SAND2007-1421P

GeoPowering the West

The Role of Geothermal in Enhancing Energy Diversity and Security in the Western US

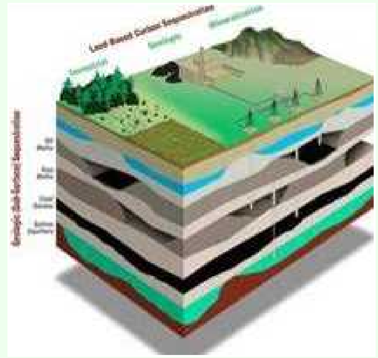
Roger Hill
Technical Director of GeoPowering the West

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.

National Nuclear Security Administration

Sandia National Laboratories

Sandia Energy Programs



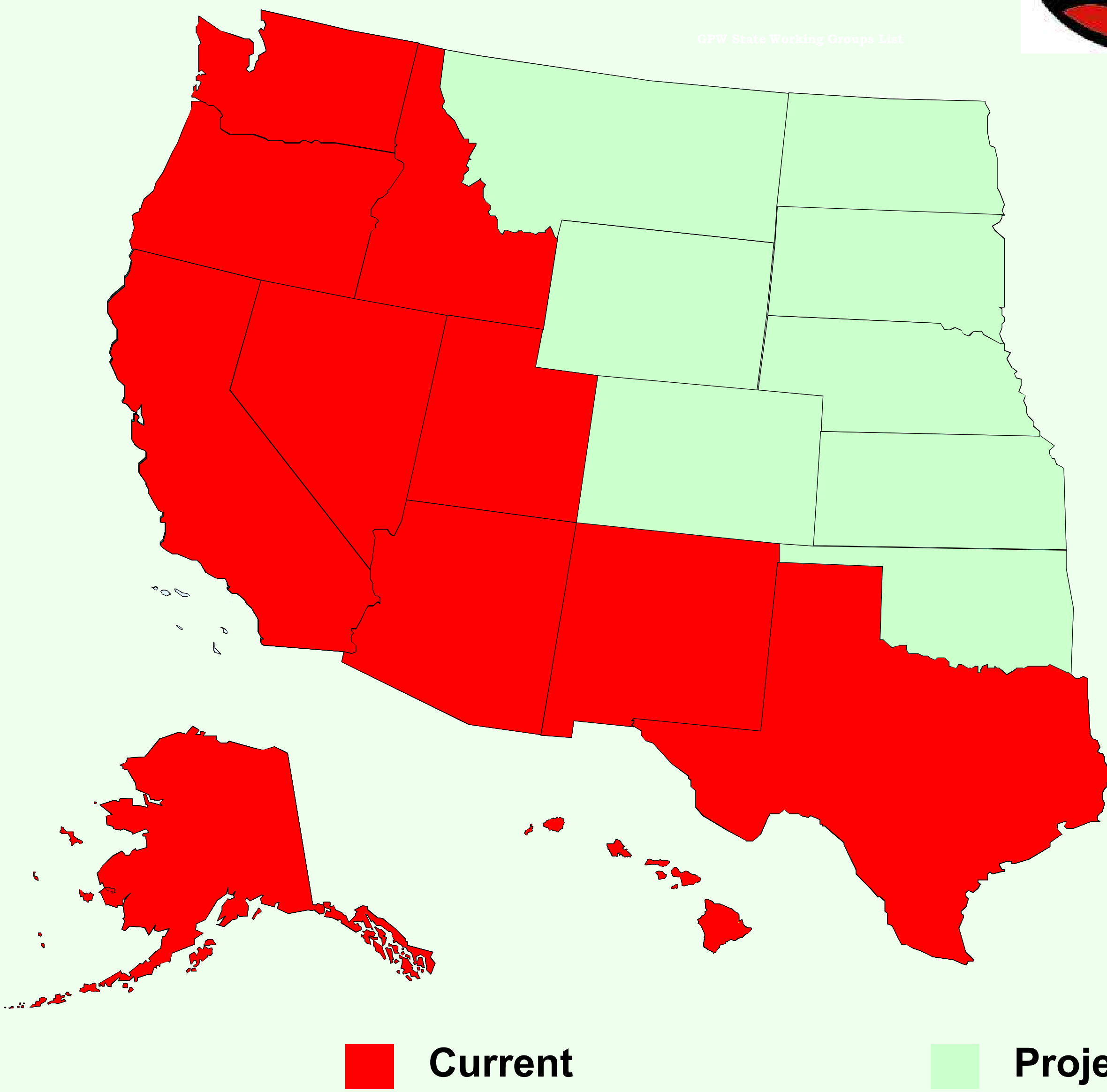
Technologies include Concentrating Solar Power, Photovoltaics, Wind, Geothermal, Energy Storage, Well Construction, Reservoir Evaluation and Production, Storage and Transmission, Energy and Water, Fuel Utilization

