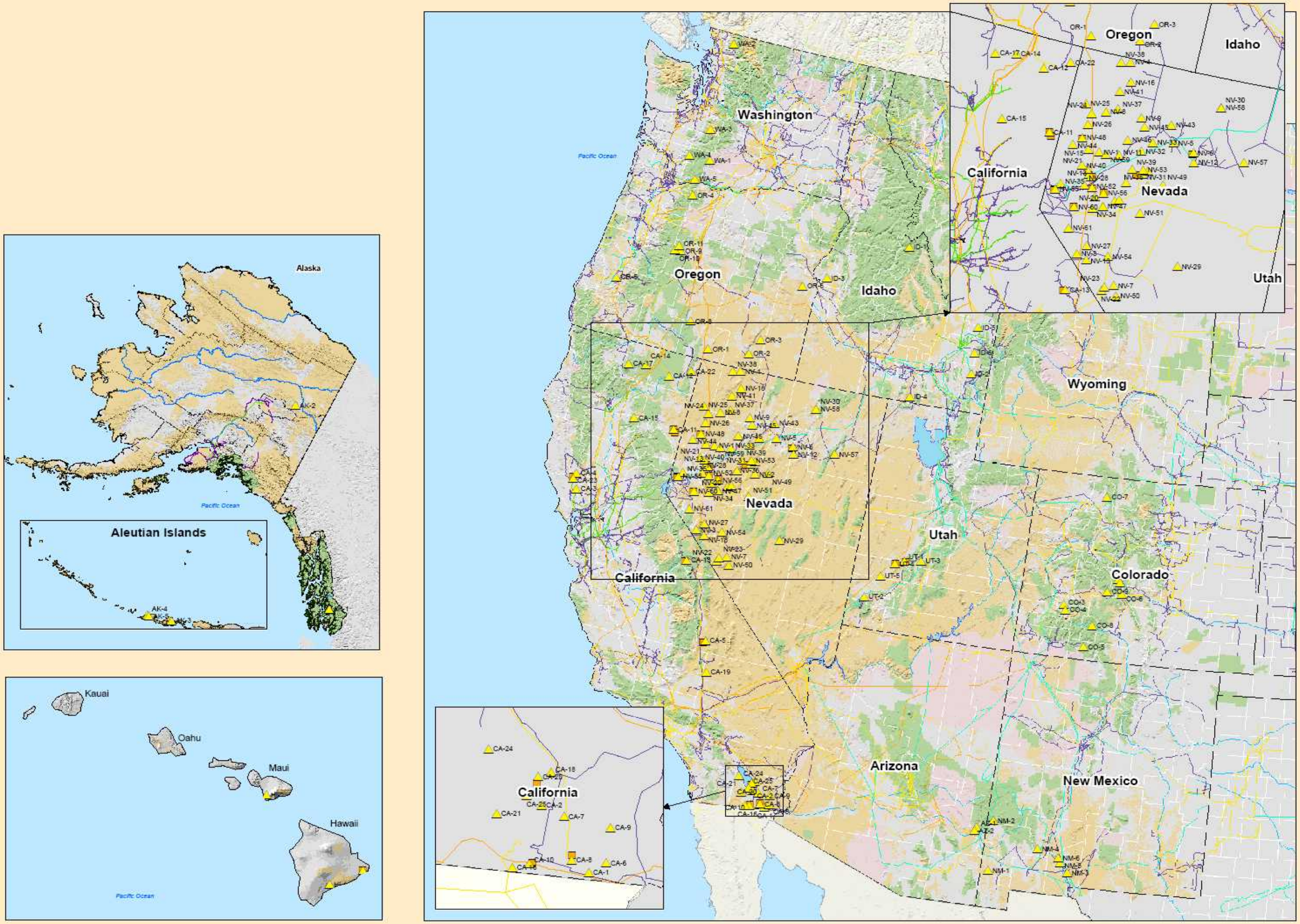
Over 2800 MW (electric)

Over 500 MW (heat)

Greater Than 20 MW

Less than 20 MW

Geothermal Power Potential in the Western United States



Legend

- Rivers/Streams
- County Boundaries
- Lakes/Reservoirs
- Electrical Generation
- Resource Sites
- 100 to 138 kv
- 161 to 220 kv
- 230 kv
- 240 to 287 kv
- 345 kv
- 360 to 765 kv

Ownership

- State and Private Lands
- Bureau of Land Management and Other Federal Lands
- Major Lakes and Reservoirs
- Native American Lands
- U.S. Forest Service Lands

Map Prepared by Patrick Laney and Julie Brizzee at the Idaho National Laboratory For The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Geothermal Technologies Program

Western United States Geothermal Resources
August 15, 2005

Map Projection Information:
Projection: Albers
Central Meridian: -96.00
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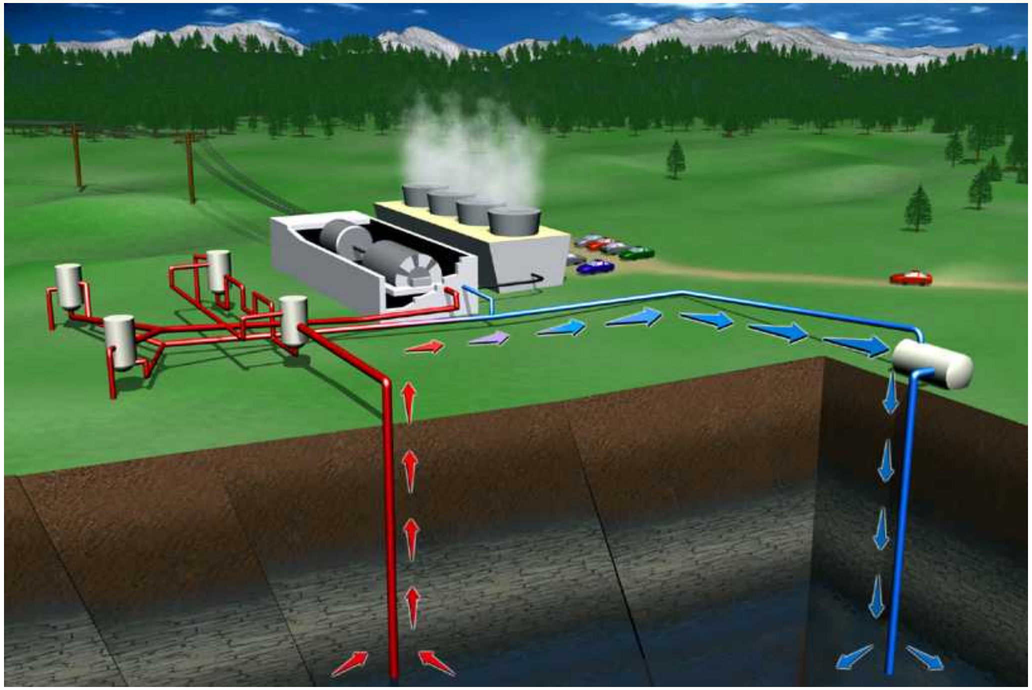
Standard Parallel 2: 60.00
Latitude Of Origin: 40.00

KEY	RESOURCE NAME
AK-1	Bailey Bay Hot Springs
AK-2	Circle
AK-3	Dutch Harbor
AK-4	Geyser Bight
AK-5	Hot Springs Cove
AZ-1	Clifton Hot Springs
AZ-2	Gillard Hot Springs
CA-1	Border
CA-2	Brawley
CA-3	Calistoga Hot Springs
CA-4	Clear Lake Volcanic Field Area
CA-5	Coso Area
CA-6	Dunes
CA-7	East Brawley
CA-8	East Mesa
CA-9	Glamis
CA-10	Heber
CA-11	Honey Lake & Wendel & Amidy
CA-12	Kelly Hot Springs
CA-13	Long Valley Caldera
CA-14	Medicine Lake
CA-15	Morgan Springs-Growler Springs
CA-16	Mount Signal
CA-17	Mt Shasta - Military Pass Road Area
CA-18	Niland
CA-19	Randsburg Area
CA-20	Salton Sea Area
CA-21	Superstition Mountain
CA-22	Surprise Valley / Lake City
CA-23	The Geysers
CA-24	Truckhaven
CA-25	Westmorland
CO-1	Cottonwood Hot Springs
CO-2	Mt. Princeton Hot Springs
CO-3	Orvis Hot Springs
CO-4	Ouray
CO-5	Pagosa Springs
CO-6	Poncha Hot Springs
CO-7	Routt Hot Springs
CO-8	Wagon Wheel Gap
CO-9	Waunita Hot Springs
HI-1	Kilauea Southwest Rift
HI-2	Maui
HI-3	Puna (including Kamalii & Kapoho)
ID-1	Big Creek Hot Springs
ID-2	China Cap
ID-3	Crane Creek-Cove Creek Area
ID-4	Raft River
ID-5	Rexburg
ID-6	Willow Springs
NM-1	Lightning Dock
NM-2	Lower Rio Grande Rift
NM-3	Lower San Francisco Hot Springs
NM-4	McGregor
NM-5	Radium Hot Springs
NM-6	San Diego
NV-1	Adobe Valley
NV-2	Antelope
NV-3	Aurora
NV-4	Baltazor Hot Springs
NV-5	Battle Mountain
NV-6	Beowawe Hot Springs
NV-7	Big Smoky Valley
NV-8	Black Rock Desert
NV-9	Blue Mountain
NV-10	Brady Hot Springs
NV-11	Colado
NV-12	Cressent Valley
NV-13	Desert Peak Area
NV-14	Dixie Valley
NV-15	Dry Lake
NV-16	Dyke Hot Springs
NV-17	Elevenmile Canyon
NV-18	Excelsior
NV-19	Fallon / Carson Lake
NV-20	Fallon-Salt Wells
NV-21	Fireball Ridge
NV-22	Fish Lake
NV-23	Fish Lake Valley - Emigrant Peak
NV-24	Fly Ranch (Granite Ranch)
NV-25	Fox Mountain
NV-26	Great Boiling Springs (Gerlach)
NV-27	Hawthorne
NV-28	Hazen (Black Butte)
NV-29	Hot Creek Canyon
NV-30	Hot Sulphur Springs
NV-31	Hot Sulphur Springs (Tuscarora)
NV-32	Hyder Hot Springs
NV-33	Kyle Hot Springs (Granite Mtn)
NV-34	Leach Hot Springs
NV-35	Lee & Allen Hot Springs
NV-36	Lockwood
NV-37	McCoy Mine
NV-38	Mcfarlanes
NV-39	McGee Mountain
NV-40	New York Canyon
NV-41	North Valley / Black Warrior Peak
NV-42	Pinto Hot Springs
NV-43	Pirouette Mountain
NV-44	Pumpernickel Valley
NV-45	Pyramid Lake Indian Reserve
NV-46	Rose Creek
NV-47	Rye Patch (Humboldt House District)
NV-48	Salt Wells
NV-49	San Emidio Desert Area (Empire)
NV-50	Shoshone
NV-51	Shoshone-Reese River
NV-52	Silver Peak
NV-53	Smith Creek Valley Area
NV-54	Soda Lake Area
NV-55	Sou Hot Springs
NV-56	Southern Pacific
NV-57	Steamboat Springs
NV-58	Stillwater Area
NV-59	Sulfur (Double - Black Rk Hot Springs)
NV-60	Sulphur Hot Spring
NV-61	Trinity Mountains
NV-62	Wabuska Hot Springs
NV-63	Wilson Hot Spring
OR-1	Crump's Hot Springs
OR-2	Lakeview /Hot Lake Area
OR-3	Mickey Hot Springs
OR-4	Mt Hood (Excluding Park)
OR-5	Mt Rose (East)
OR-6	Neal Hot Springs
OR-7	Newberry Caldera
OR-8	Summer Lake
OR-9	Three Creek Butte
OR-10	Three Sisters
OR-11	Trout Creek Area
UT-1	Cove Fort-Sulphurdale
UT-2	Monroe-Red Hill Hot Springs
UT-3	Other (Monroe, Mineral Mtn, etc.)
UT-4	Roosevelt Hot Springs (McKeans)
UT-5	Thermo Hot Springs
WA-1	Mt Adam Area
WA-2	Mt Baker Area
WA-3	Mt Rainer Area
WA-4	Mt St Helen Area
WA-5	Wind River Area

Geothermal Applications



Courtesy of Geothermal Education Association

Electricity Generation
- Central Station Power
- Distributed Power

Mineral Recovery
- Zinc
- Silica

Heat Production
- District Heating
- Industrial Process Heat
- Agriculture
- Aquaculture

Two Kinds of Geothermal Application

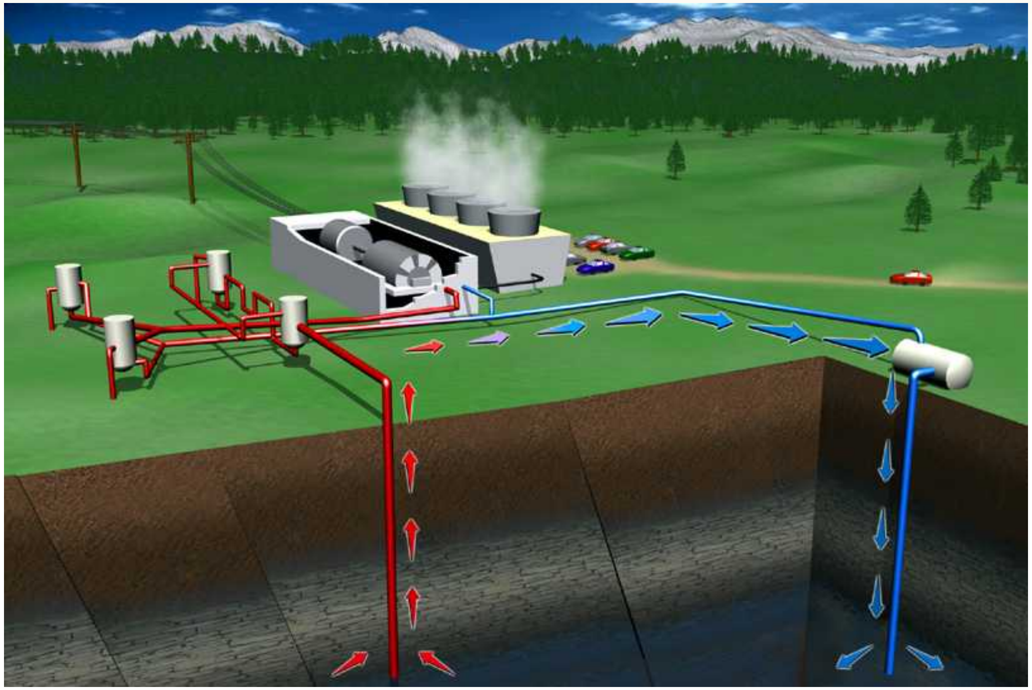
Direct Use

(30-acre Greenhouse, NM)

