GeoPowering the West

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

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Geothermal Technologies Program

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Sandia National Laboratories

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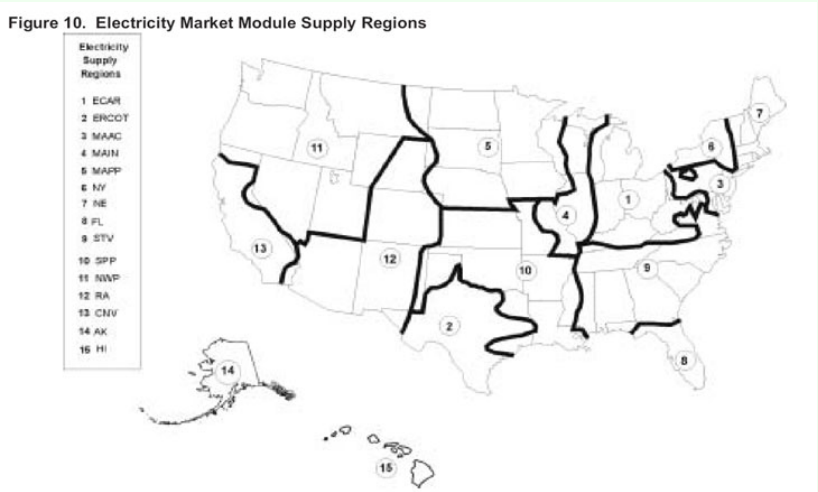
A Mean-Variance Portfolio Optimization of the Region's Generating Mix to 2013