,

Geothermal Energy

GeoPowering the West

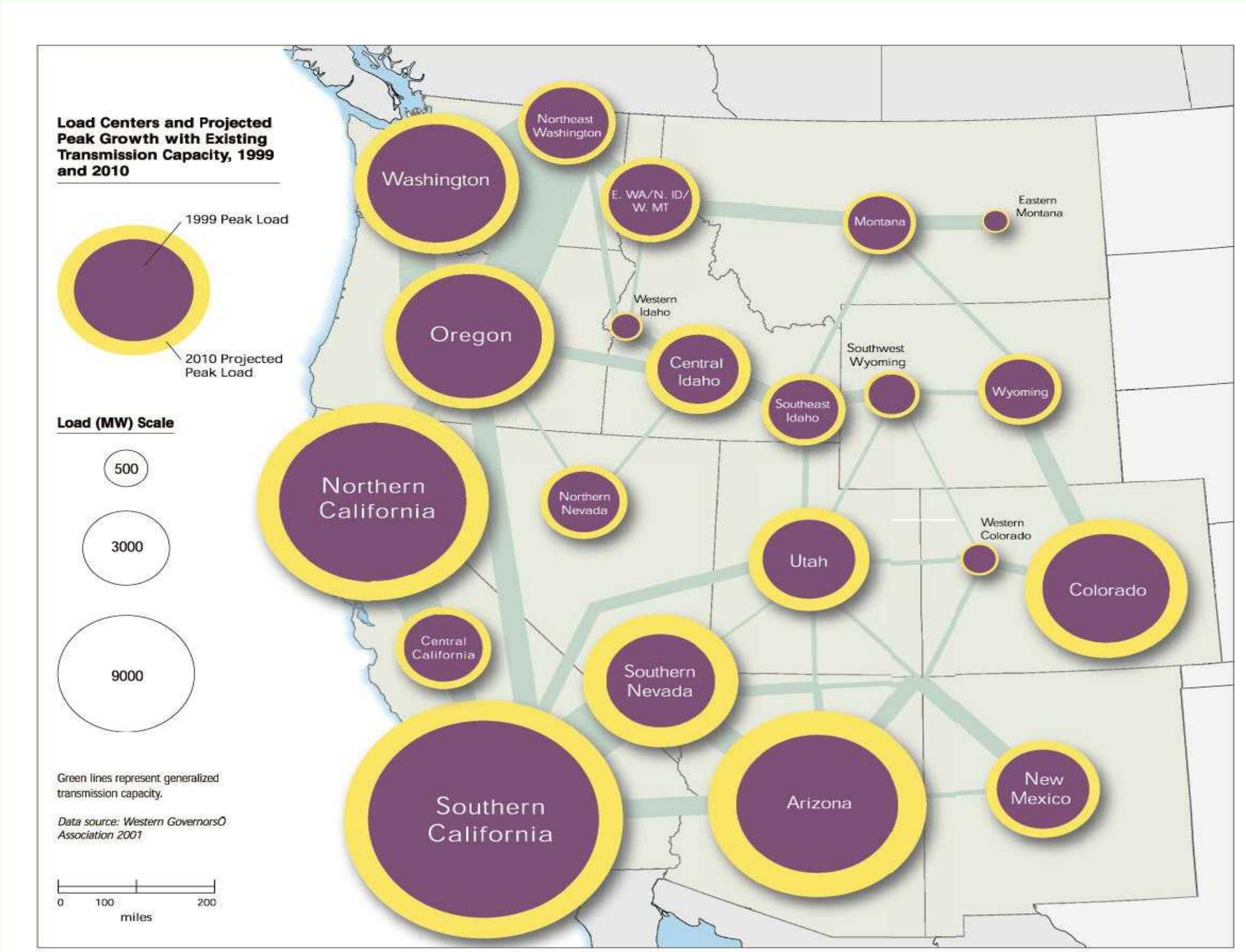
GeoPowering the West



State Working Groups

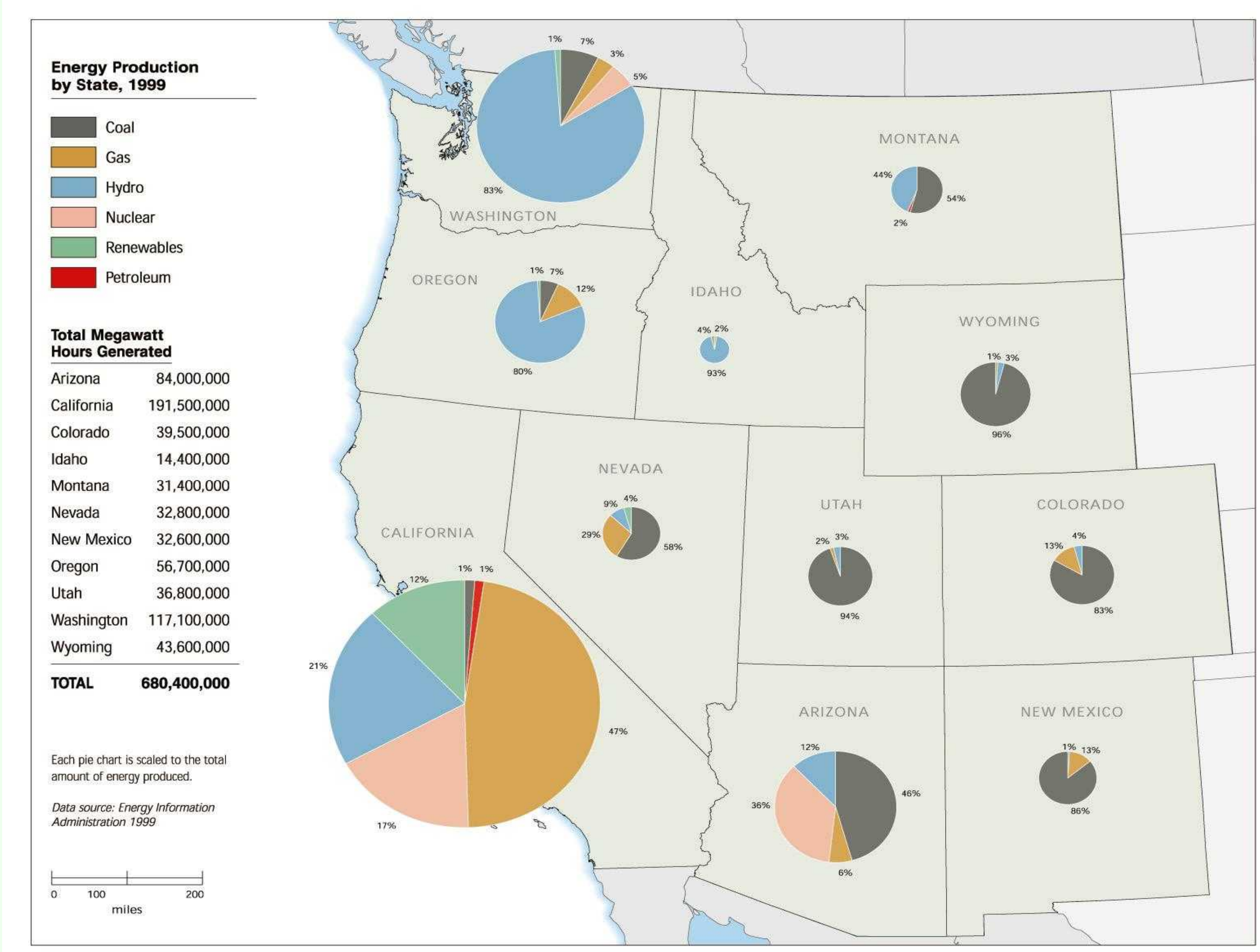
1. Alaska, est. in 2002
2. Arizona, est. in 2002
3. California, est. in 2003
4. Hawaii, est. in 2003
5. Idaho, est. in 2002
6. Oregon, est. in 2003
7. Nevada, est. in 2000
8. New Mexico, est. in 2000
9. Texas, est. in 2005
10. Utah, est. in 2002
11. Washington, est. in 2002

Western US: Load Growth



Source: Renewable Energy Atlas

Electricity Generation

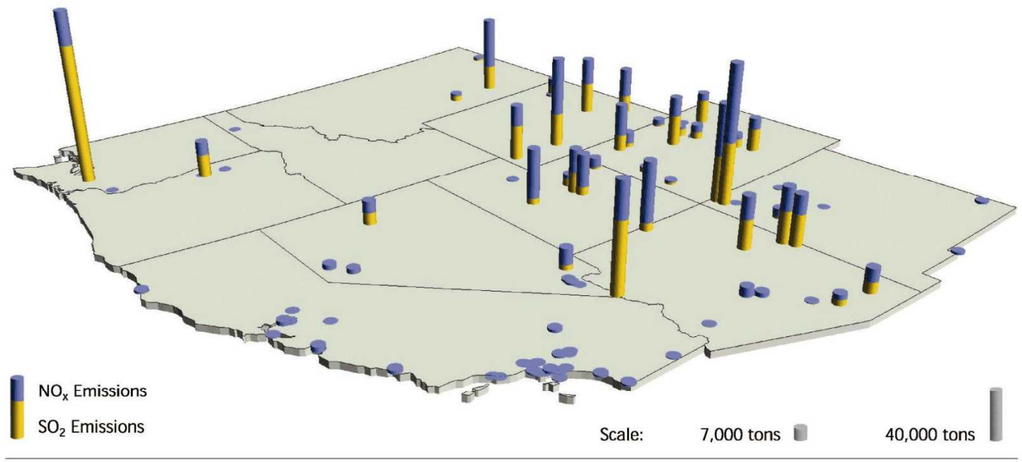


Source: Renewable Energy Atlas

Regional Power Plant Emissions

Power Plant Emissions, 2000

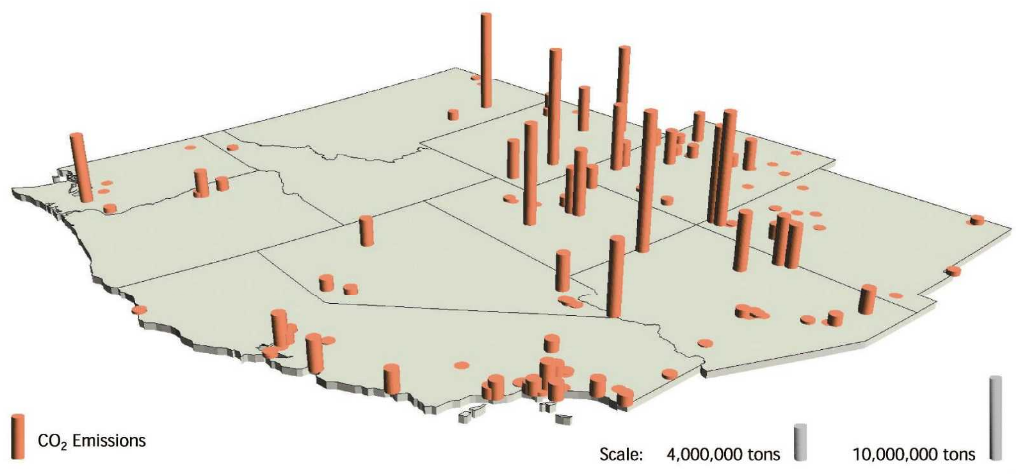
Each bar represents the location of a power plant regulated under the EPAÕ Acid Rain Program (Title IV). The height of the bars is scaled to reßect the emissions levels for each plant. Because CO_2 emissions are so much higher than either SO_2 or NO_x, different scaling factors were used to determine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