Power Generation

(The Geysers, CA)

Geothermal Applications



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Electricity Generation

- Central Station Power
- Distributed Power

Mineral Recovery

- Zinc
- Silica

Heat Production

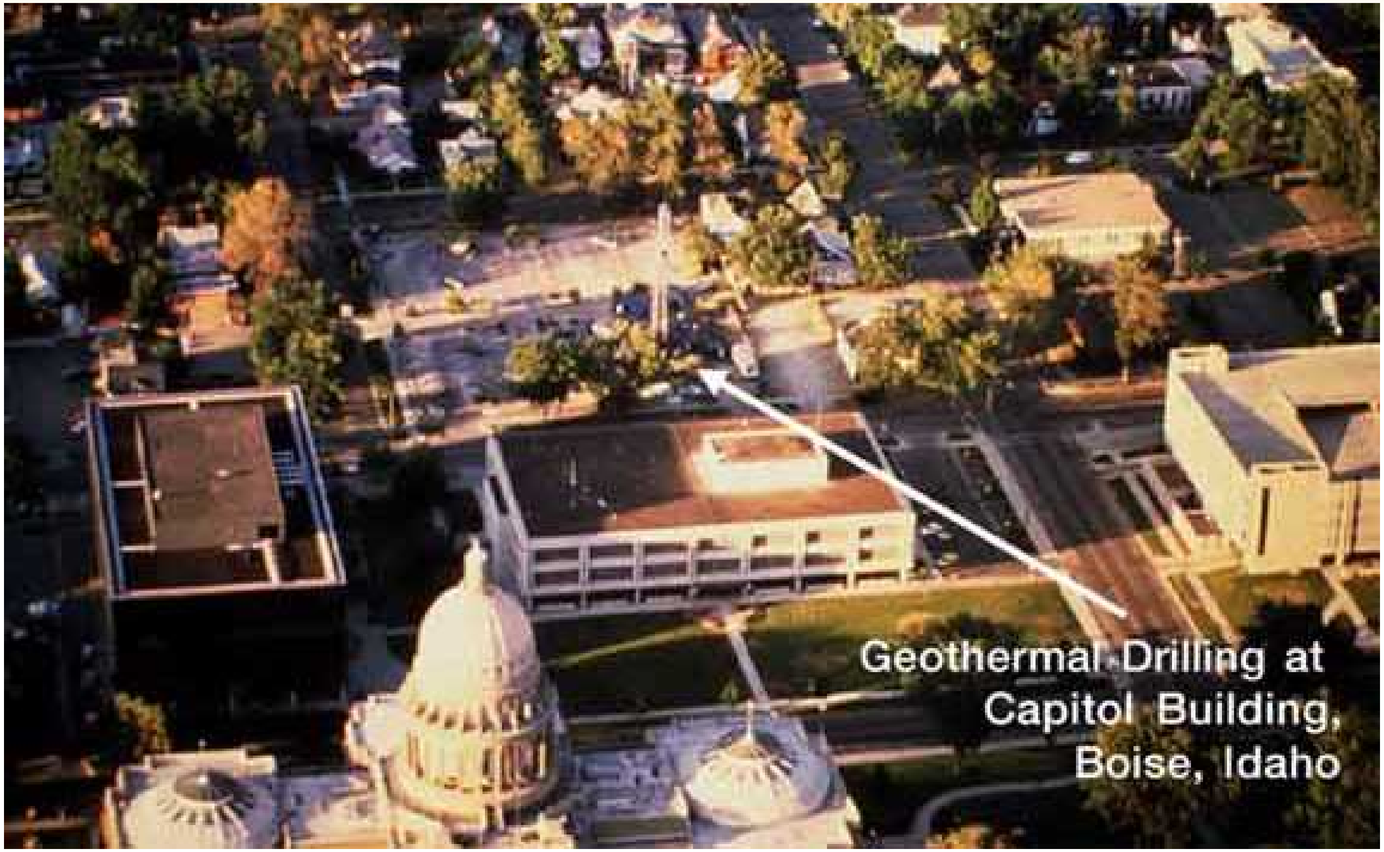
- District Heating
- Industrial Process Heat
- Agriculture
- Aquaculture

Direct Use Applications

Direct use displaces about 1.6M barrels of oil annually in the United States.

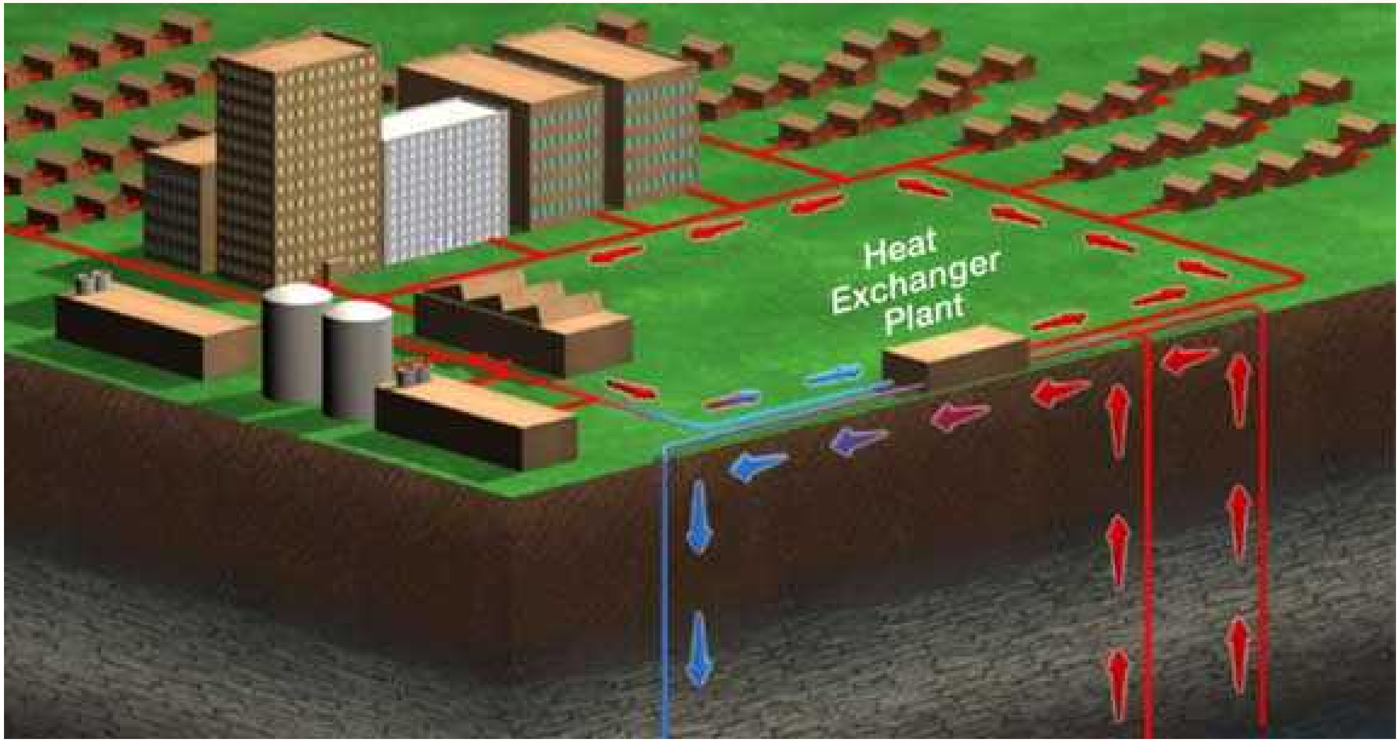
- District Heating
- Process Heat
- Agriculture
- Aquaculture
- Balneology (hot spring and water bathing)

District Heating Applications



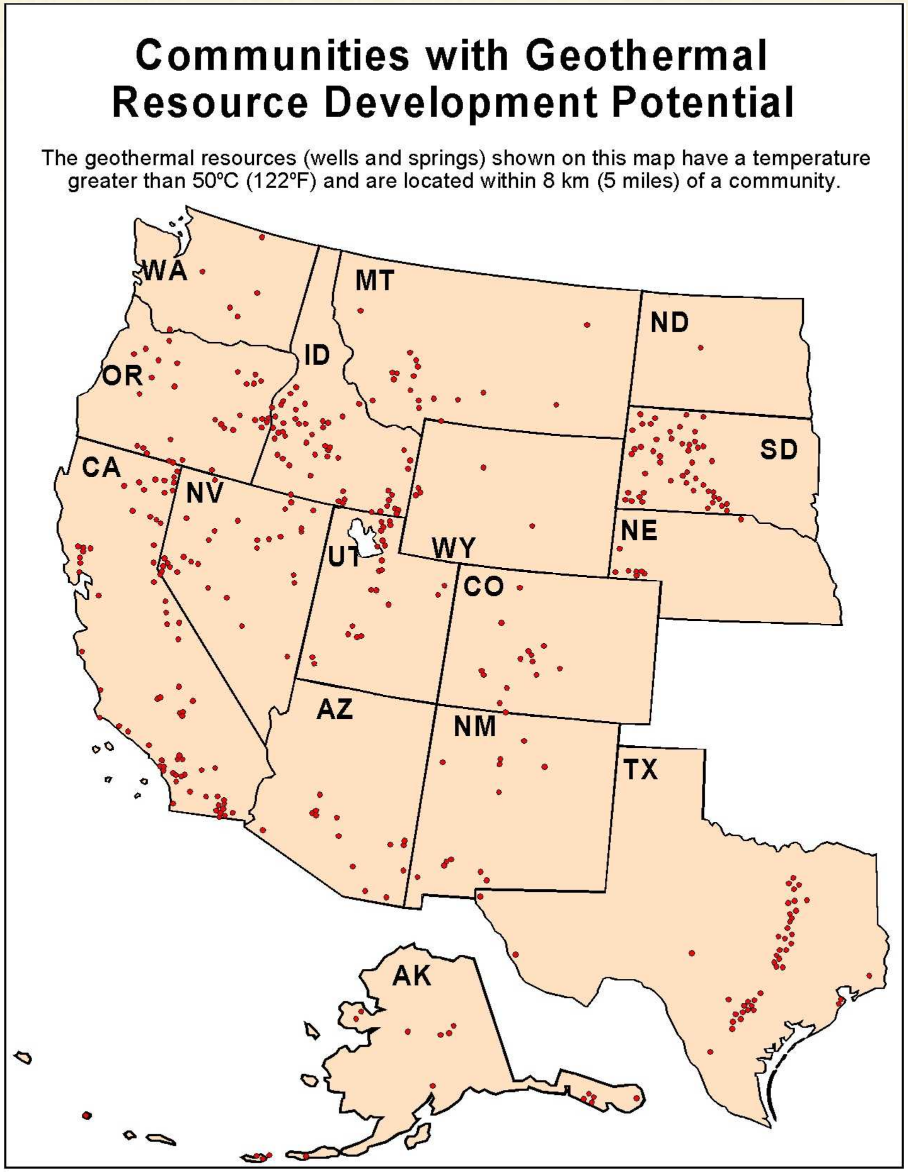
There are 18 district heating systems operating in the western United States. Over 270 U.S. cities are close enough to geothermal reservoirs to use district heating.

District Heating



Courtesy of Geothermal Education Association

Hot water from one or more geothermal wells is piped through a heat exchanger to heat water in separate pipes. The hot water is used in radiators to warm the air.