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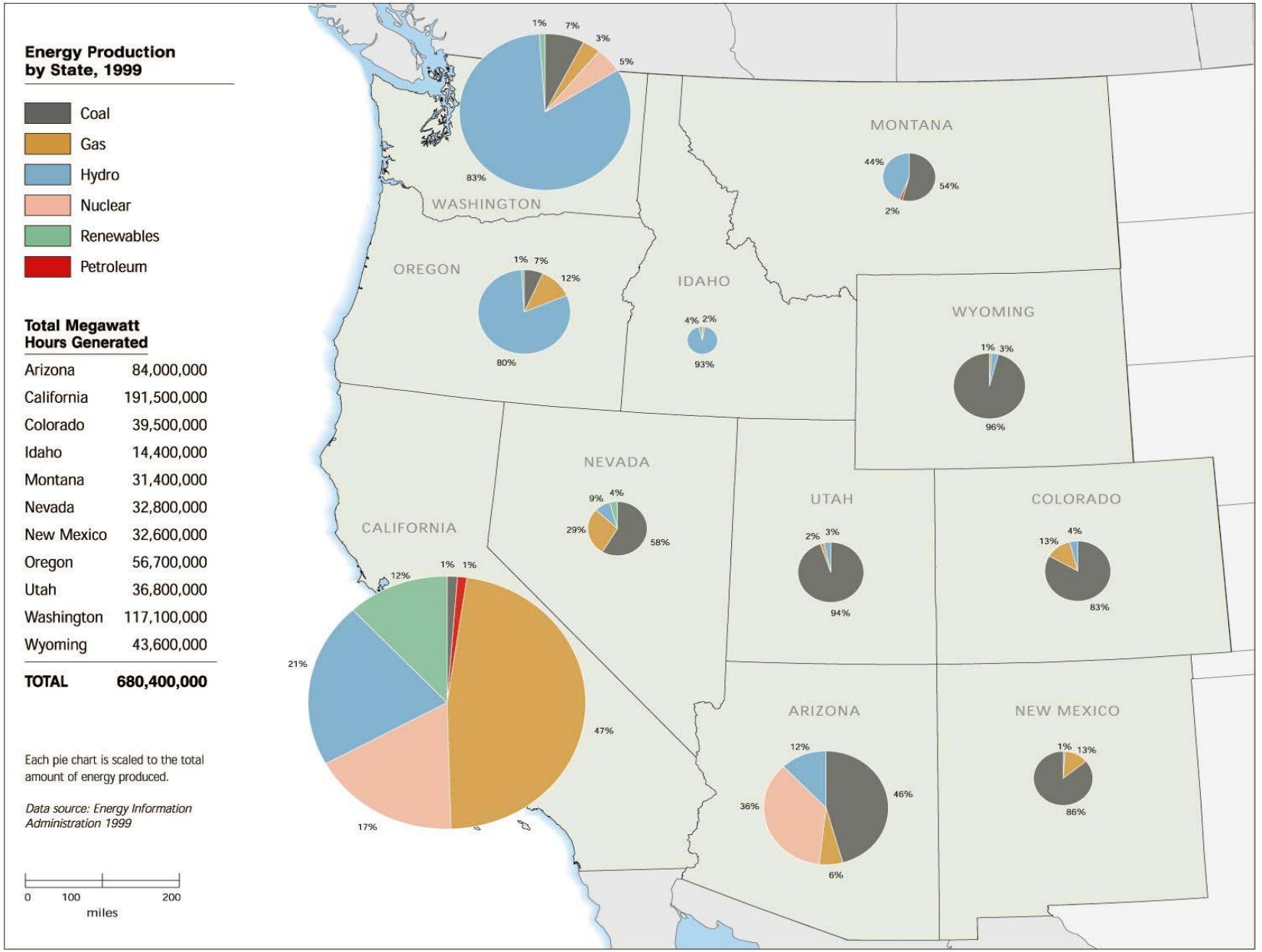
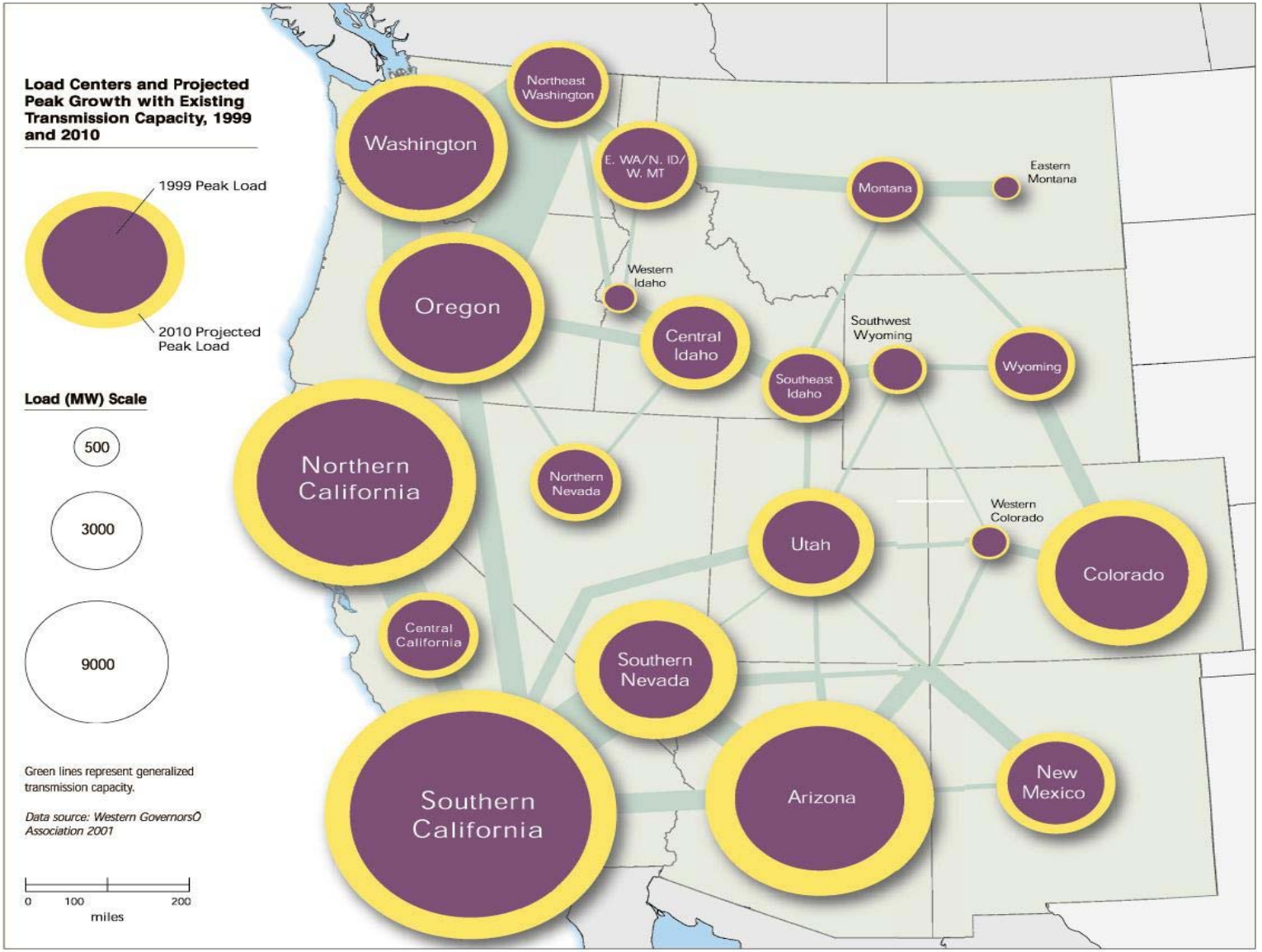
Electricity Generation