Total Emissions in Region from Title IV Plants, 2000

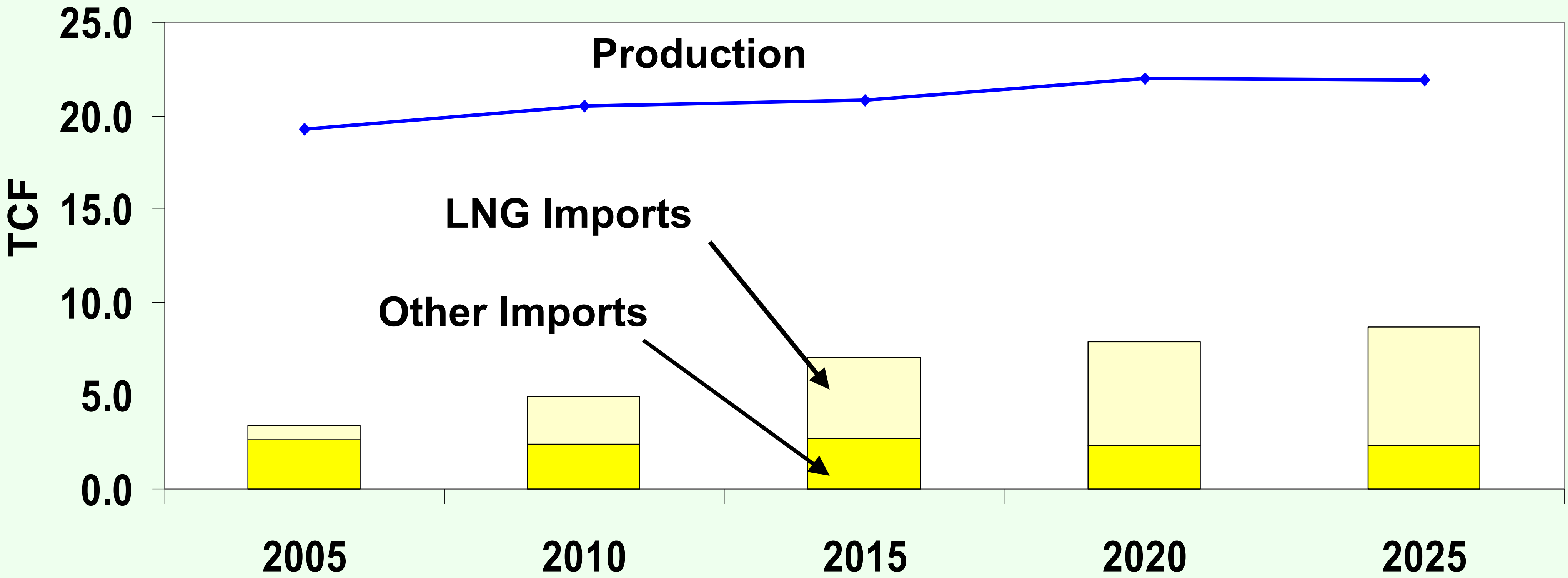
	tons
Sulfur Dioxide (SO_2)	506,662
Nitrogen Oxide (NO_X)	547,754
Carbon Dioxide (CO_2)	316,774,136

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



Source:
Renewable Energy Atlas

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



Source: DOE/EIA AEO2005

The Role of Geothermal in Enhancing Energy Diversity and Security in the Western US

A Mean-Variance Portfolio Optimization of the Region's Generating Mix to 2013

Prepared for Sandia National Labs

Roger Hill

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By

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Hobart College and Sandia National Labs

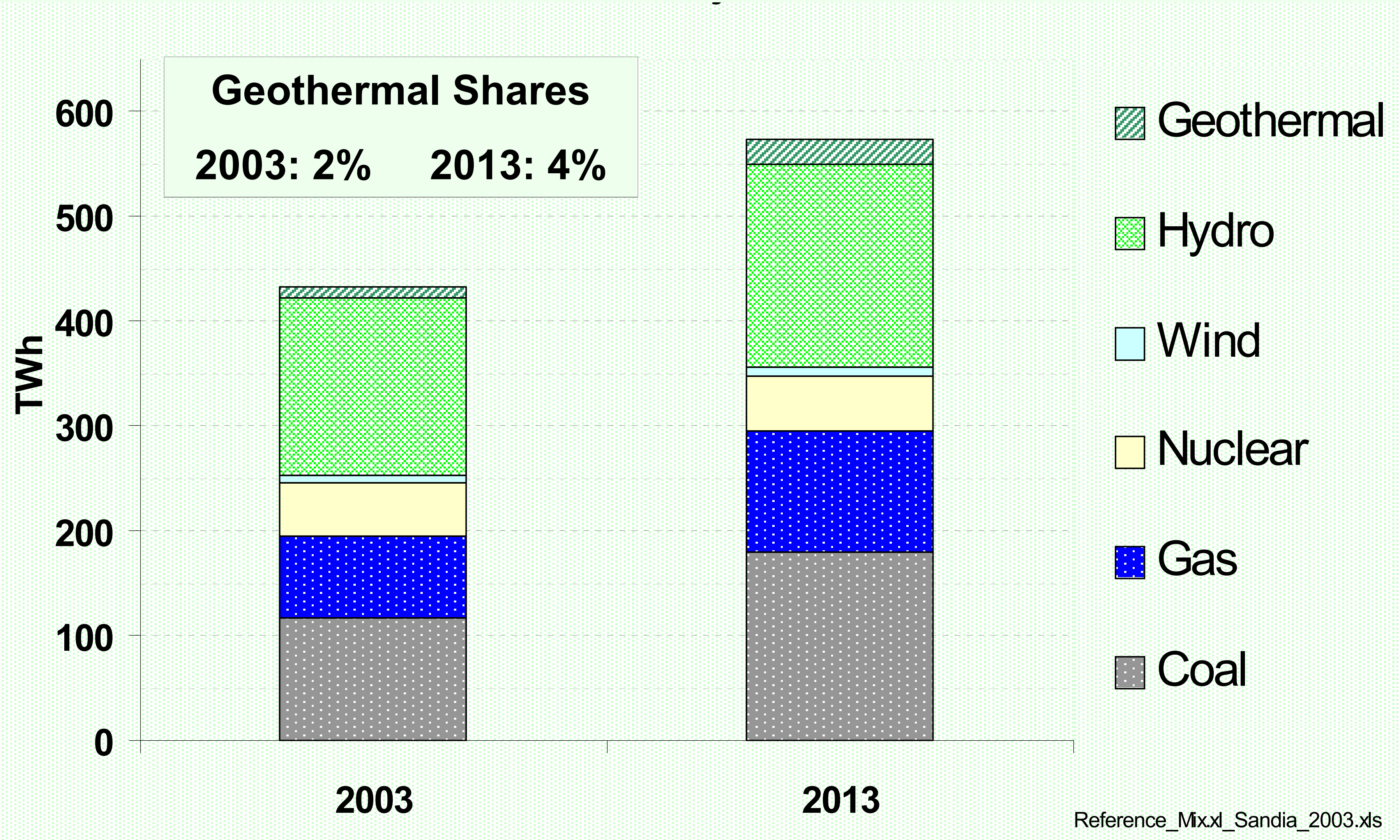
Figure 10. Electricity Market Module Supply Regions

February 28, 2005

Optimization Defines Four Bands for New Geothermal Based on Resource Accessibility

Geothermal Potential and Cost			
	Resource Availability	**Generating Cost**	
Band	**MW**	**2003**	**2013**
Existing	2,543	$.062	$.062
Geothermal-1	2,457	$.047	$.045
Geothermal-2	2,500	$.052	$.049
Geothermal-3	2,500	$.057	$.054
Geothermal-4	20,000	$.071	$.067
Total	30,000	-	-

EIA 2003 and 2013 Generating Mixes



Generating Cost Inputs: Constant 2002 $/kWh*

US Western Region Portfolio Analysis
Real Technology Cost Inputs
(2002 $/kWh)

	2003		**2013**	
Technology	Existing	New	Existing	New
Coal	$0.036	$0.047	$0.037	$0.051
Gas	$0.047	$0.036	$0.056	$0.050
Nuclear	$0.014	$0.060	$0.014	$0.060
Wind	$0.042	$0.046	$0.042	$0.046
Hydro	$0.045	$0.045	$0.045	$0.045
Geothermal	$0.062		$0.062	
New Geo 1		$0.047		$0.045
New Geo 2		$0.052		$0.049
New Geo 3		$0.057		$0.054
New Geo 4		$0.071		$0.067

Source: US-EIA and Sandia National Laboratories

*pre-tax

Generating Cost Inputs: Nominal $/kWh

US Western Region Portfolio analysis Nominal Technology Cost Inputs Assuming 3% Inflation (Nominal $/kWh)				
	2003		2013	
Technology	Existing	New	Existing	New
Coal	$0.037	$0.049	$0.049	$0.068
Gas	$0.048	$0.037	$0.075	$0.067
Nuclear	$0.014	$0.062	$0.018	$0.081
Wind	$0.043	$0.047	$0.056	$0.062
Hydro	$0.046	$0.046	$0.060	$0.060
Geothermal	$0.064		$0.083	
New Geo 1		$0.049		$0.060
New Geo 2		$0.053		$0.066
New Geo 3		$0.058		$0.072
New Geo 4		$0.073		$0.090

Based on US-EIA and Sandia National Laboratories cost estimates, adjusted for 3% inflation

Understanding Risk

- **Portfolio optimization locates generating mixes with minimum expected cost and risk**
- **For each technology, risk is the year-to-year variability (standard deviation) of the three generating cost inputs: fuel, O&M and capital (construction period risk)**
  - Fossil fuel standard deviations are estimated from historic US data
    - e.g. standard deviation for natural gas over the last 10 years is 0.30
  - Standard deviations for capital and O&M are estimated using proxy procedures (see Awerbuch and Berger, IEA, 2003)
- **The construction period risk for embedded technologies is 0.0**
- **'New' technologies are therefore riskier than embedded ones**
  - e.g. new coal is riskier than 'old' coal