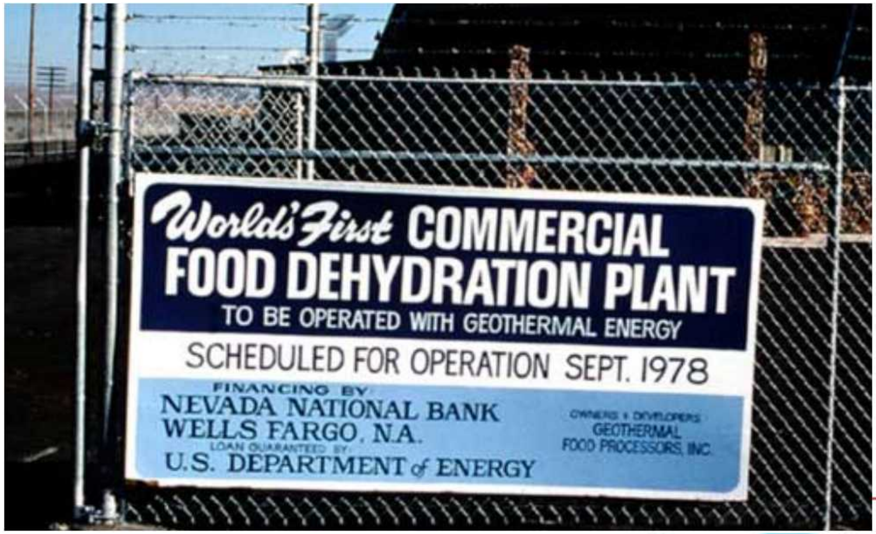


Source: Geo Heat Center

Geothermal Greenhouses in New Mexico

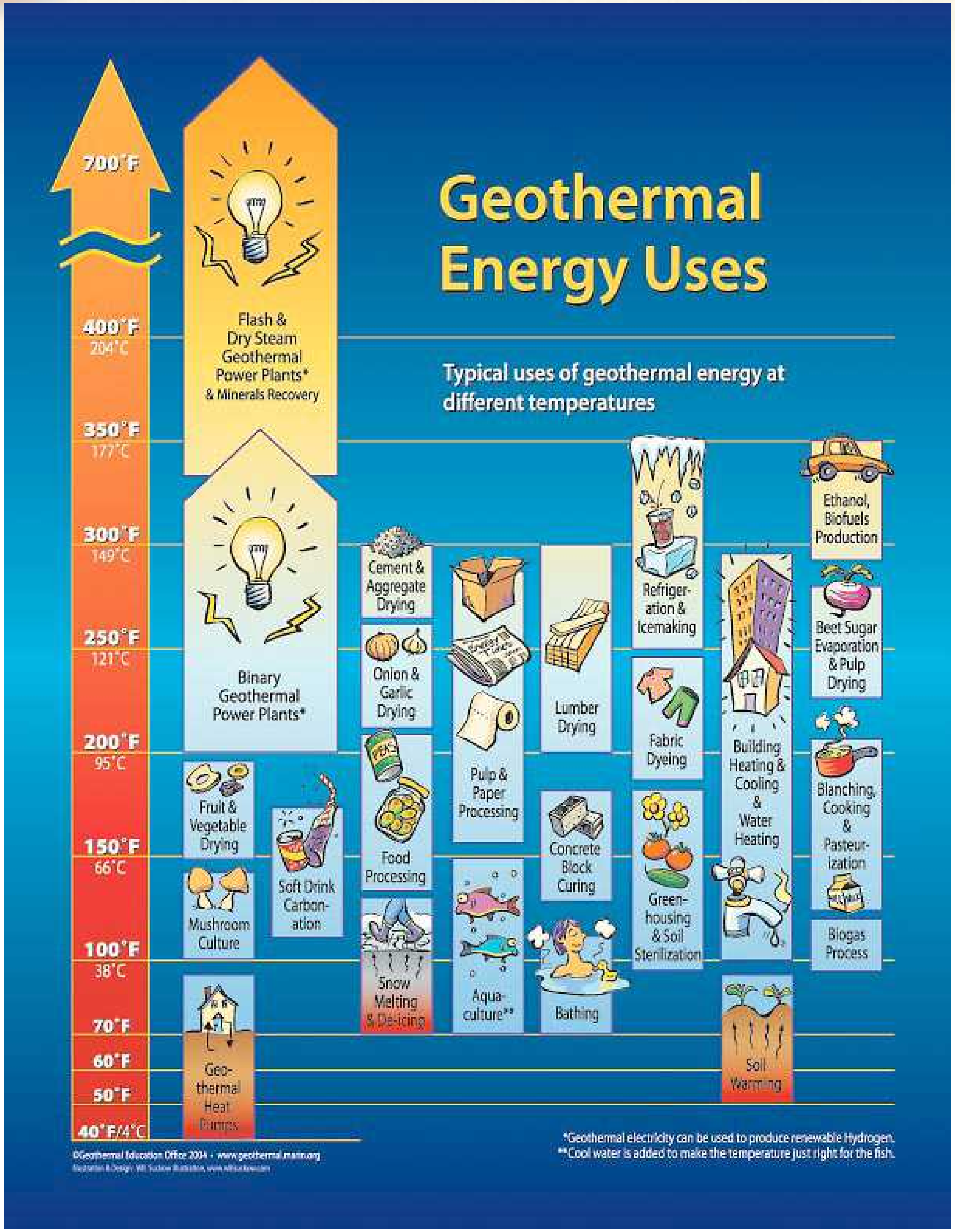
Greenhouses such as this one in New Mexico can be heated with geothermal water. Plants grow faster and larger when they have additional heat.

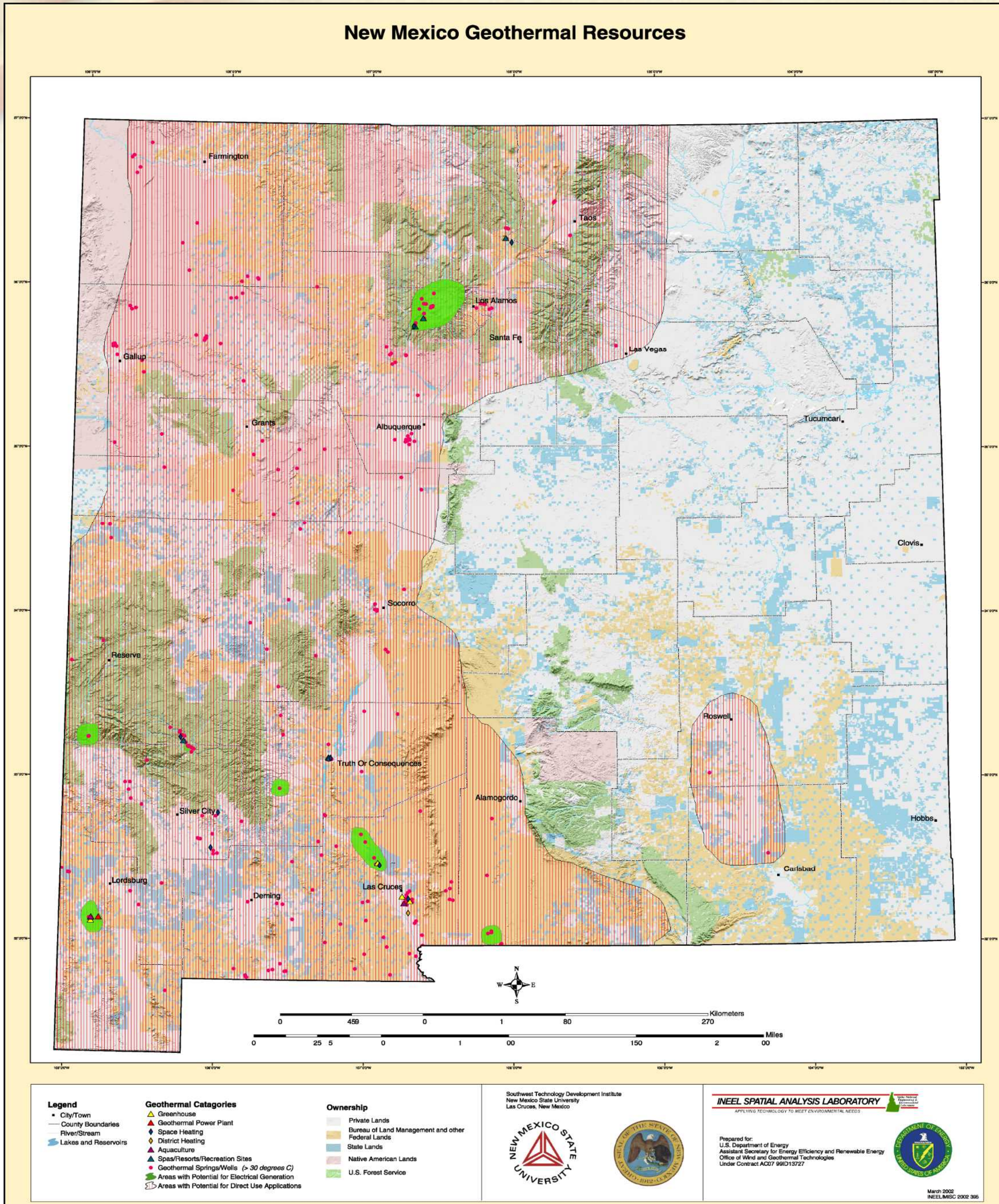
A prawn grown in geothermally heated water at the GeoHeat Center, Oregon Institute of Technology.



Geothermal energy is also used for industrial drying. This plant in Brady, Nevada, provides dried onions to Burger King.

Geothermal Applications in Summary





National Nuclear Security Administration

Sandia National Laboratories

Attributes of Geothermal Power

Advantages

- Enormous potential
- High, reliable plant capacity factor
- Greenhouse gas reduction
- Low environmental impact
- Much mature technology

Disadvantages

- Expensive drilling
- Regional resource
- Resource uncharacterized
- Threshold plant size
- Plant prefers constant load
- Environmental perception

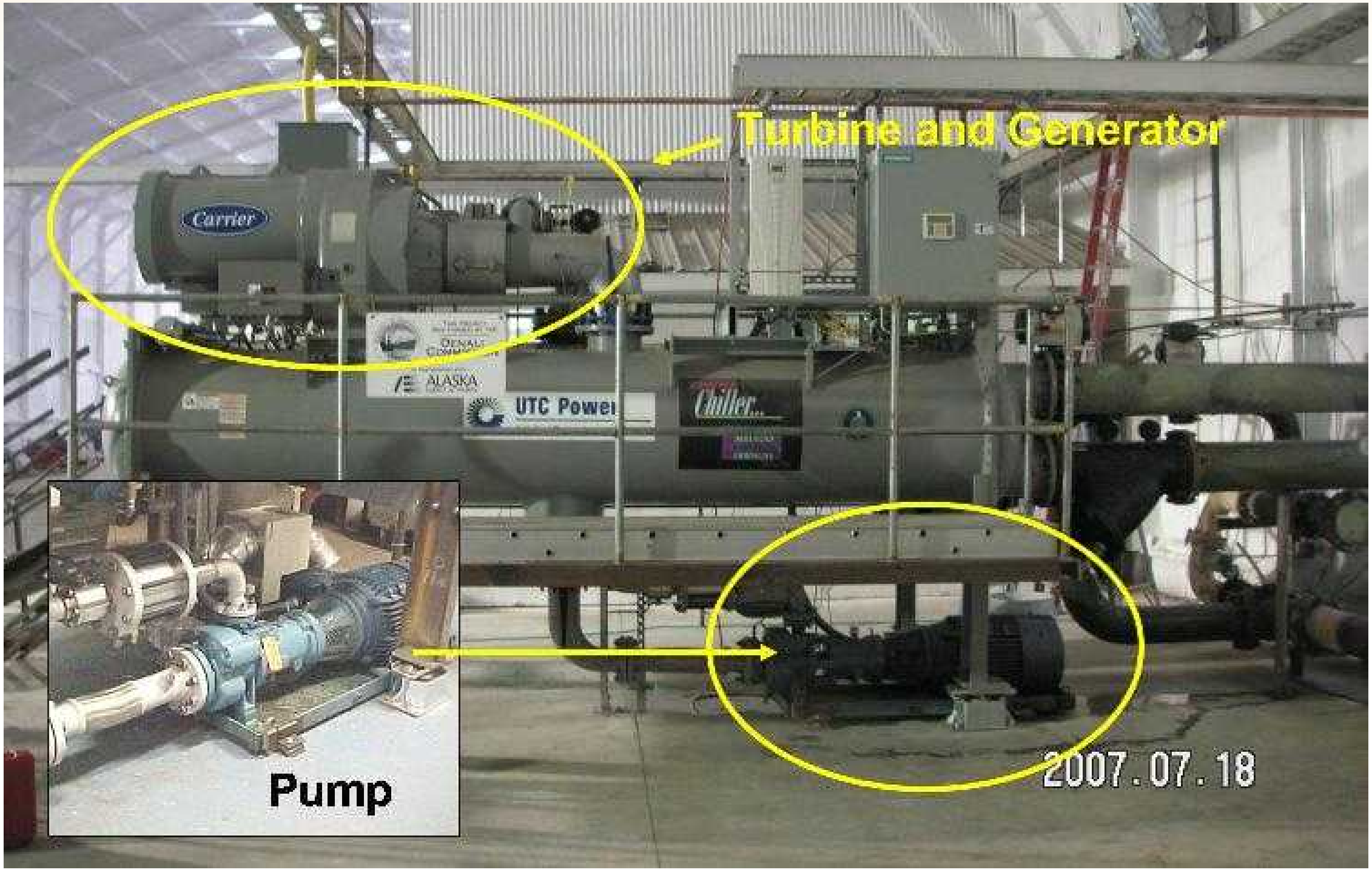
Significant Energy Production

Geothermal power plants produce almost 5% of California's electricity (12.8 million MWh in 1999)

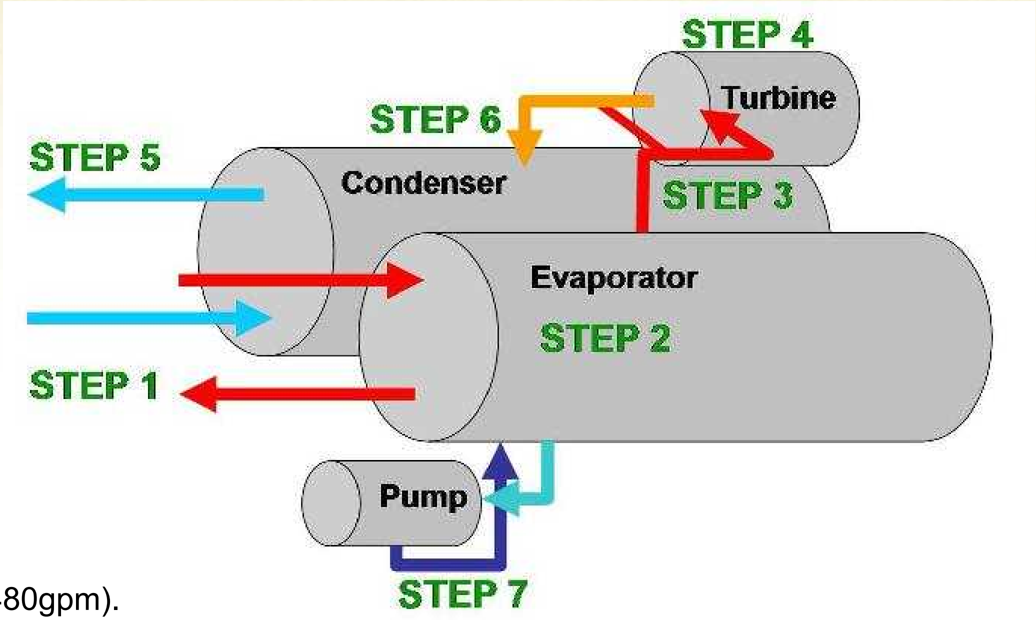
This hybrid binary/flash power plant provides about 25% of electricity demand on the Big Island of Hawaii


First Geothermal Power Plant, 1904, Larderello, Italy

Prince Piero Ginori Conti invented the first geothermal power plant in 1904, at the Larderello dry steam field in Italy.



Source: Chena Hot Springs



STEP 1: Hot water enters the evaporator at 165ºF (480gpm).

STEP 2: The evaporator shell is filled with R-134a, The 165ºF water entering the evaporator is hot enough to boil the R-134a refrigerant.

STEP 3: The vapor bypasses the turbine or is routed to the turbine and returns directly to the condenser once there is adequate boiling/evaporation.

STEP 4: The vapor is expanded, causing the turbine blades to turn at 13,500rpm. The turbine is connected to a generator, which it spins at 3600rpm, producing electricity.

STEP 5: Cooling Water (40ºF-45ºF) enters from our cooling water well (1500gpm) located 3000ft distant and 33ft higher elevation than the power plant.

STEP 6: The cooling water entering the condenser and recondenses the vapor refrigerant back into a liquid.

STEP 7: The pump pushes the liquid refrigerant back over to the evaporator, so the cycle can start again. By doing so, it also generates the pressure which drives the entire cycle.

Source: Chena Hot Springs

This binary power plant, at Wendell-Amadee, California, runs by itself. If it detects a problem, it automatically radios the operator to come to the site.