Source: Renewable Energy Atlas

Western US: Load Growth

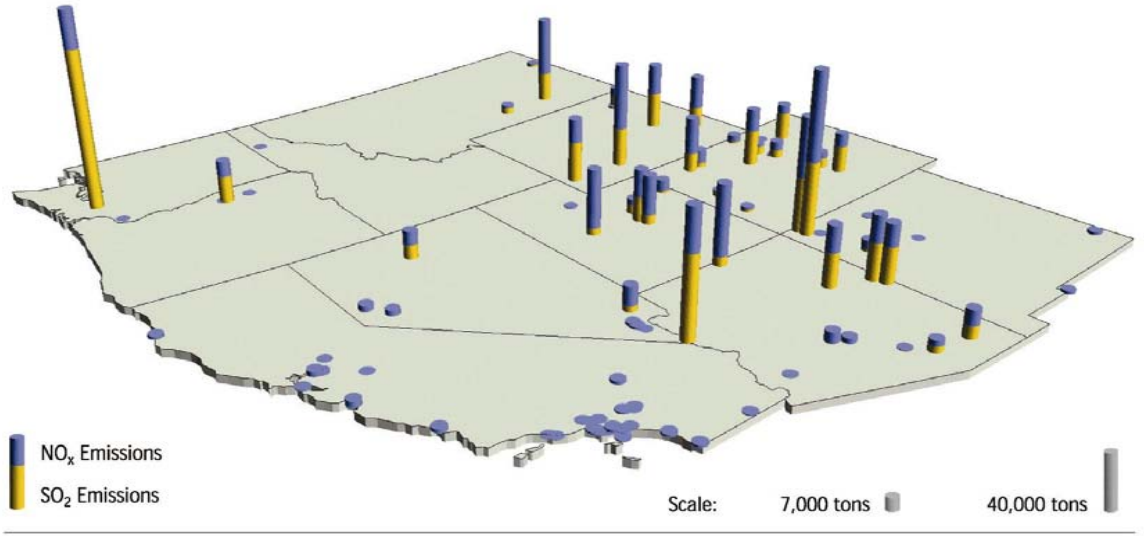


Source: Renewable Energy Atlas

Regional Power Plant Emissions

Power Plant Emissions, 2000

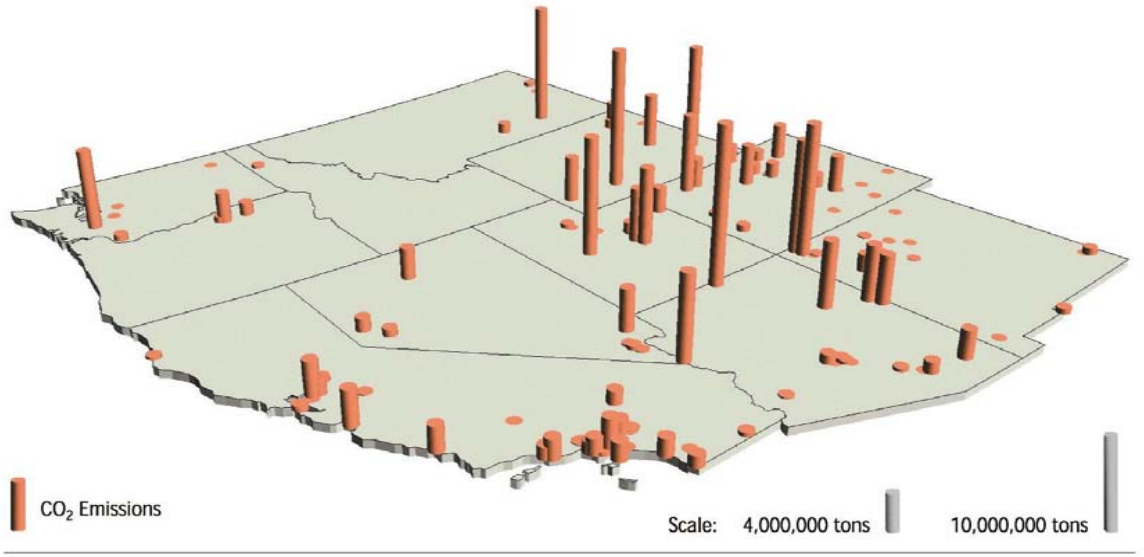
Each bar represents the location of a power plant regulated under the EPA® Acid Rain Program (Title IV). The height of the bars is scaled to reßect the emissions levels for each plant. Because CO_2 emissions are so much higher than either SO_2 or NO_x, different scaling factors were used to determine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