Technology Risk Estimates
(Standard Deviation) [a/]

	Construction Period [b/]	Fuel [c/]	Variable O&M	Fixed O&M
Coal	0.20	0.020	0.2	0.087
Gas	0.15	0.300	0.2	0.087
Nuclear	0.20	0.194	0.2	0.087
Wind	0.05	-	0.2	0.087
Hydro	0.20	-	0.2	0.087
Geothermal [d/]	0.15	-	0.2	0.087

a. Estimation procedures developed in Awerbuch and Berger (Paris, IEA, 2003)

b. Construction period costs for existing (embedded) technologies is 0.0

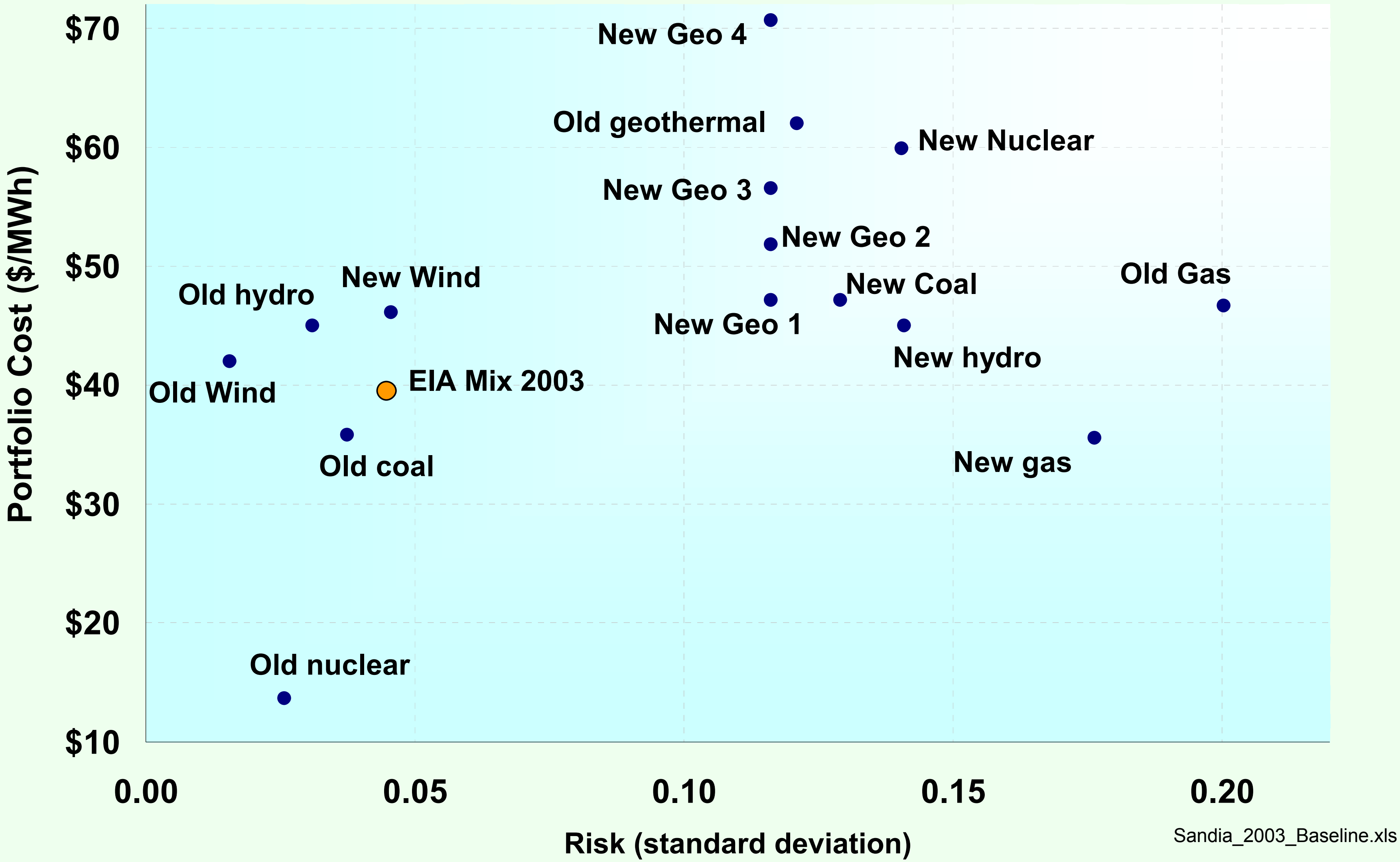
c. Empirical estimate based on 1994-2003 data

d. Four geothermal categories are used in the analysis. While exploration and other costs increase, construction period risk is assumed to remain constant.

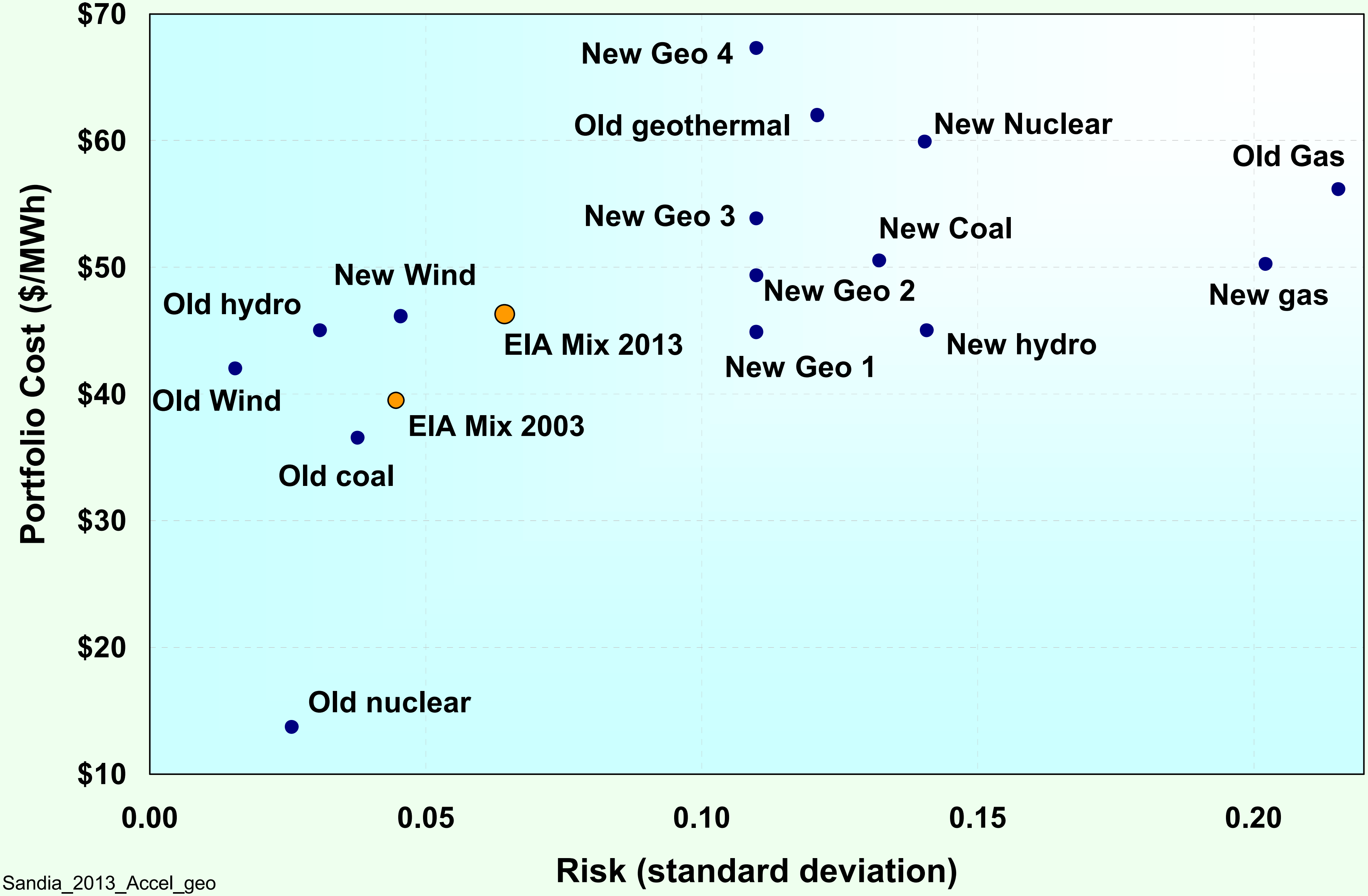
cost_variance_correlation_fuel_tech.xls

Total Risk for each generating technology is a weighted statistical summation of the component risks