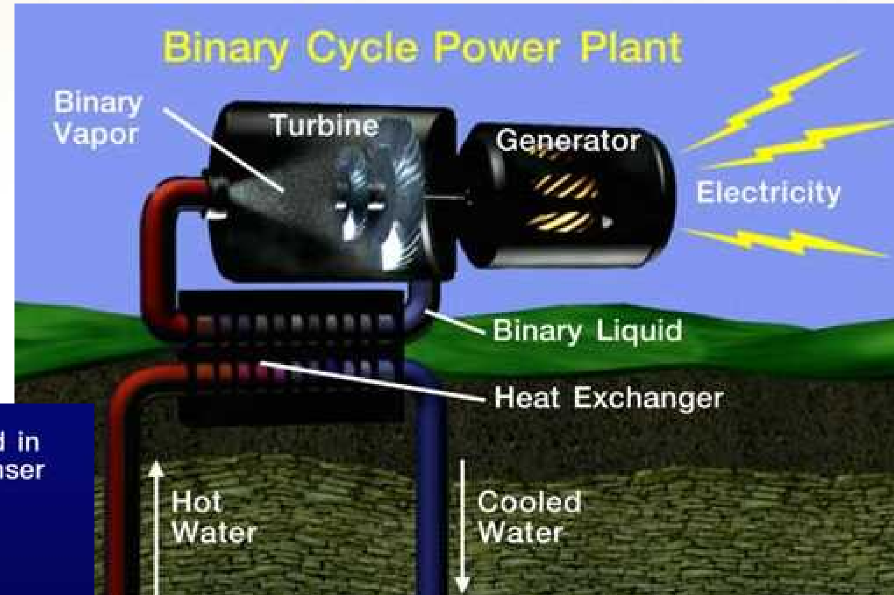
Source: GEO

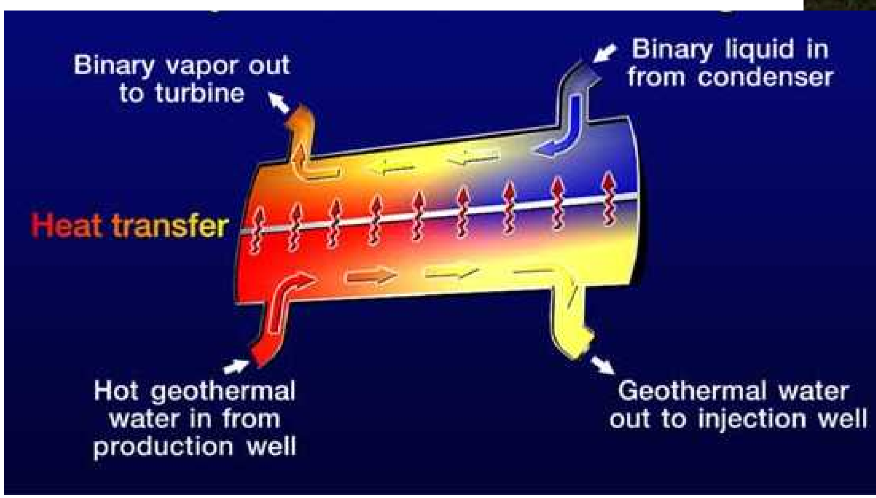
Ormat small power plant

This small binary power plant is in Fang, Thailand.

Binary Cycle Geothermal Plant

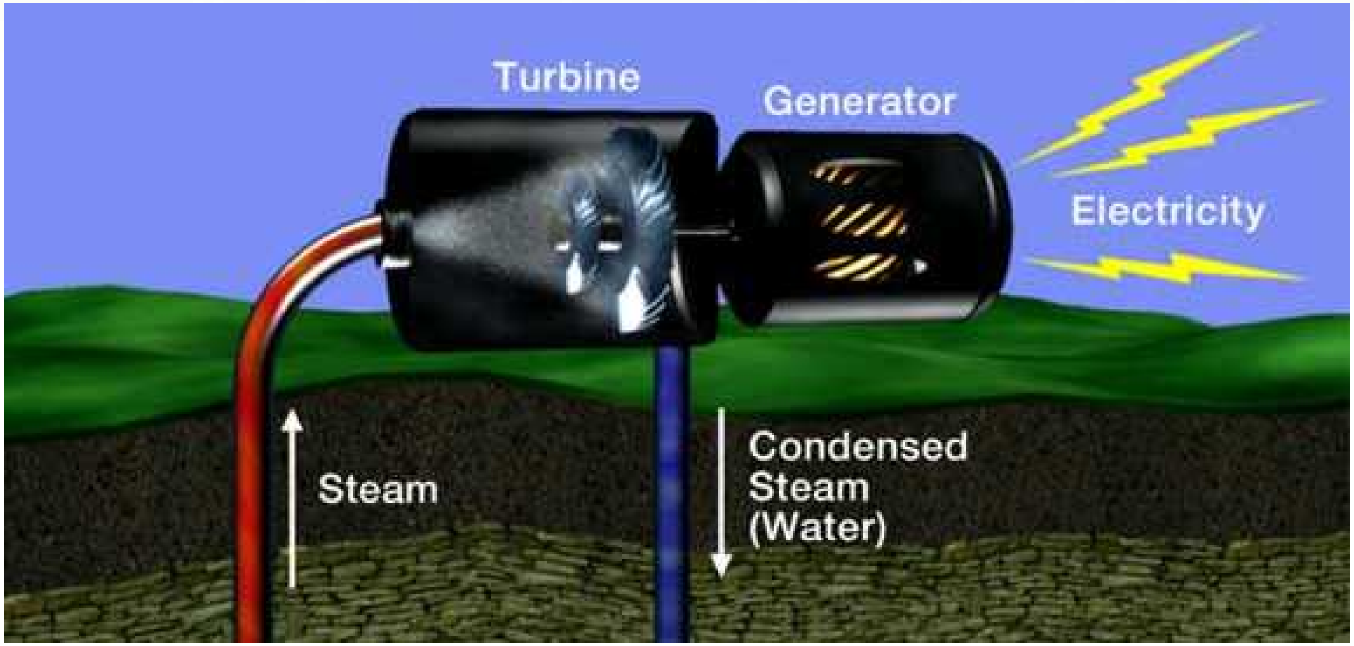
In a binary cycle plant, hot water is run through a heat exchanger to vaporize a working fluid that powers the turbine generator. The geothermal water is injected back into the reservoir.





This plate-type heat exchanger passes geothermal water over metal plates for heat transfer to the working fluid on the other side.

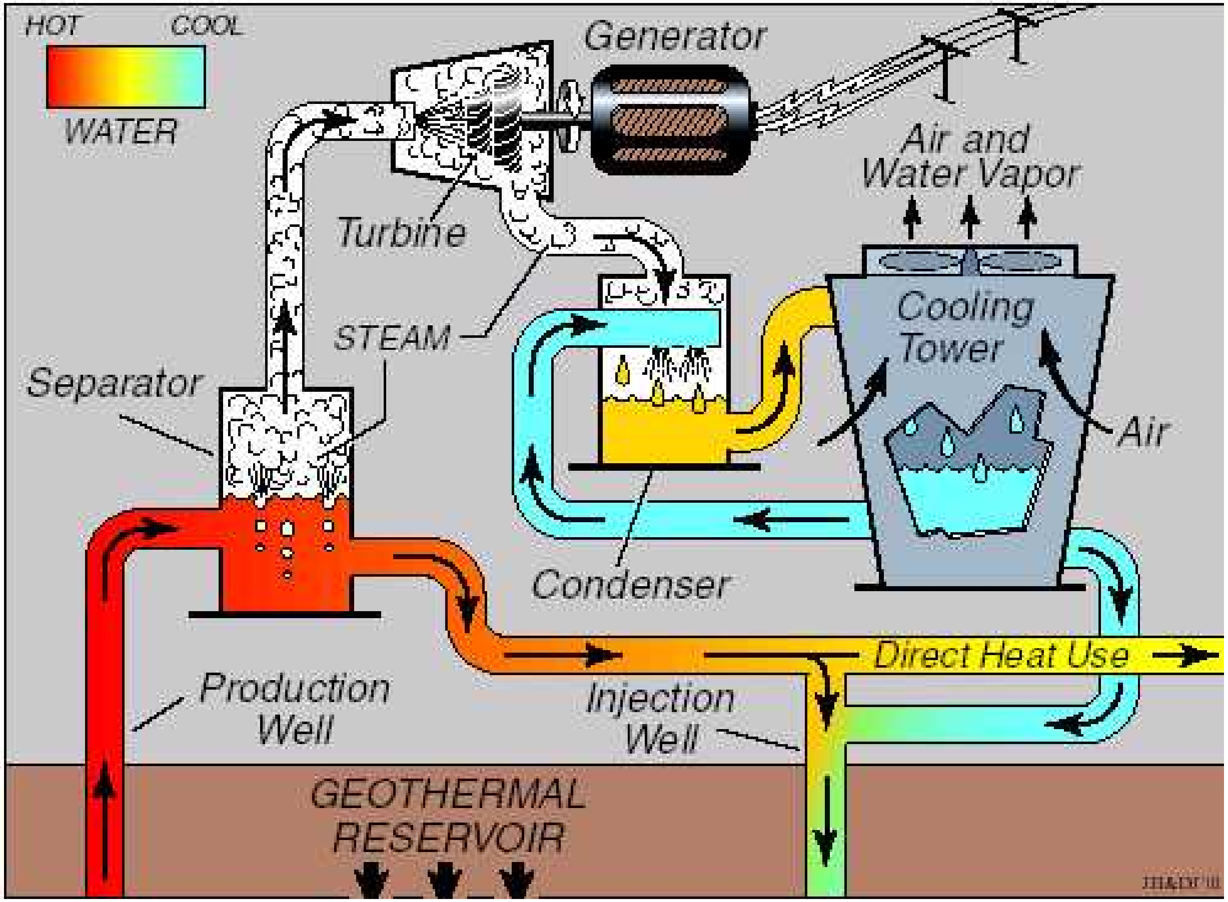
Dry Steam Power Plant



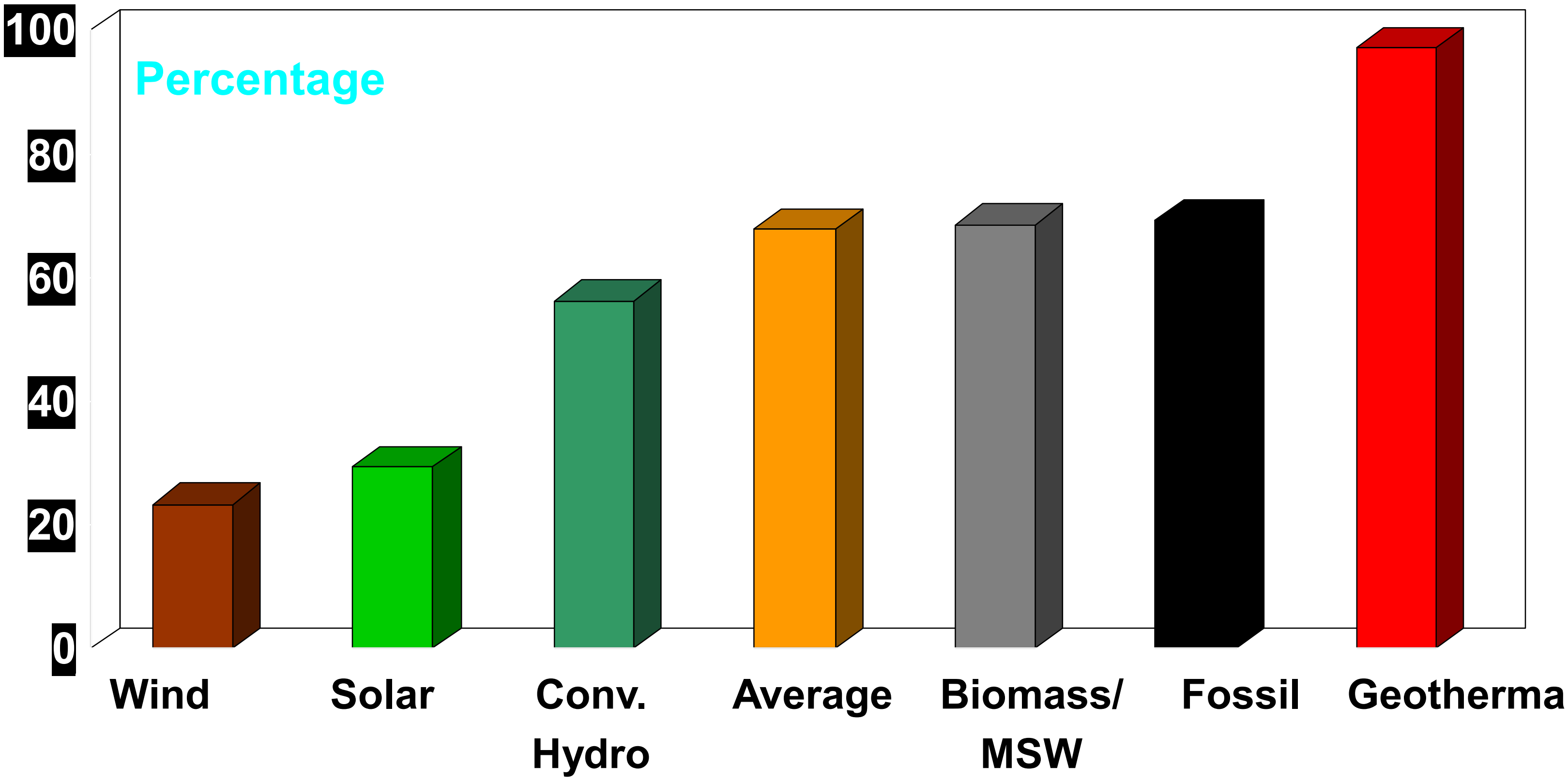
Courtesy of Geothermal Education Association

In dry steam power plants, the steam passes through a rock catcher (not shown) and then directly into the turbine. The steam spins the turbine blades, which spin the generator.