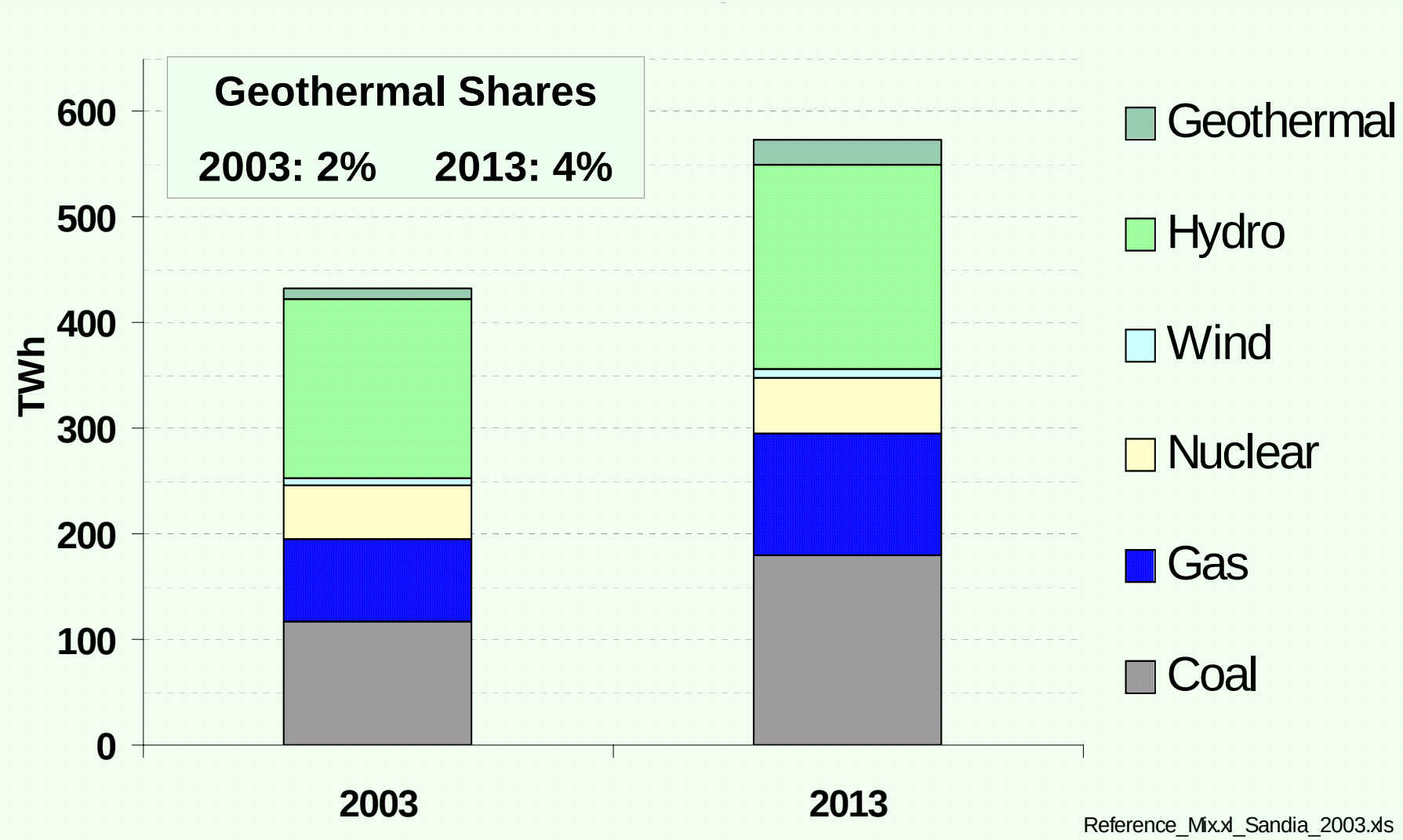


Source:
Renewable Energy Atlas

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)

Technology	2003		2013	
	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)