2003 EIA Technology Generating Costs and Estimated Technology Risk



2013 EIA Technology Generating Costs
and Estimated Technology Risk



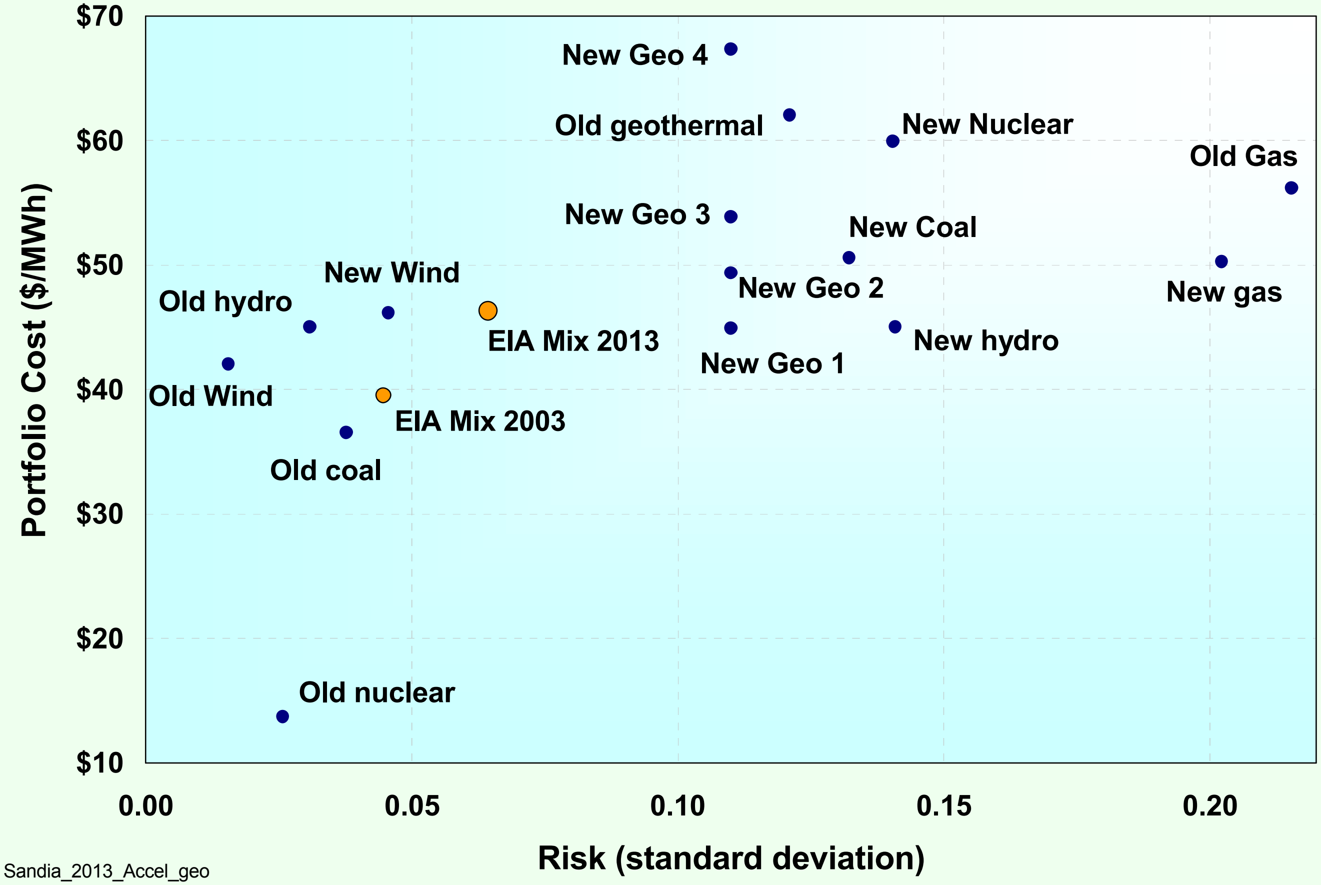
Sandia_2013_Accel_geo

Western Region Generating Cost-Risk Trends

- **2013 EIA Mix has higher cost and risk relative to 2003**
  – Driven by 32% demand increase, decommissioning existing plant, resource shortages and limitations on available options
- **Move to larger gas/coal shares adds to portfolio cost and risk**
  – Increases year-to-year expected generating cost volatility

- **Reduces Energy Diversity/ Security**

- **Geothermal and wind are ideally positioned to diversify the generating mix and reduce cost/risk**

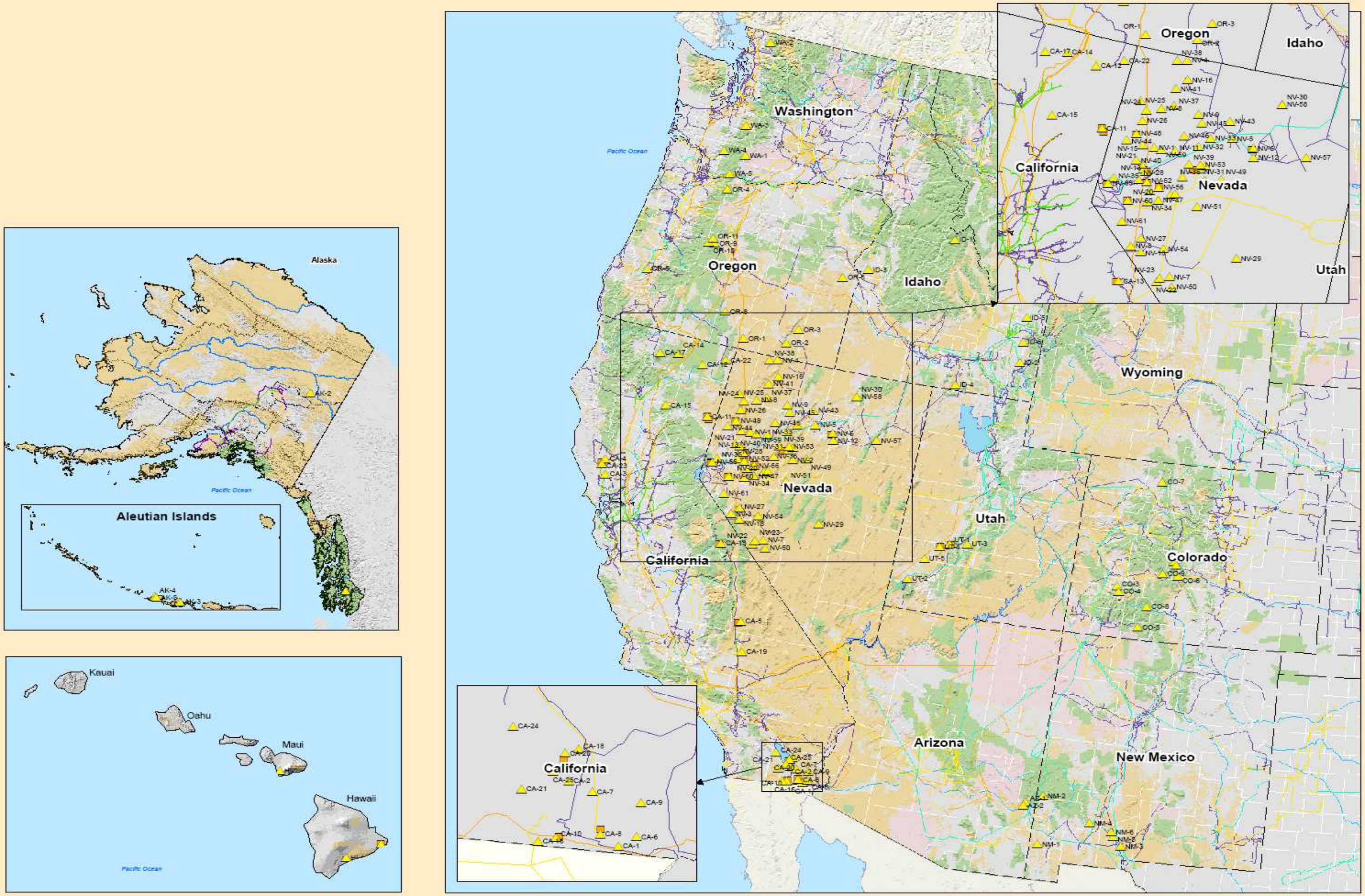


Sandia_2013_Accel_geo

A Mean-Variance Portfolio Optimization of the Western Region's Generating Mix to 2013

- **Portfolio optimization locates generating mixes with lowest-expected cost at every level of risk**
  - Risk is the year-to-year variability of technology generating costs
- EIA (NEMS) projected generating mixes serve as a benchmark or starting point;
  - Detailed decommissioning date assumptions using *World Electricity Power Plant Database* age of existing plants
- The optimal results generally indicate that compared to EIA target mixes, there exist generating mixes with larger geothermal shares at no greater expected cost or risk
  - There exist mixes with larger geothermal shares that exhibit *lower* expected cost and risk

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 Reserviors
- 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