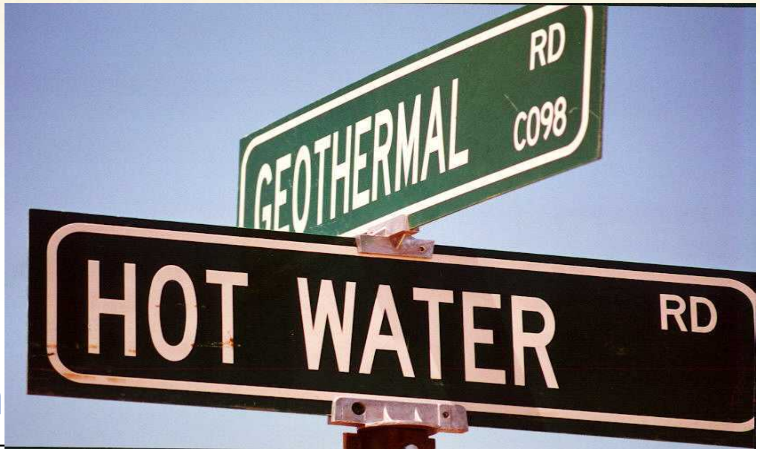
Geothermal Power Plant (flash)



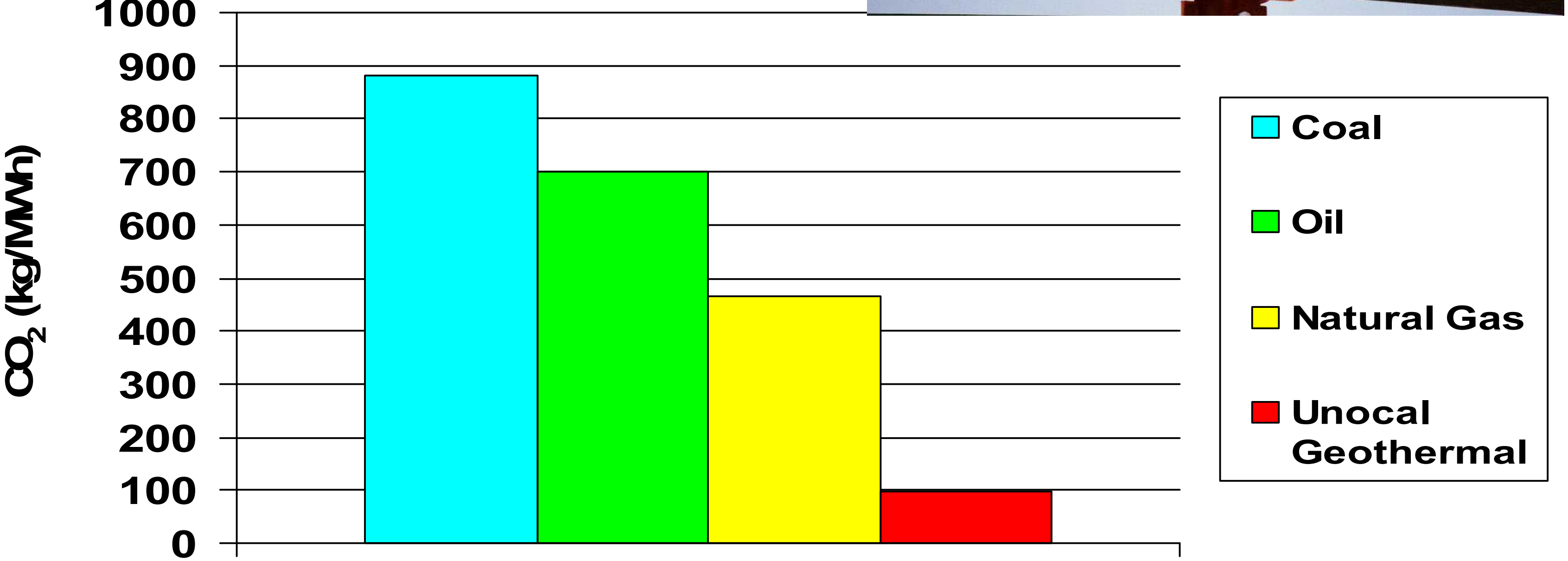
Capacity Factors



Source: DOE/Energy Information Agency: data for 1996



Power Plant CO_2 Emission



Fossil fuel data from Goddard and Goddard (1990)
Unocal data includes The Geysers

(EXAMPLE)

DRILLING AND WELL FIELD DEVELOPMENT

Medium risk – Investor Financing Possible

- Production/injection wells $1.0 to $3.0M each
- Production wells provide between 3MW and 30MW
- One injection well serves two or more production wells
- Well drilling success averages over 70%
- 3,000 foot average depth – Assume $1.5 M per well

20 MW Nevada project: 7 prod. & 3 inject. wells

Budget for 10 wells @3,000 feet depth is $15M
Timetable including permitting would be 12 to 18 months

Source: Ormat

(EXAMPLE)

PROJECT DEVELOPMENT BUDGET 20MW
Uses of Funds

Exploration & resource assessment	**$ 5.0 M**
Well field drilling and development	**15.0**
Power plant, surface facilities, & transm.	**30.0**
Financing "soft costs" including:	**5.0**

- **Commitment fees**
- **Legal & accounting fees**
- **Consultants, and**
- **Interest during construction**
- **Debt service and operating reserve**

TOTAL *FINANCED* COST FOR 20MW PROJECT **$ 55 M**

To be provided as construction phase financing

Source: Ormat

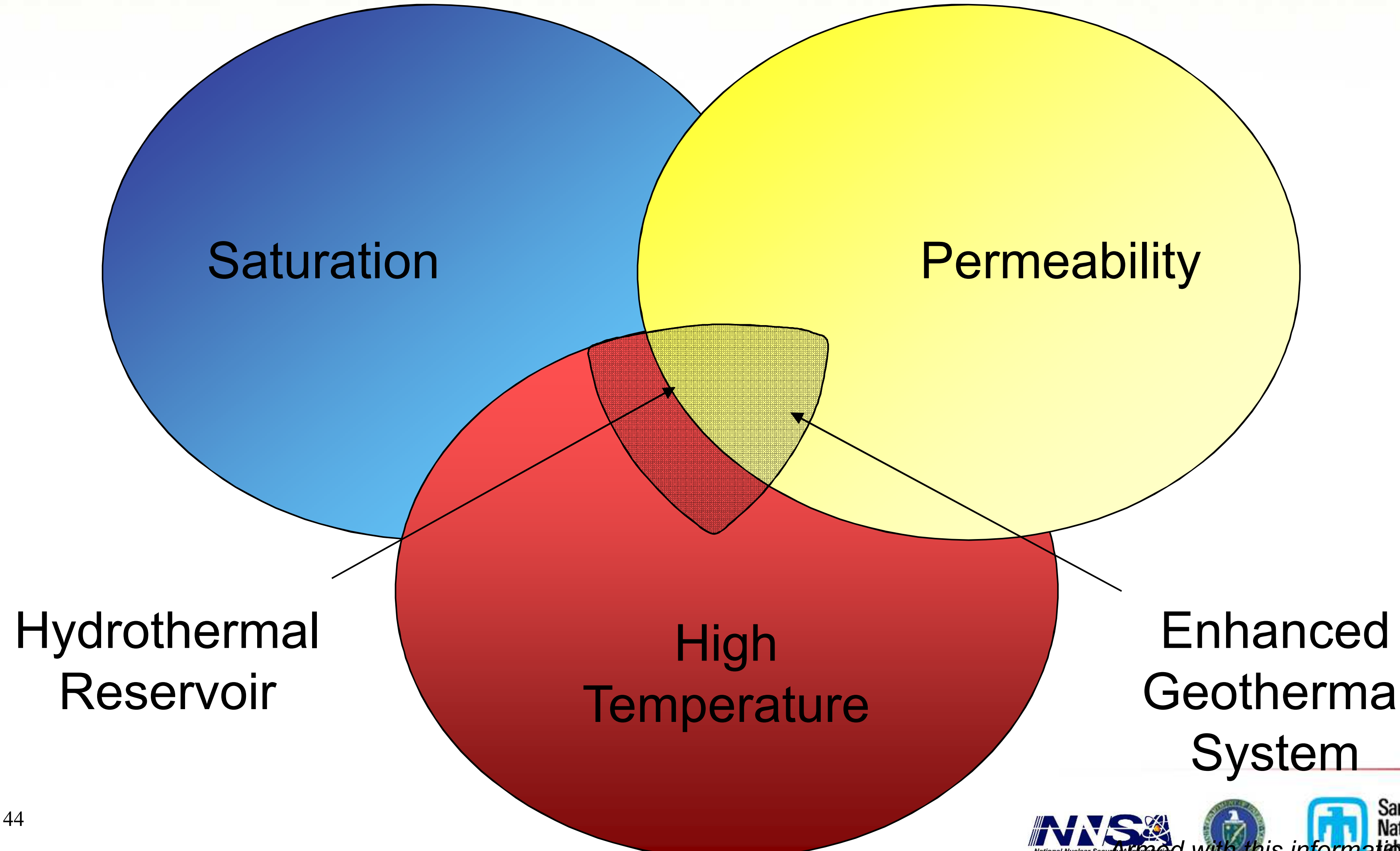
Challenges to Geothermal Development

- Competition with fossil fuels
- Financing
- Long project lead times
- Siting and Permitting
- Obvious sites already taken
- Industry focus overseas
- Large projects at high costs
- Exploration cost and risk

Research Needs

- Cheaper drilling
- Better reservoir exploration and identification
- Better reservoir evaluation and management
- More efficient power plants for lower temperatures