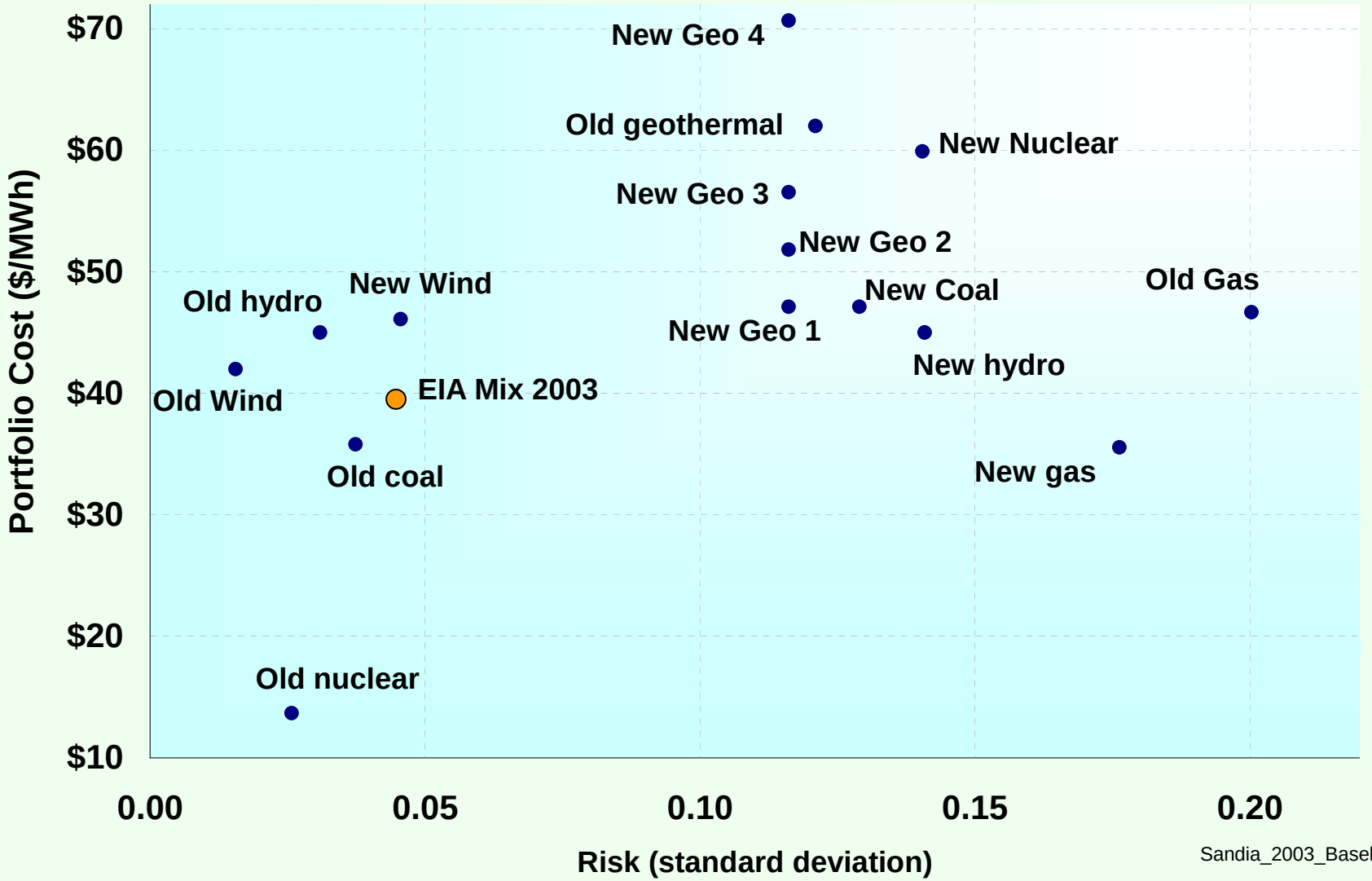
Technology	2003		2013	
	Existing	New	Existing	New
Coal	$0.037	$0.049	$0.049	$0.068
Gas	$0.048	$0.037	$0.075	$0.067
Nuclear	$0.014	$0.062	$0.018	$0.081
Wind	$0.043	$0.047	$0.056	$0.062
Hydro	$0.046	$0.046	$0.060	$0.060
Geothermal	$0.064		$0.083	
New Geo 1		$0.049		$0.060
New Geo 2		$0.053		$0.066
New 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