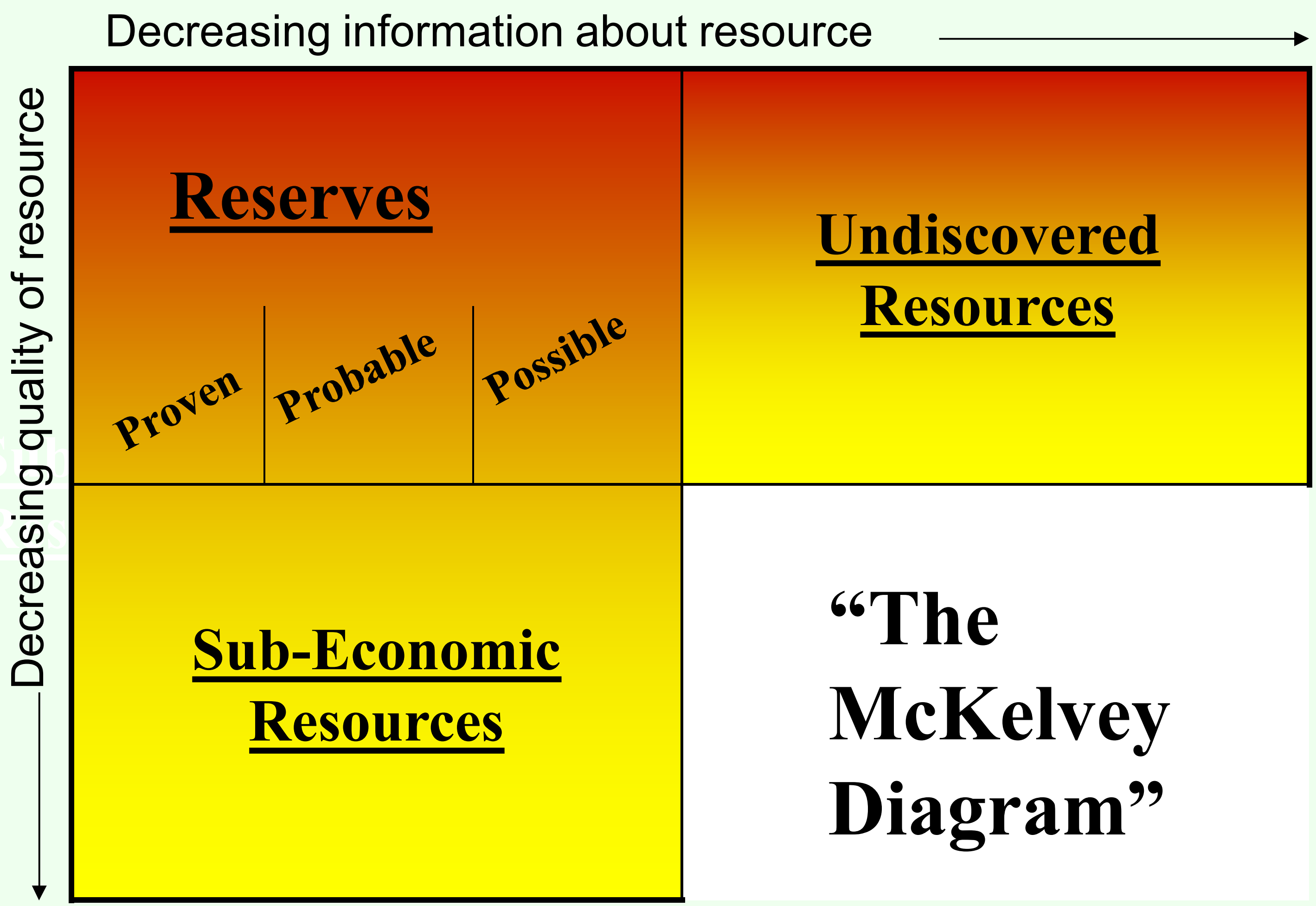
Map Projection Information:
Projection: Albers
Central Meridian: -96.00
Standard Parallel 1: 20.00
Standard Parallel 2: 60.00
Latitude Of Origin: 40.00

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 Kamaili & 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

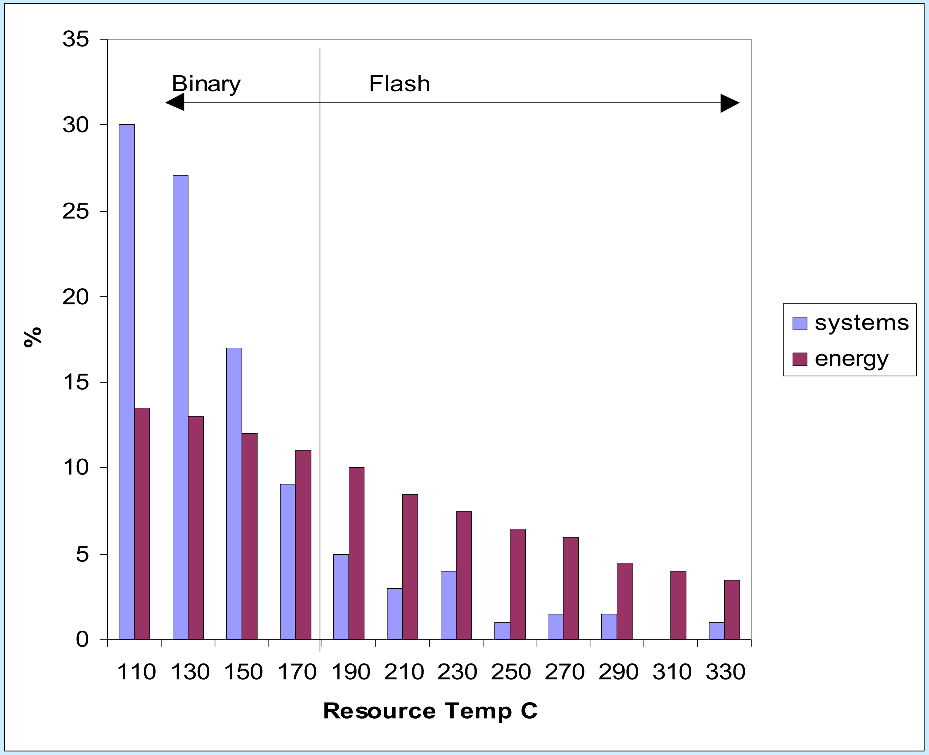
Geologic Assurance and Economic Feasibility

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.



Low-Temp Resources are More Common



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

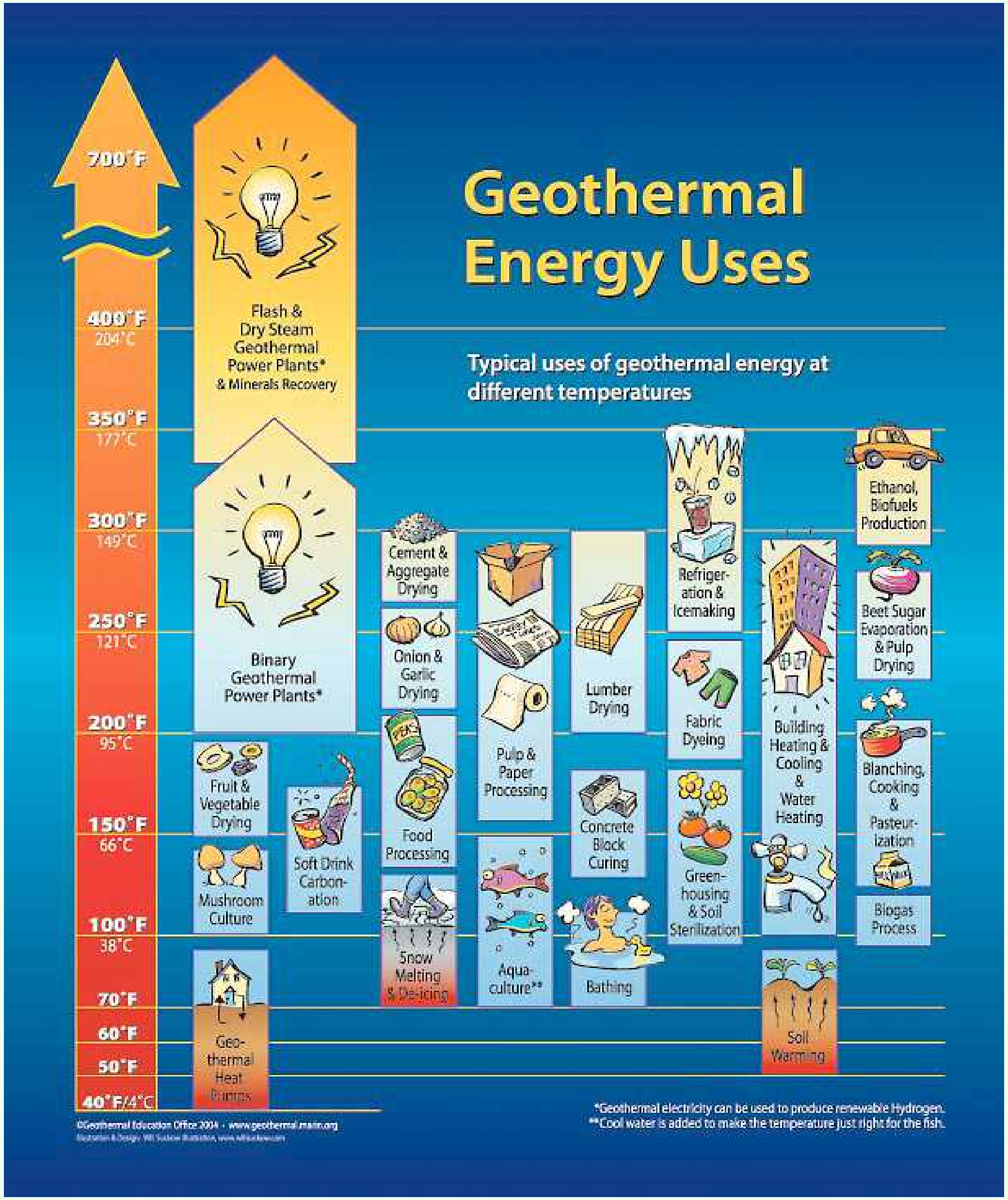
- 83% of the sites require binary plants (also, EGS/HDR will most likely need binary plants)
- And 50% of the available energy is below temperatures requiring binary plants (170C)