Geothermal Domains

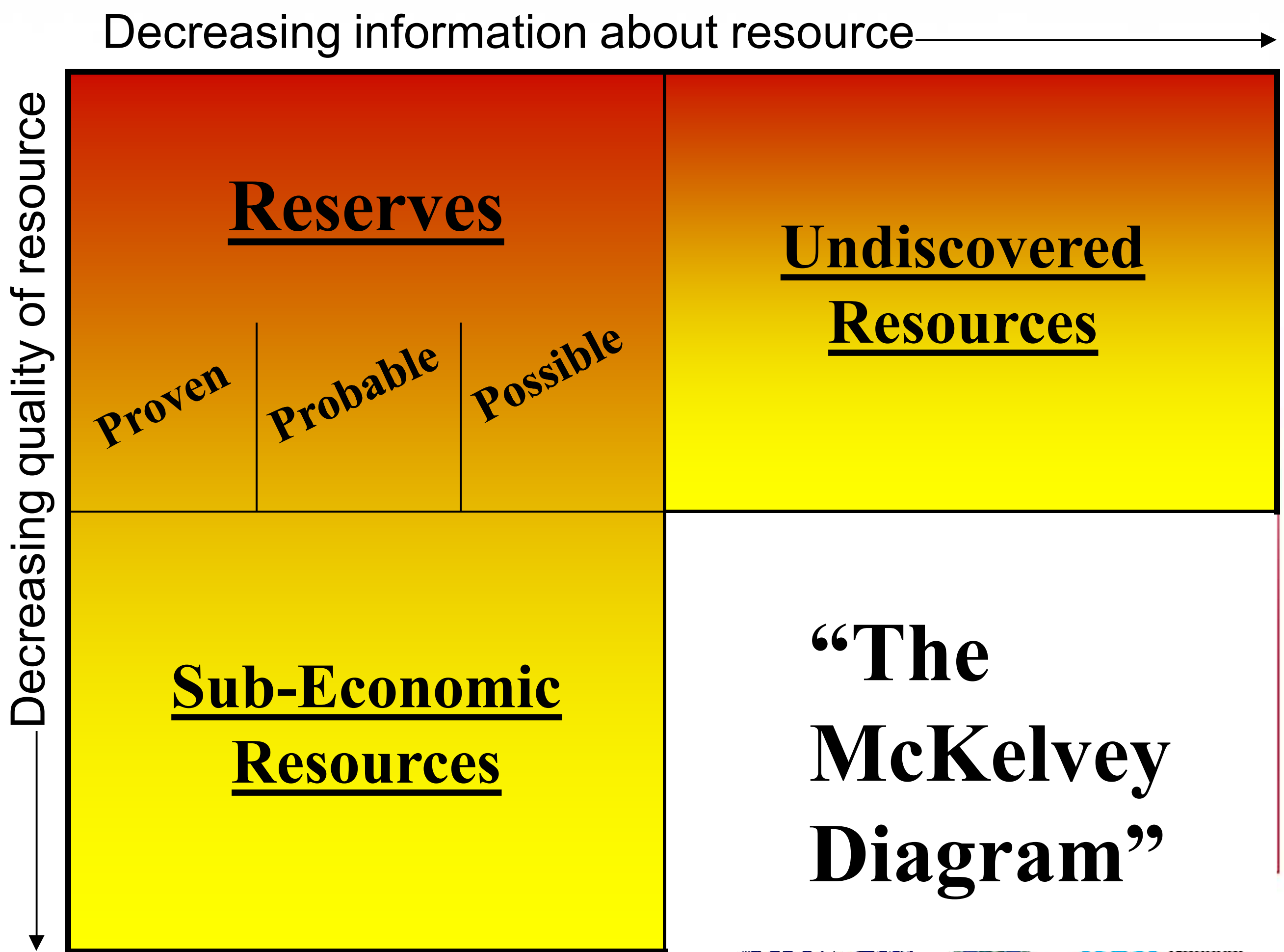


Armed with this information…

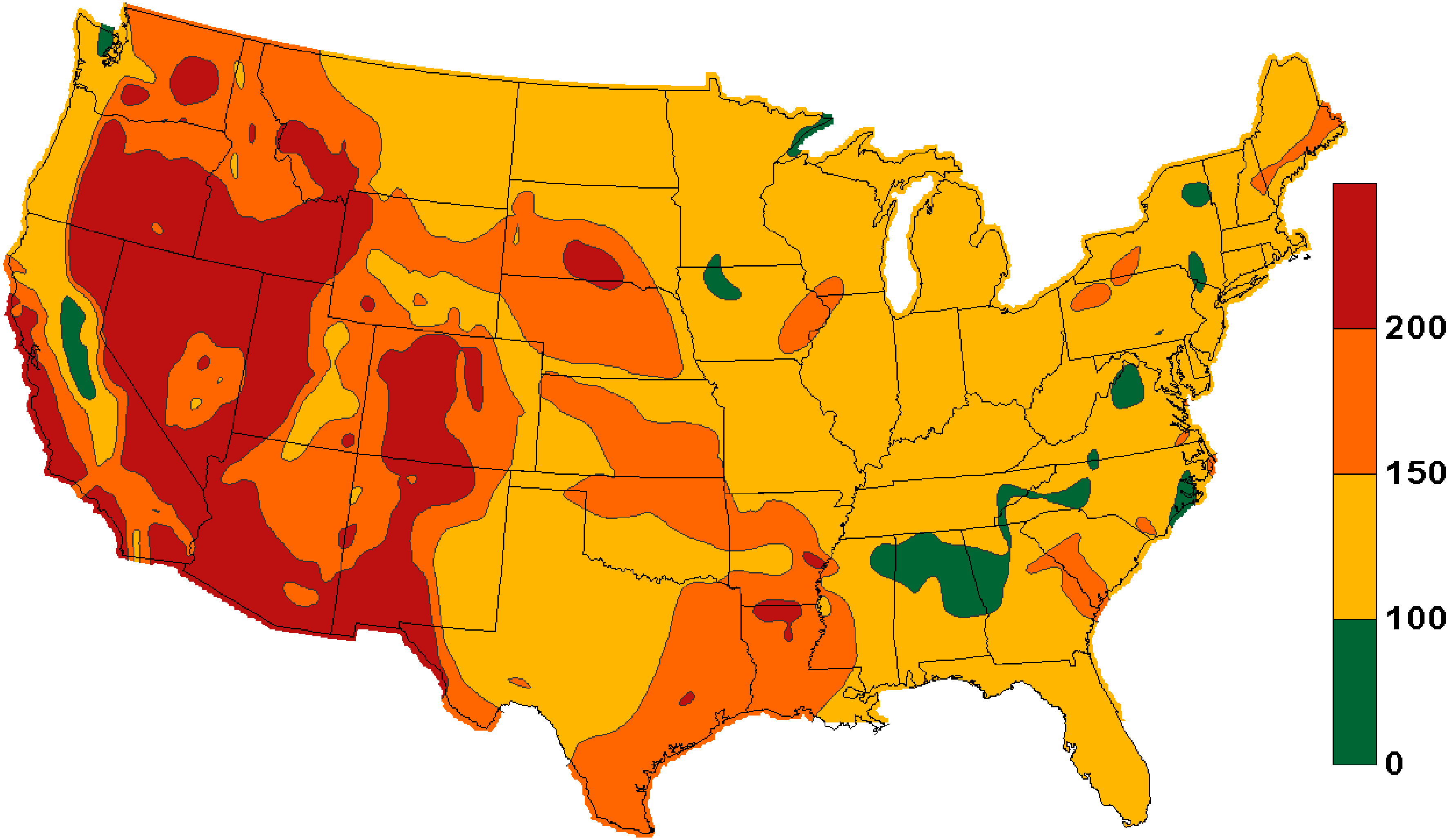
Geologic Assurance and Economic Feasibility

National R&D helps to expand the geothermal resource base:

- ✓Geophysics and geoscience to locate and define reservoirs
- ✓Drilling research to reduce costs
- ✓ Improving capabilities and efficiencies of power plants.

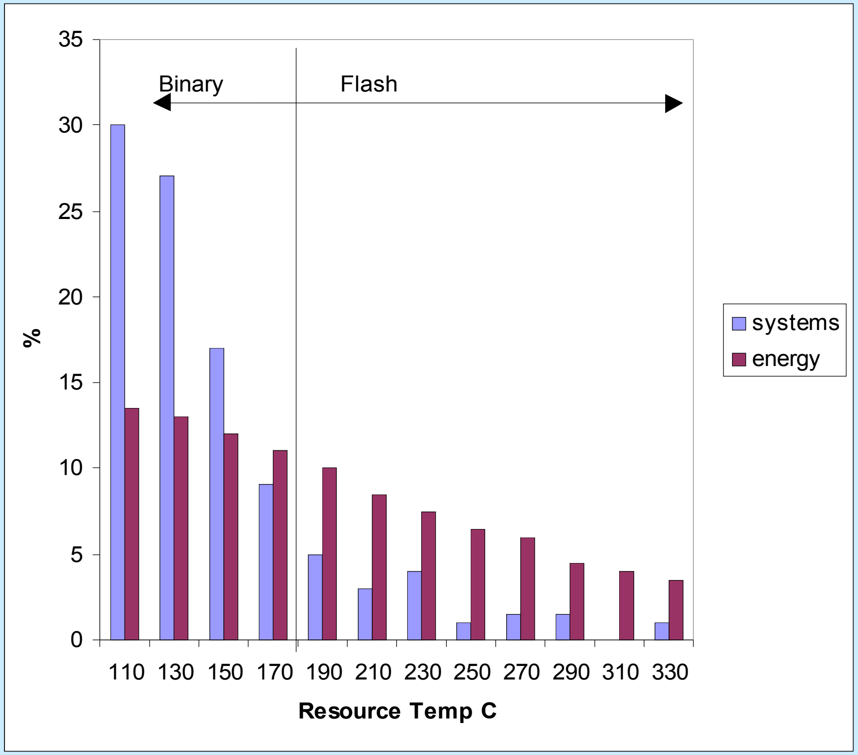


The Early Years!



Estimated Earth Temperatures at 6 km Depth (°C)

Low-Temp Resources are More Common

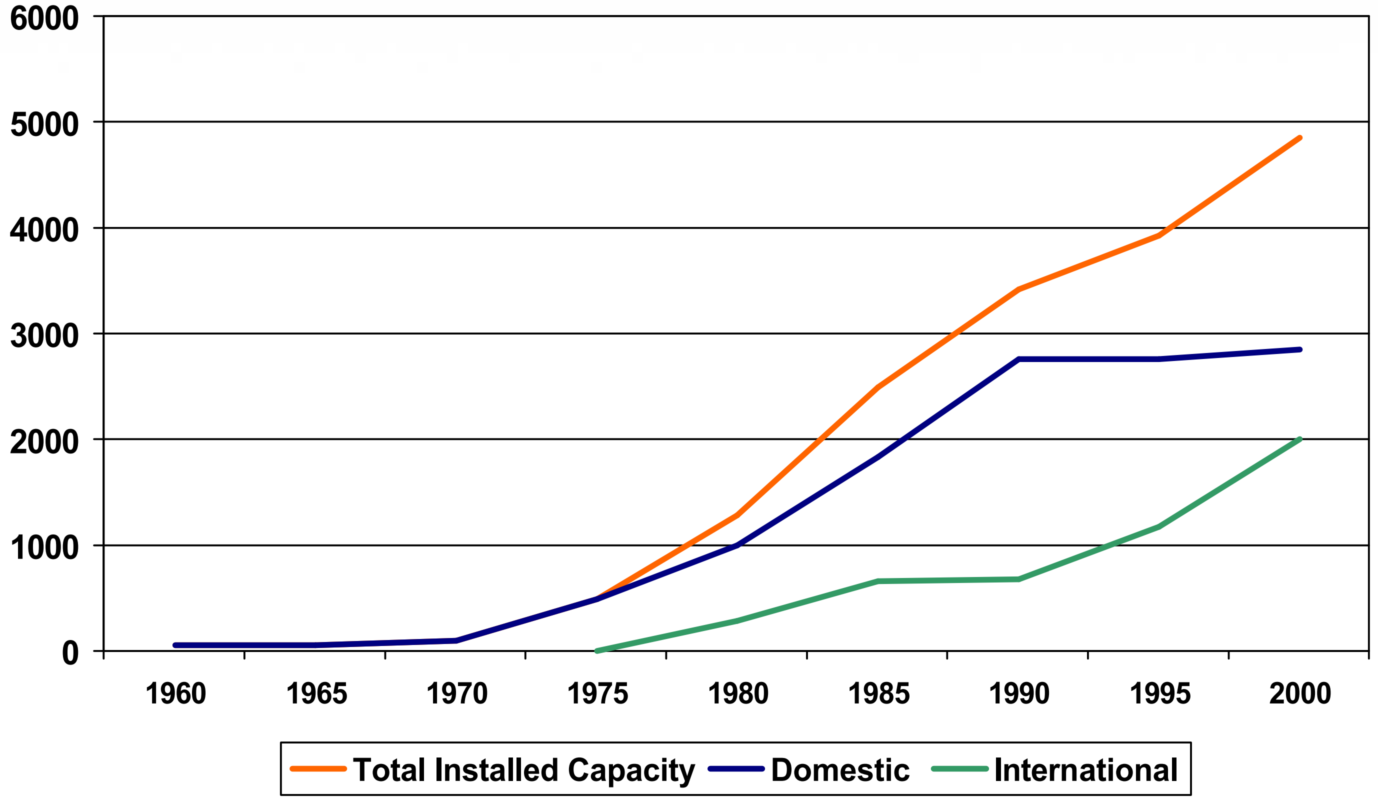


Frequency of occurrence and energy of hydrothermal convection systems identified by the USGS in 1978

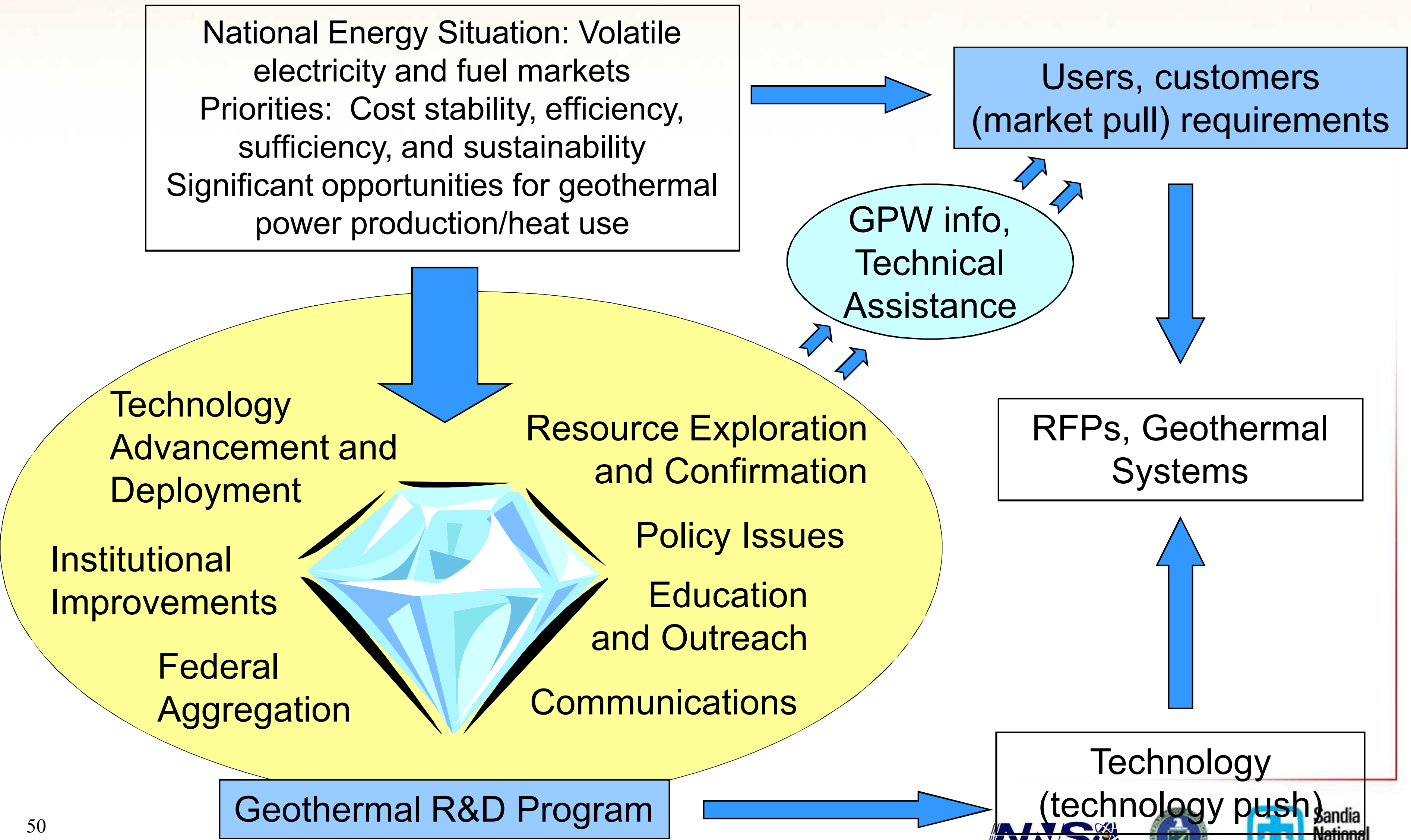
- 83% of the sites require binary plants (also, EGS/HDR will most likely need binary plants)
- And 50% of the available energy is below temperatures requiring binary plants (170C)

Source: NREL

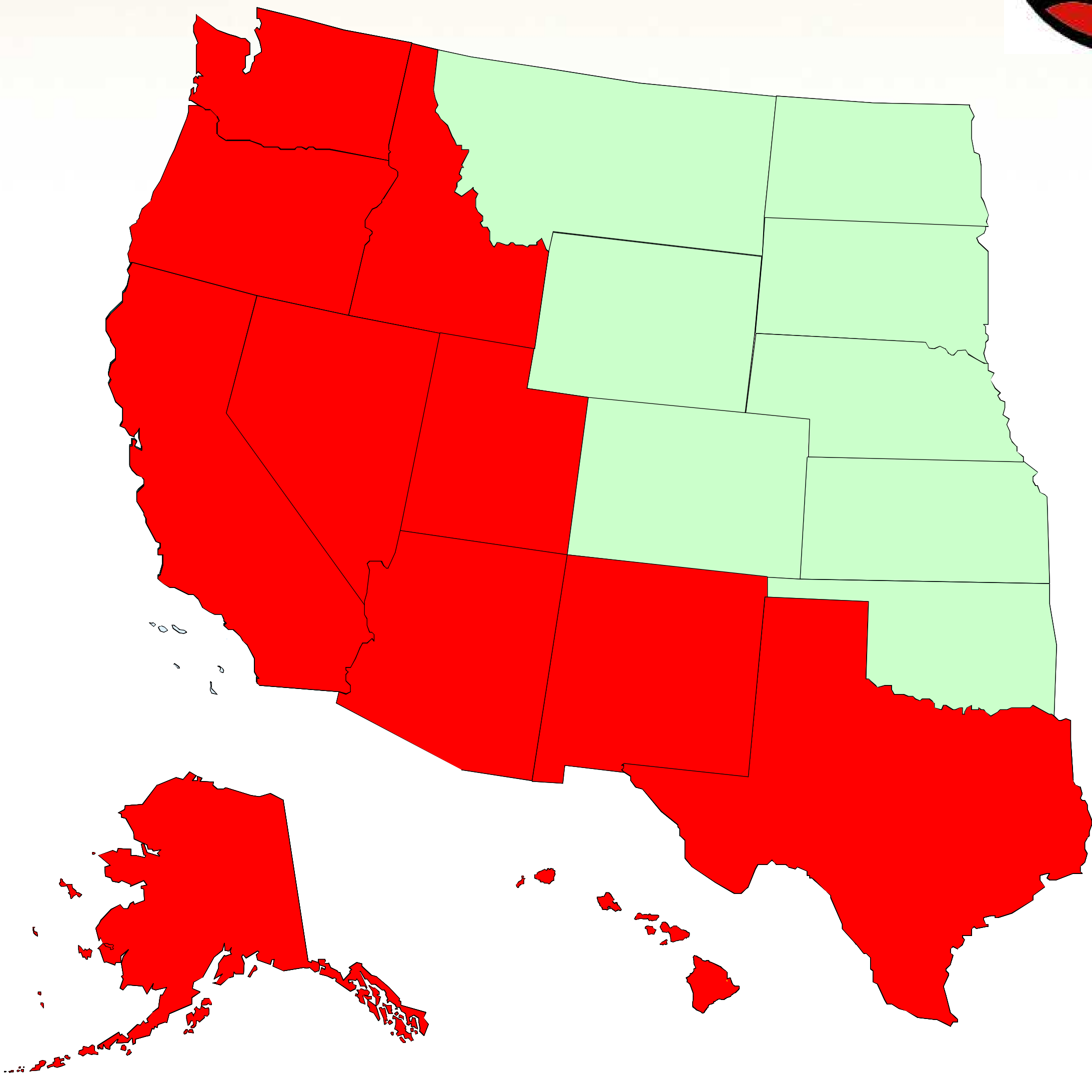
Geothermal Capacity Installed by U.S. Industry