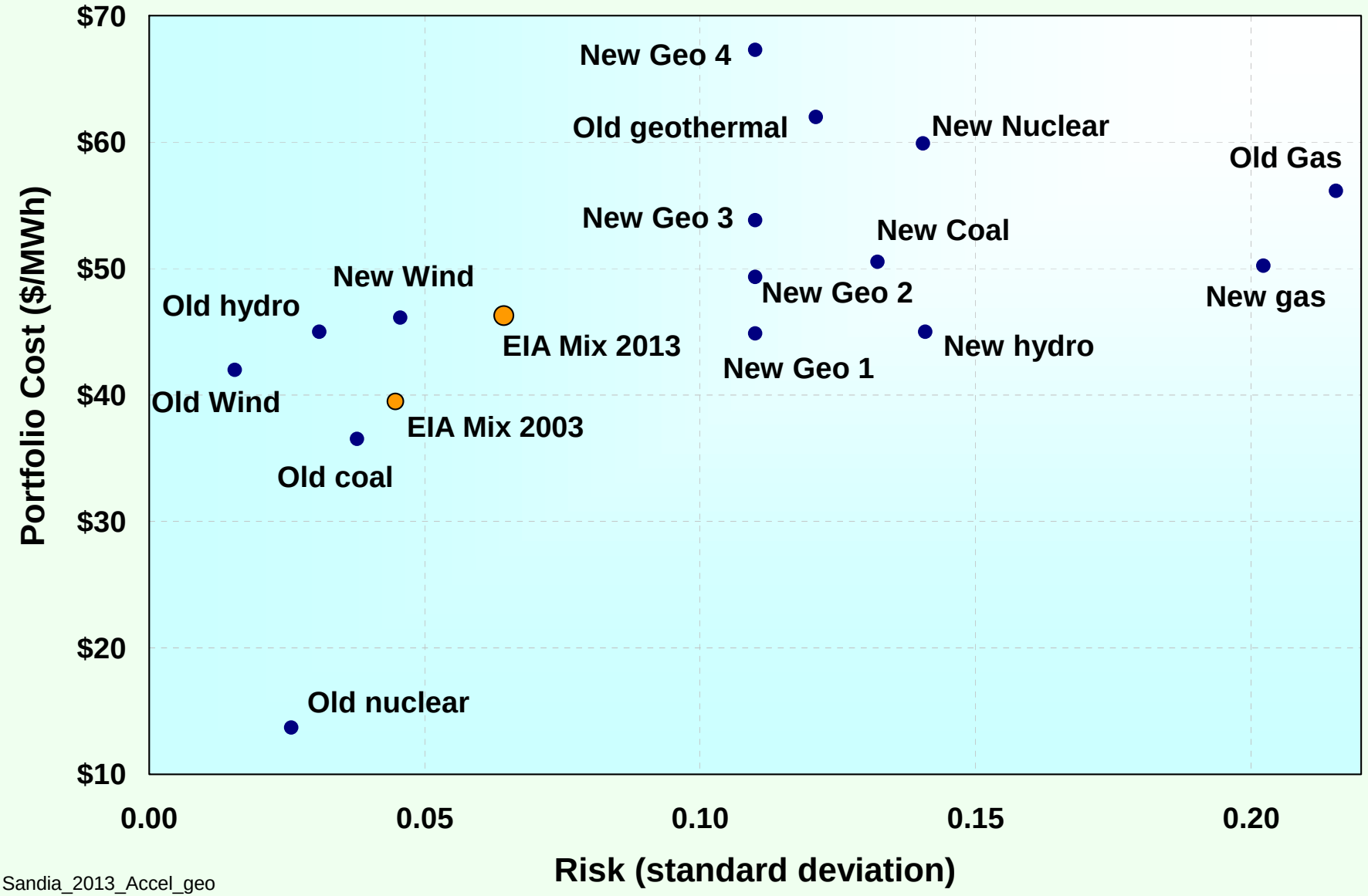
- **Portfolio optimization locates generating mixes with minimum expected cost and risk**
- **For each technology, risk is the year-to-year variability (standard deviation) of the three generating cost inputs: fuel, O&M and capital (construction period risk)**
  - Fossil fuel standard deviations are 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