Source: NREL

Geothermal Resource Prospecting

The Early Years!

Geothermal Applications in Summary



Attributes of Geothermal Power

Advantages

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

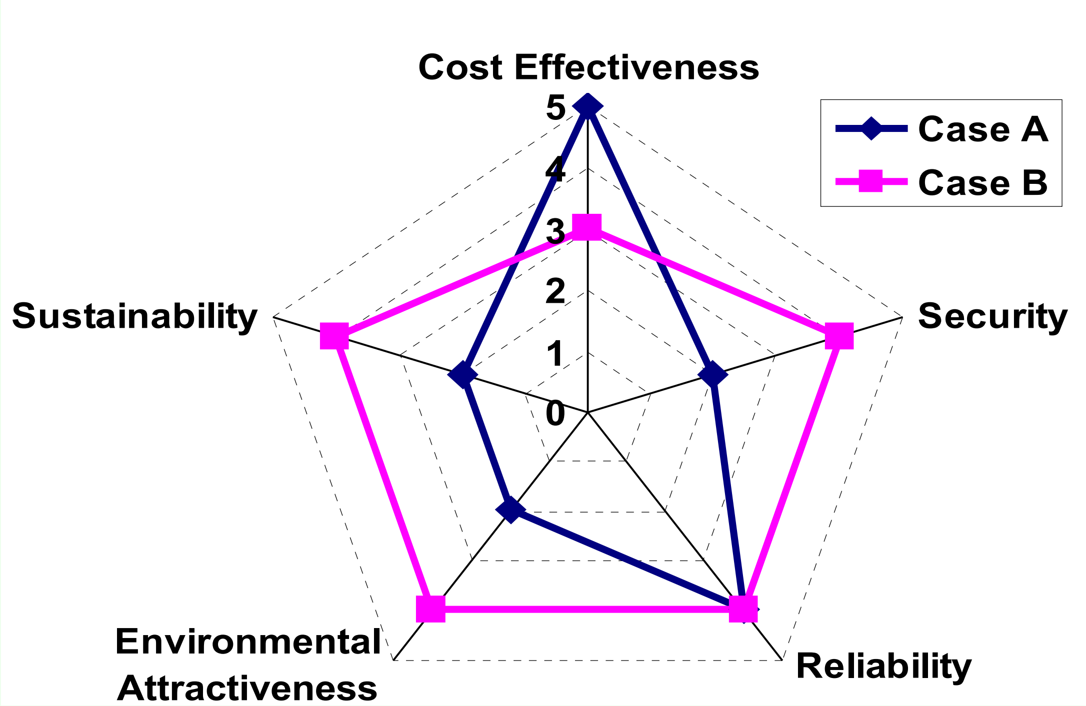
Disadvantages

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

Expected Trends in Future

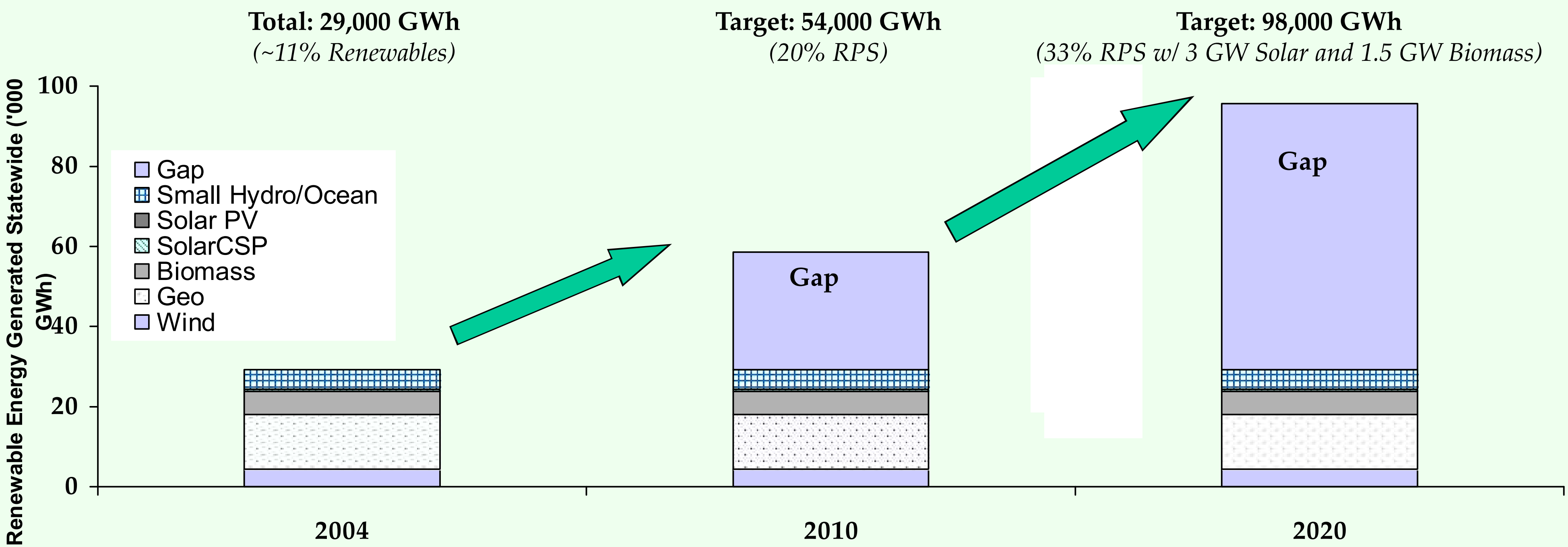
Energy System Evolution

- 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?