GeoPowering the West Approach



GeoPowering the West



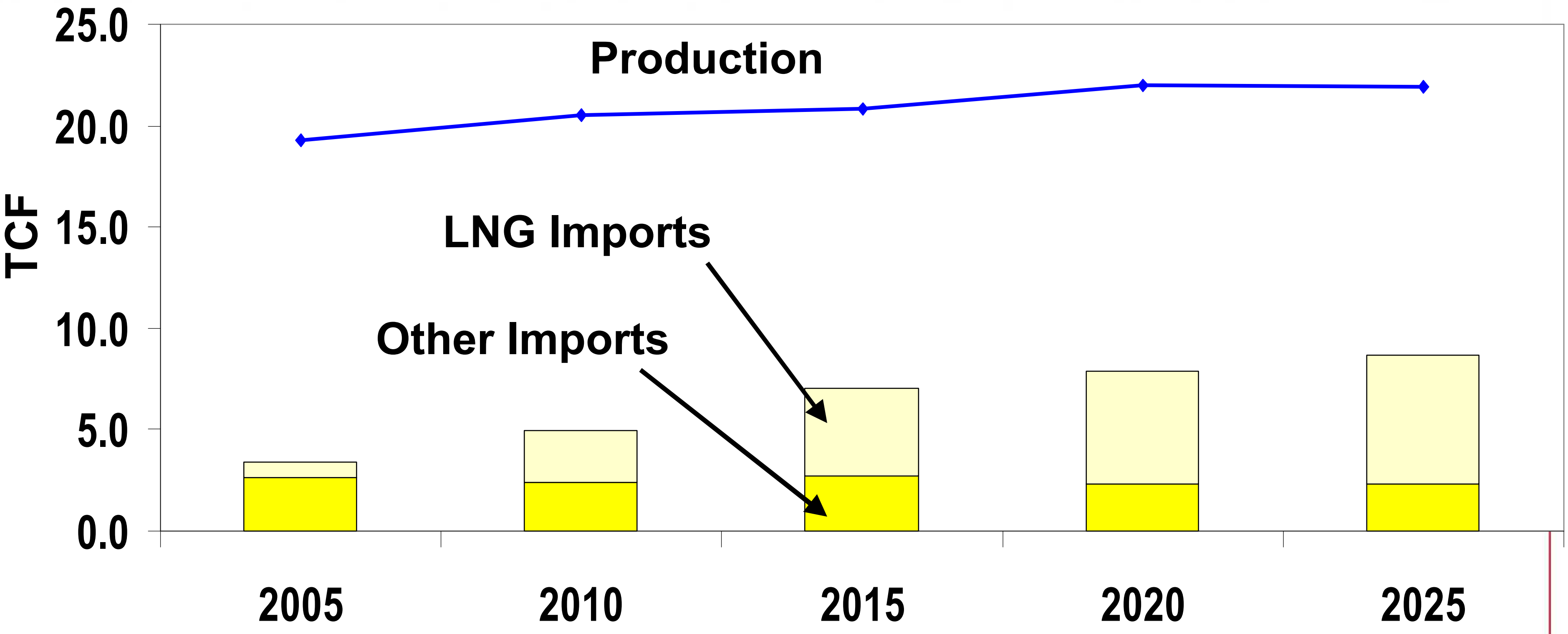
Current Projected

State Working Groups

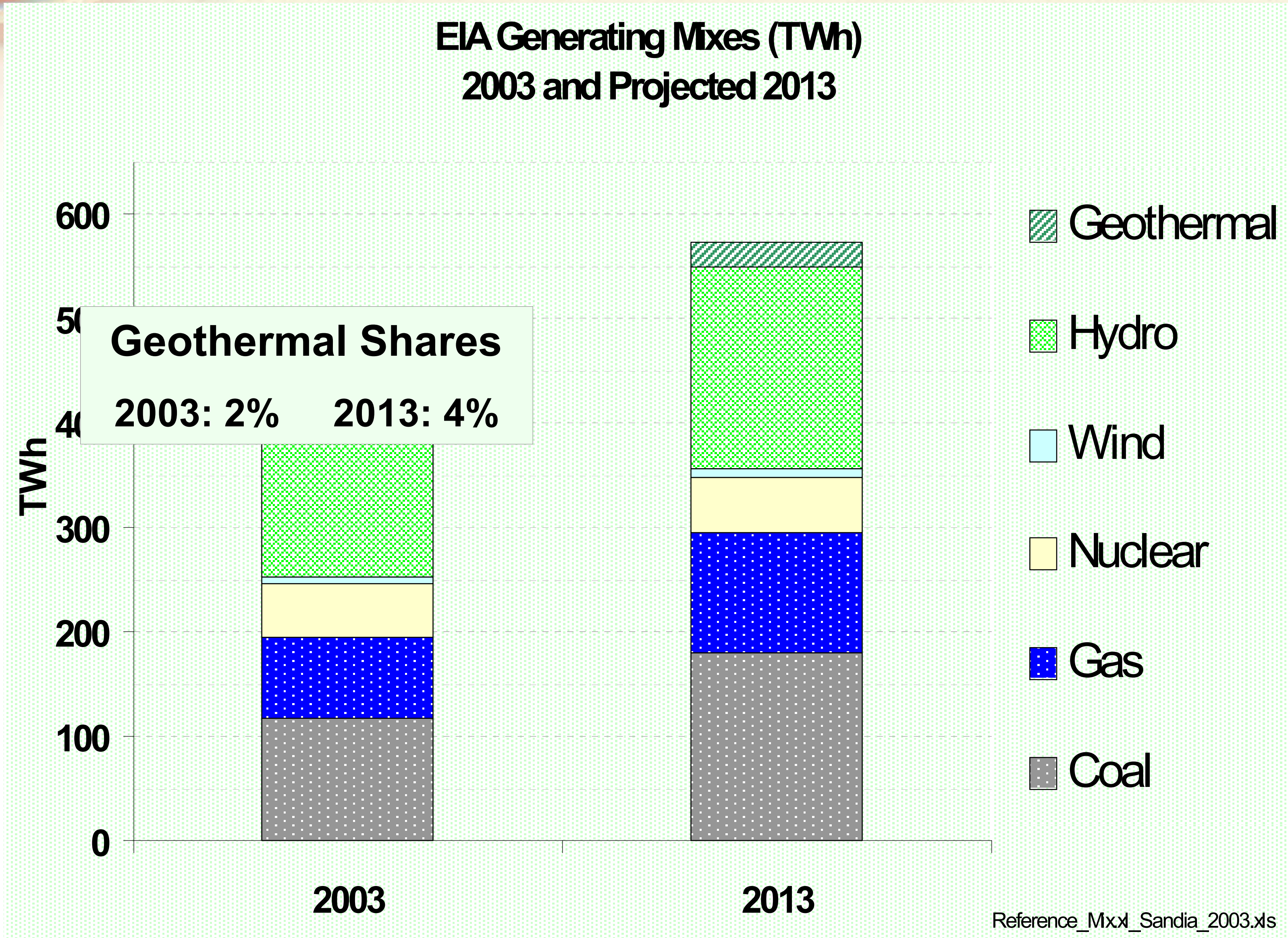
1. Alaska, est. in 2002
2. Arizona, est. in 2002
3. California, est. in 2003
4. Hawaii, est. in 2003
5. Idaho, est. in 2002
6. Oregon, est. in 2003
7. Nevada, est. in 2000
8. New Mexico, est. in 2000
9. Texas, est. in 2005
10. Utah, est. in 2002
11. Washington, est. in 2002

Sandia National Laboratories

US Natural Gas Prod. Will Grow 13% Imports Will Grow 157%

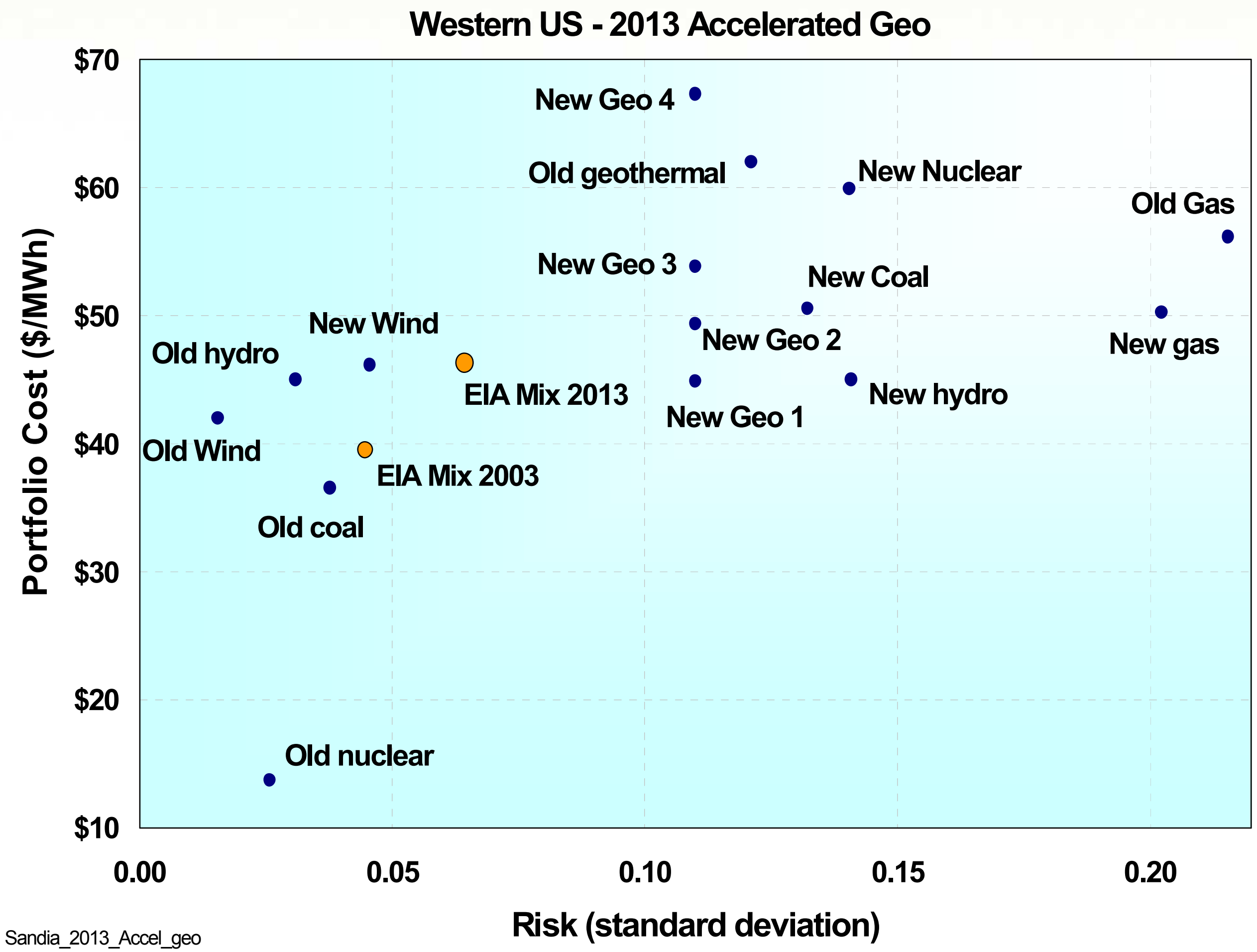


Source: DOE/EIA AEO2005


EIA Generating Mixes (TWh)
2003 and Projected 2013
Geothermal Shares
2003: 2%
2013: 4%
TWh
600
300
200
100
0
2003
2013
Geothermal
Hydro
Wind
Nuclear
Gas
Coal
Reference_Mxxl_Sandia_2003.xls

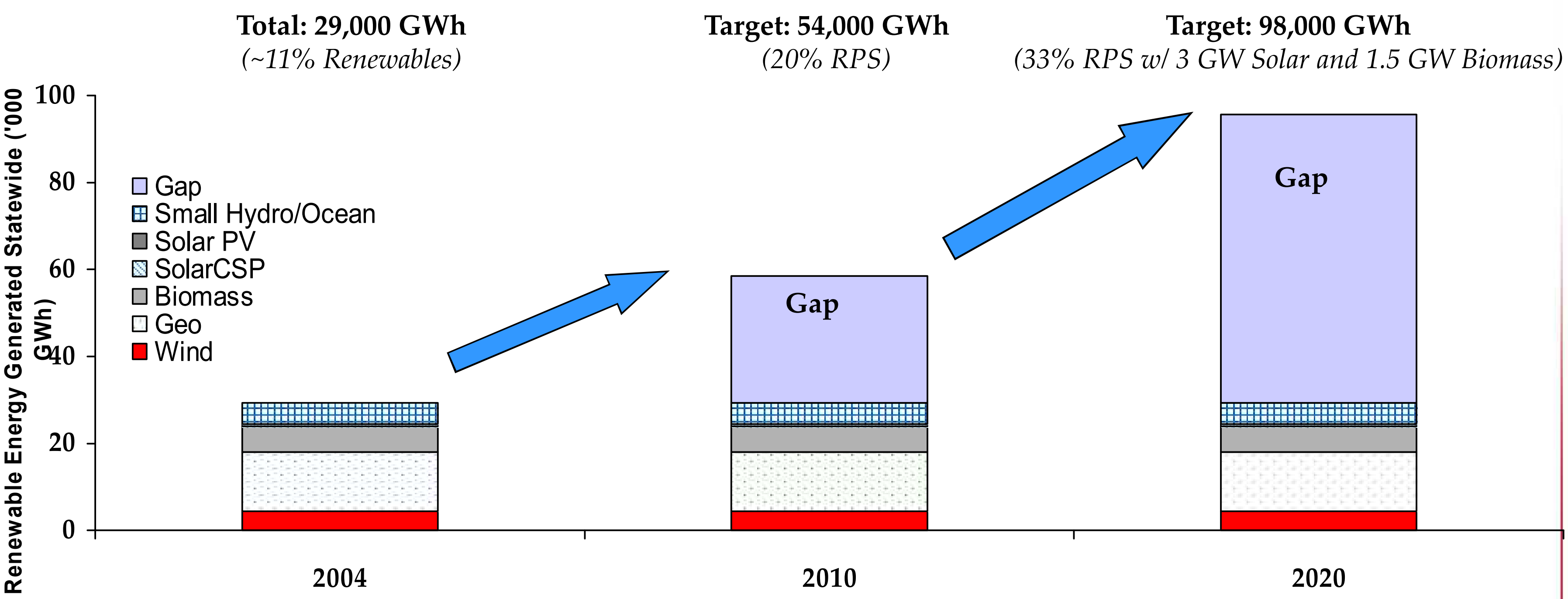
Western Region Generating Cost-Risk Trends

- **2013 EIA Mix has higher cost and risk relative to 2003**
- **Move to larger gas/coal shares adds to portfolio cost and risk, volatility**
- **Reduces Energy Diversity/ Security**
- **Geothermal and wind are ideally positioned to diversify the generating mix and reduce cost/risk**



The primary role of PIER Renewables is to help the State meet aggressive renewable energy policy goals by investing in high priority RD&D issues.