2003 EIA Technology Generating Costs and Estimated Technology Risk



Sandia_2003_Baseline.xls

2013 EIA Technology Generating Costs
and Estimated Technology Risk

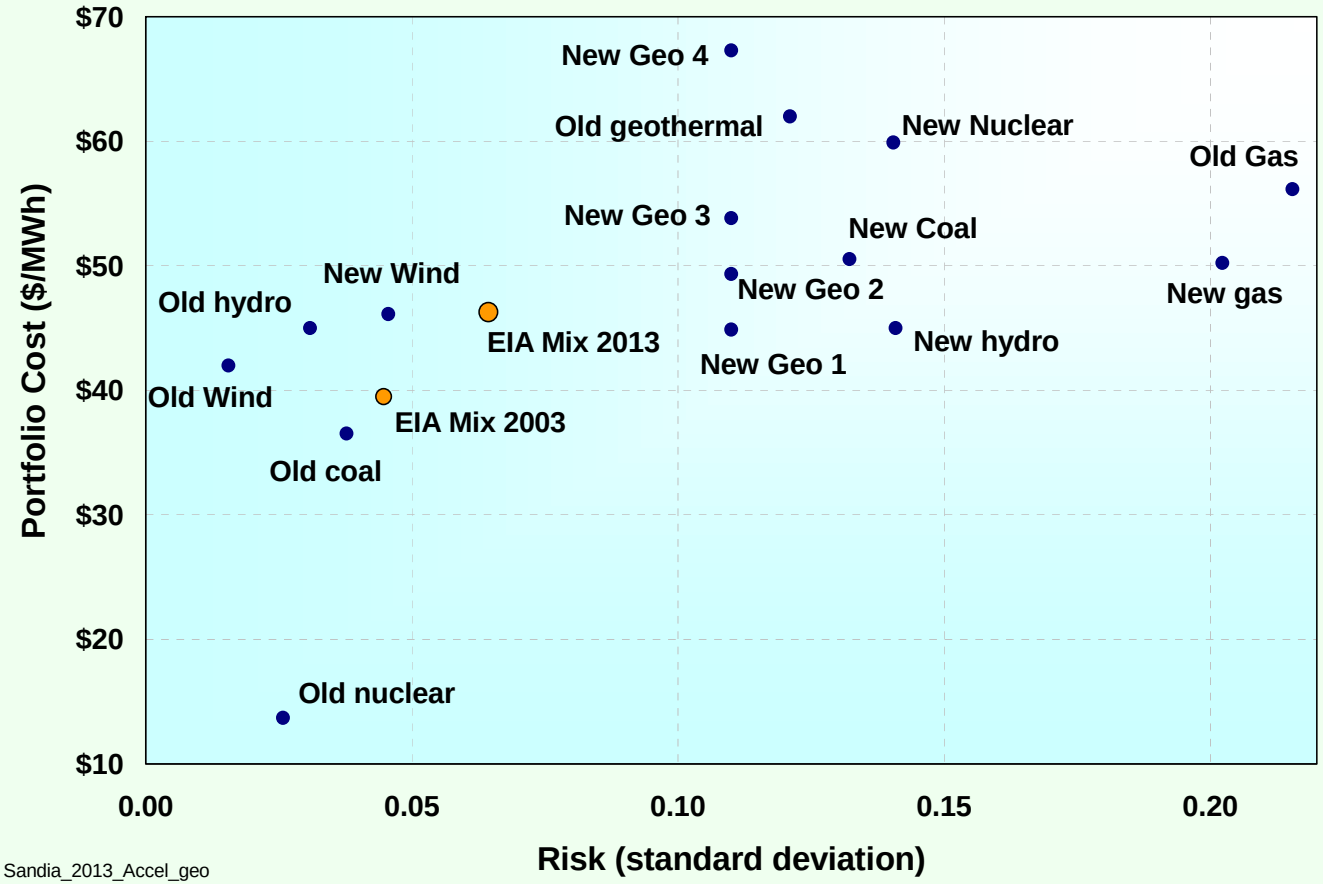


Sandia_2013_Accel_geo

Western Region Generating Cost-Risk Trends

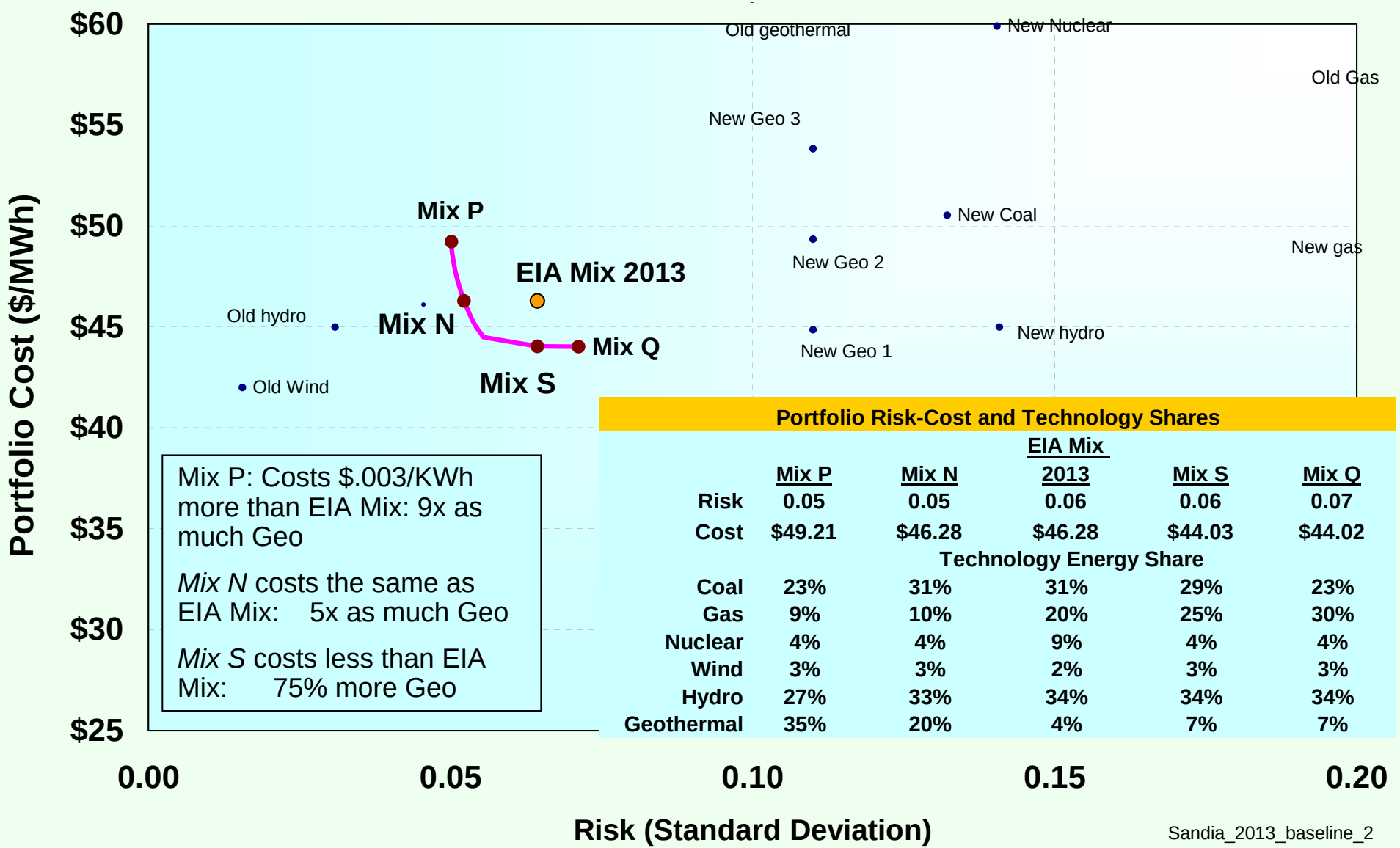
- **2013 EIA Mix has higher cost and risk relative to 2003**
  - Driven by 32% demand increase, decommissioning existing plant, resource shortages and limitations on available options
- **Move to larger gas/coal shares adds to portfolio cost and risk**
  - Increases year-to-year expected generating cost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