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

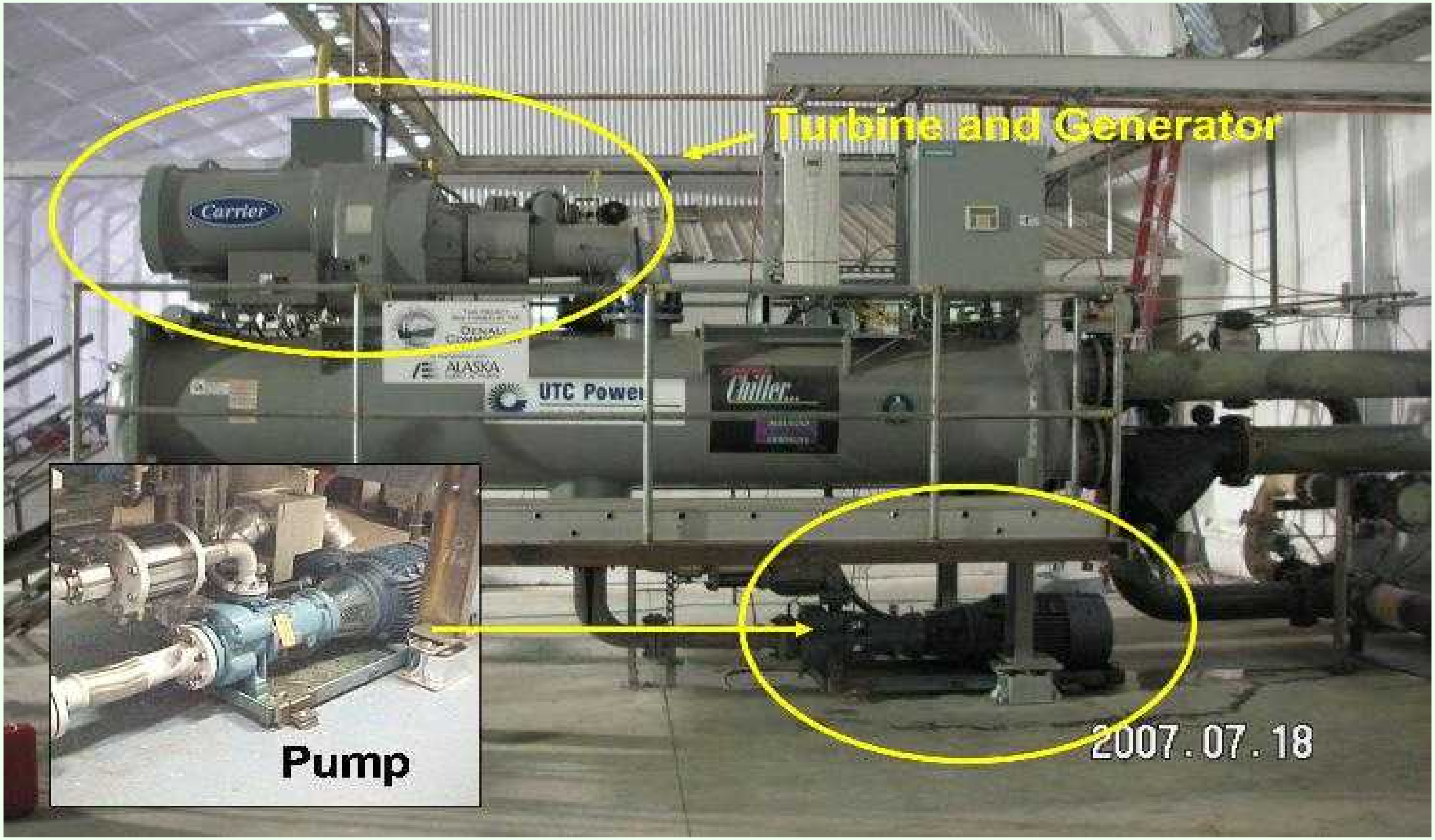


Data Sources: 2004, CEC Electricity Report which includes all renewables in the State, not just IOUs; 2010 and 2020, PIER Renewables Projections.

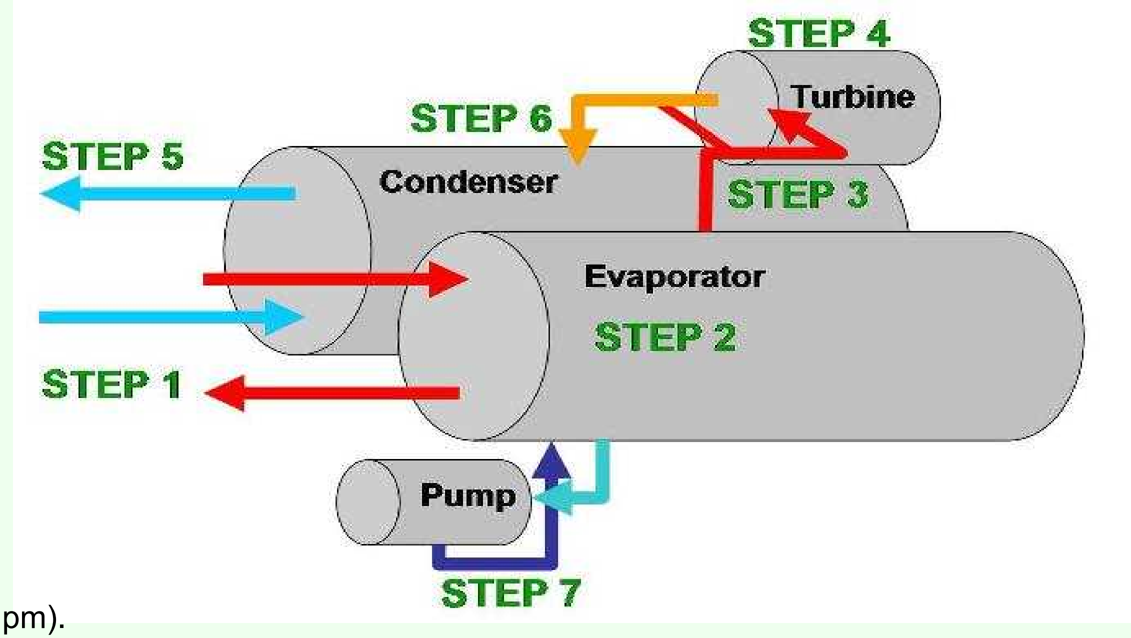
Source: CEC

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.

Small Geothermal Power Plants in the Oil Patch

Advantages for O&G industry

- Helps to service pumping
- O&G industry has similar technology and infrastructure
- Potentially supplements resources exploitation

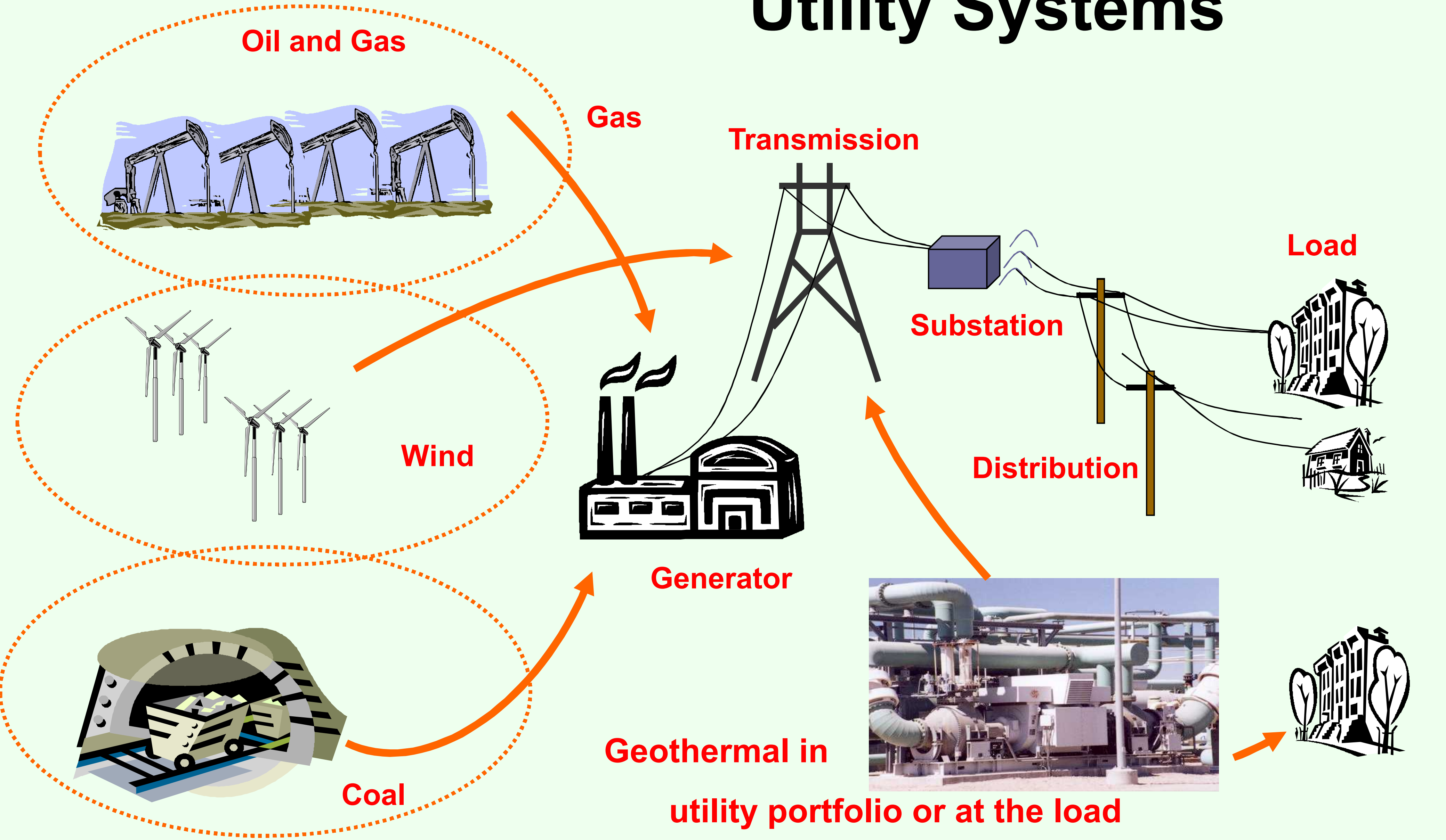
Economic advantages

- 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

You've Heard of Combined Heat and Power?

Geothermal offers combined:

Heat…………Power……… and Pleasure!

Sources: Geothermal Education Office

Geothermal Energy

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