Projected Renewables to Meet California Policy Goals

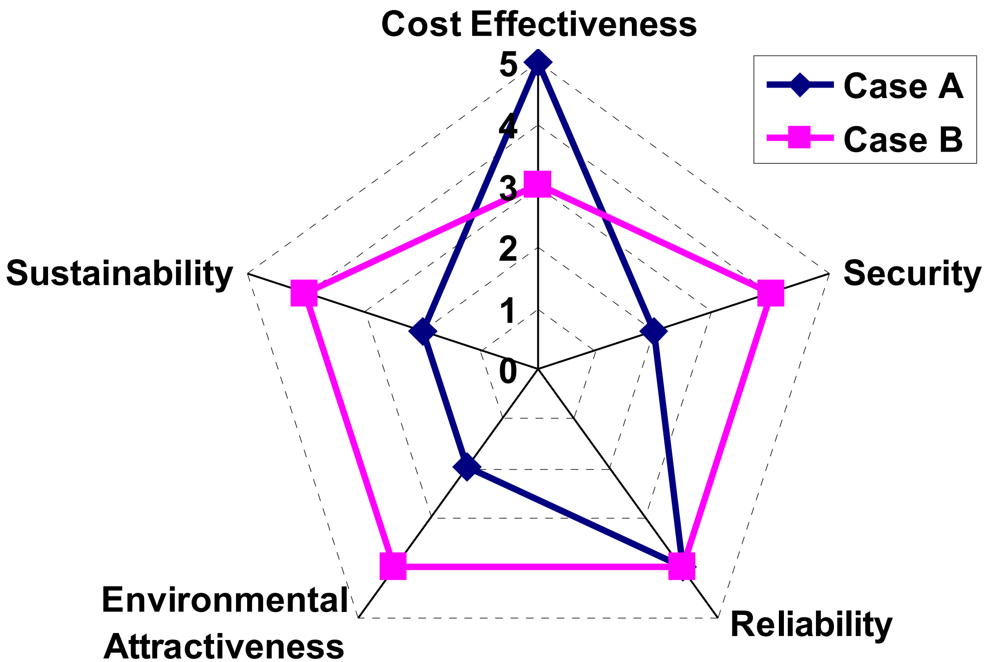


Data Sources: 2004, CEC Electricity Report which includes all renewables in the State, not just IOUs; 2010 and 2020, PIER Renewables Projections.

Source: CEC

Expected Trends in Future Energy System Evolution

- Energy safety, security, reliability, and sustainability have become important energy system design parameters
- This will change how energy systems are optimized and upgraded
- This will impact future decisions on energy policy, supply, and use
- How do we efficiently and cost-effectively transition to this new future infrastructure?



Definition: Renewable Portfolio Standard

The Renewable Portfolio Standard (RPS) is a flexible, market-driven policy that can ensure that the public benefits of solar, biomass, geothermal, and wind energy continue to be recognized as electricity markets become more competitive.

The policy ensures that a minimum amount of renewable energy is included in the portfolio of electricity resources serving a state or country, and -- by increasing the required amount over time -- the RPS can put the electricity industry on a path toward increasing sustainability.

Because it is a market standard, the RPS relies almost entirely on the private market for its implementation. Market implementation will result in competition, efficiency and innovation that will deliver renewable energy at the lowest possible cost.

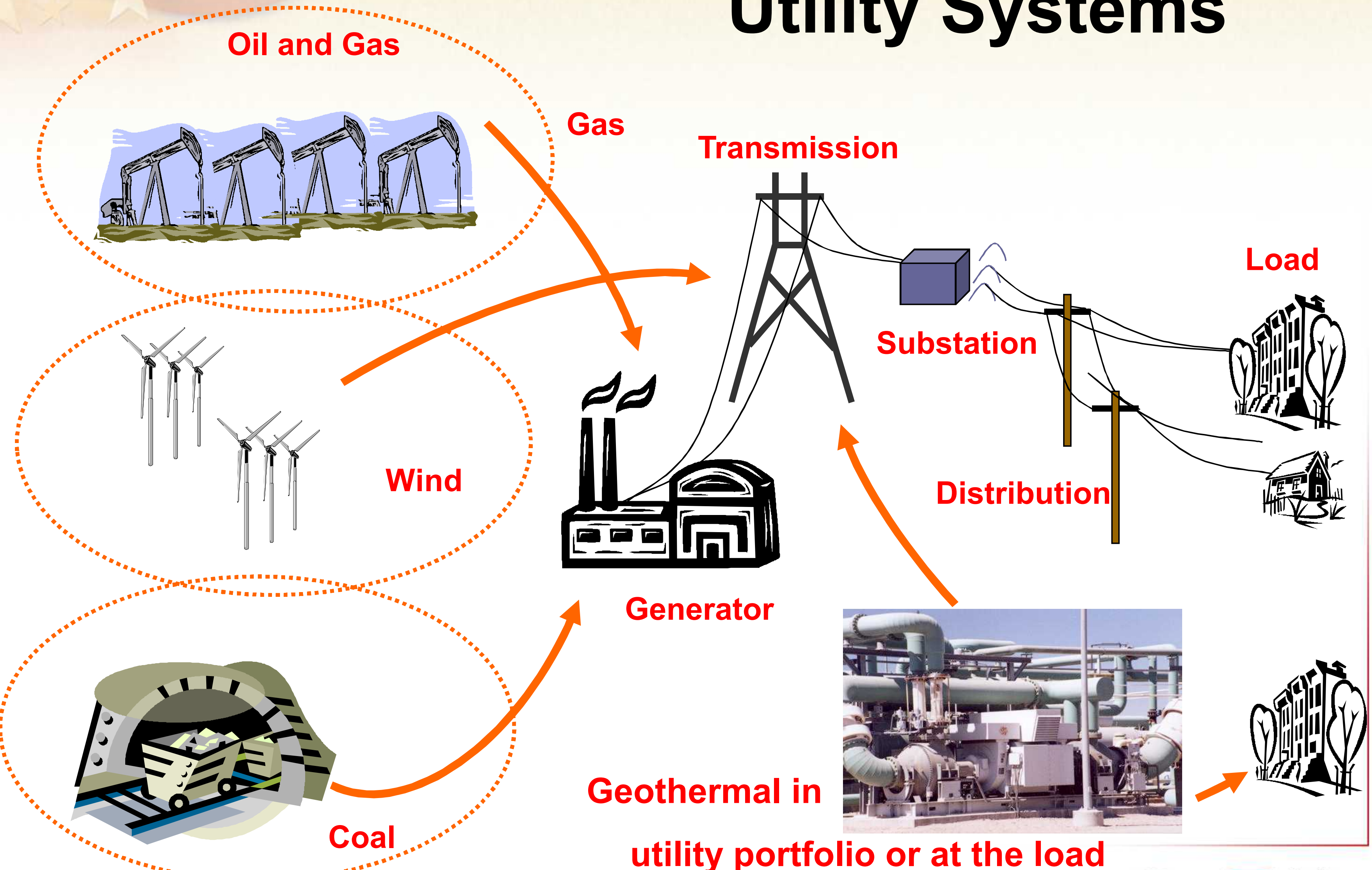
Small Geothermal Power Plants in the Oil Patch

Advantages for O&G industry
•Helps to service pumping
•O&G industry has simlar technology and infrastructure
•Potentially supplements resources exploitation

Economic advantages
•Distributed power at full retail cost
•Enhanced or extended operations uneconomical
•Exploration already is largely characterized
•Modular and can start small

Advantages for the Nation
•Offers addition energy choice

Utility Systems



Criteria for Sites Suitable for Geothermal Development

1. Need a good geothermal resource
2. Must have access to loads or grid
3. The land must be developable

0. Must have a buyer

Geothermal and the Tribes

- Increased attention to tribes by the geothermal community
- Economic opportunities, empowerment, and more energy choices
- Contribution to nation's domestic power supplies
- Significant opportunity for rural economic development through direct-use applications

List of Reservations with Known or Suspected Geothermal Resources

Nevada
- Pyramid Lake
- Walker River
- Fallon
- Duckwater
- Yerrington
- Summit Lake
- Lovelock
- Duck Valley

Oregon
- Warm Springs
- Umatilla
- Klamath
- Burns

California
- Morongo
- Fort Yuma
- Upper Lake
- Ft. Bidwell

Utah
- Newcastle

Washington
- Yakima

Idaho
- Fort Hall
- Nez Perce?

Montana
- Crow
- Northern Cheyenne

Wyoming
- Wind River

New Mexico
- Acoma
- Jemez
- Navajo
- Jicarilla Apache

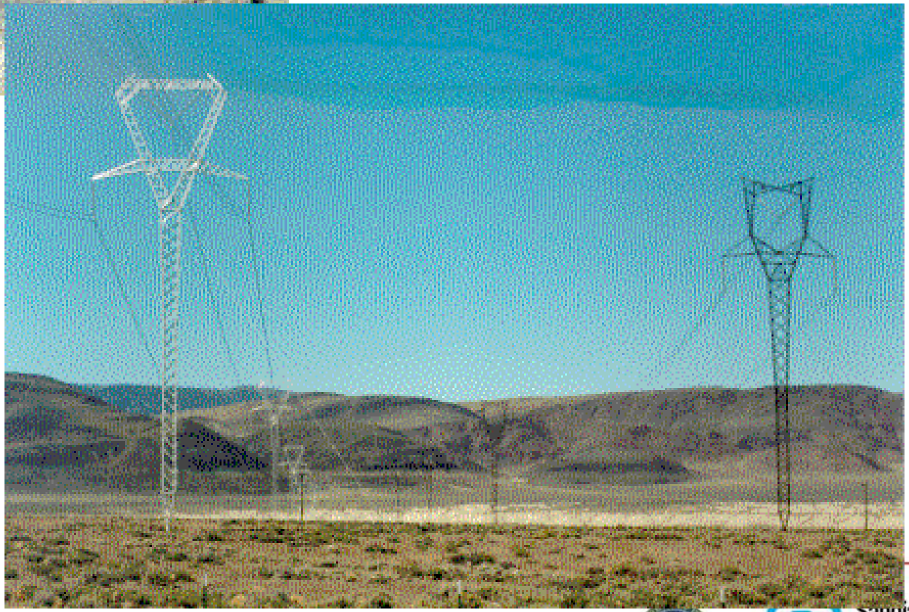
South Dakota
- Rosebud
- Yankton

Colorado
- Southern Ute

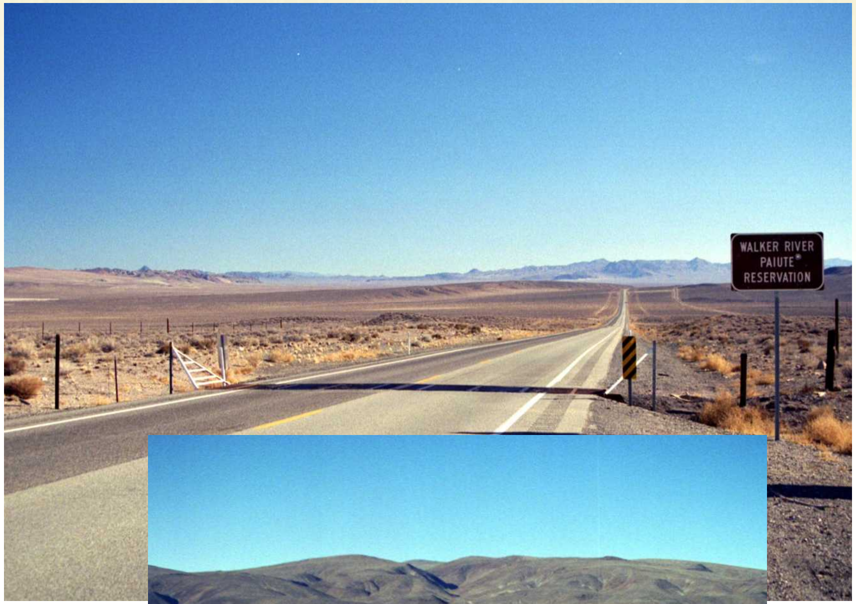
Alaska
- TBD


TRIBAL
OFFICES
of
Pyramid Lake Paiute Tribe
Nixon Nevada

Geothermal Manifestations at Pyramid Lake, Nevada




TRIBAL HALL
WALKER
RIVER
PAIUTE
TRIBE


WALKER RIVER
PAIUTE
RESERVATION


DANGER
HOT WATER
185°

You’ve Heard of Combined Heat and Power?

Geothermal offers combined:

Heat………..Power……… and Pleasure!

Sources: Geothermal Education Office