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



Sandia_2013_Accel_geo

2013 Baseline Portfolio Optimization



Mix P: Costs $.003/KWh more than EIA Mix: 9x as much Geo

Mix N costs the same as EIA Mix: 5x as much Geo

Mix S costs less than EIA Mix: 75% more Geo

Portfolio Risk-Cost and Technology Shares

	Mix P	Mix N	EIA Mix 2013	Mix S	Mix Q
Risk	0.05	0.05	0.06	0.06	0.07
Cost	$49.21	$46.28	$46.28	$44.03	$44.02
			Technology Energy Share		
Coal	23%	31%	31%	29%	23%
Gas	9%	10%	20%	25%	30%
Nuclear	4%	4%	9%	4%	4%
Wind	3%	3%	2%	3%	3%
Hydro	27%	33%	34%	34%	34%
Geothermal	35%	20%	4%	7%	7%

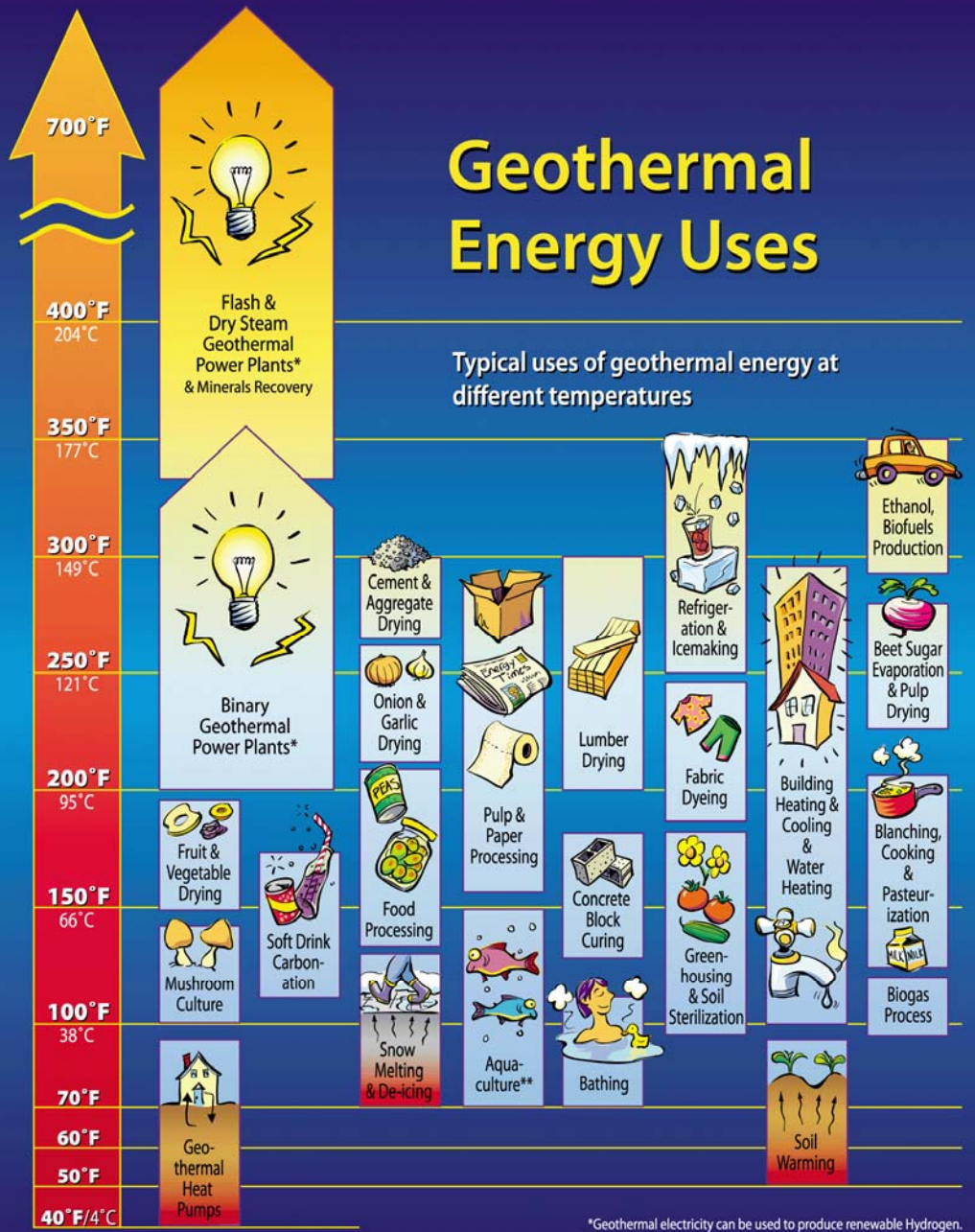
Sandia_2013_baseline_2

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 Energy Uses

Typical uses of geothermal energy at different temperatures



*Geothermal electricity can be used to produce renewable Hydrogen.
**Cool water is added to make the temperature just right for the fish.

A Vision for the Future

- Ready Access to Land
- Thoroughly Mapped and Developed Resources
- Cost Competitive Technology

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