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

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

Prepared for Sandia National Labs

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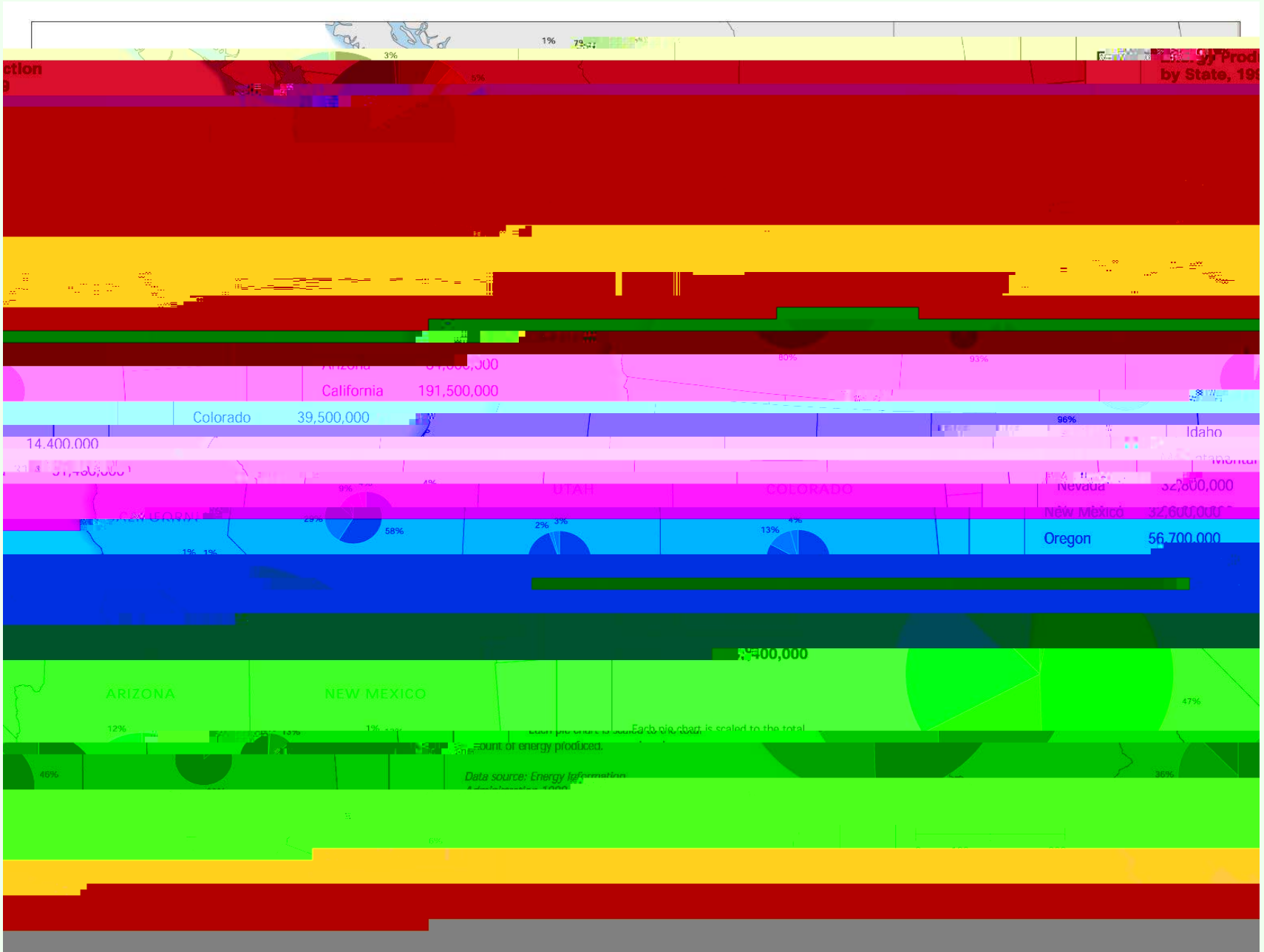
Electricity Generation

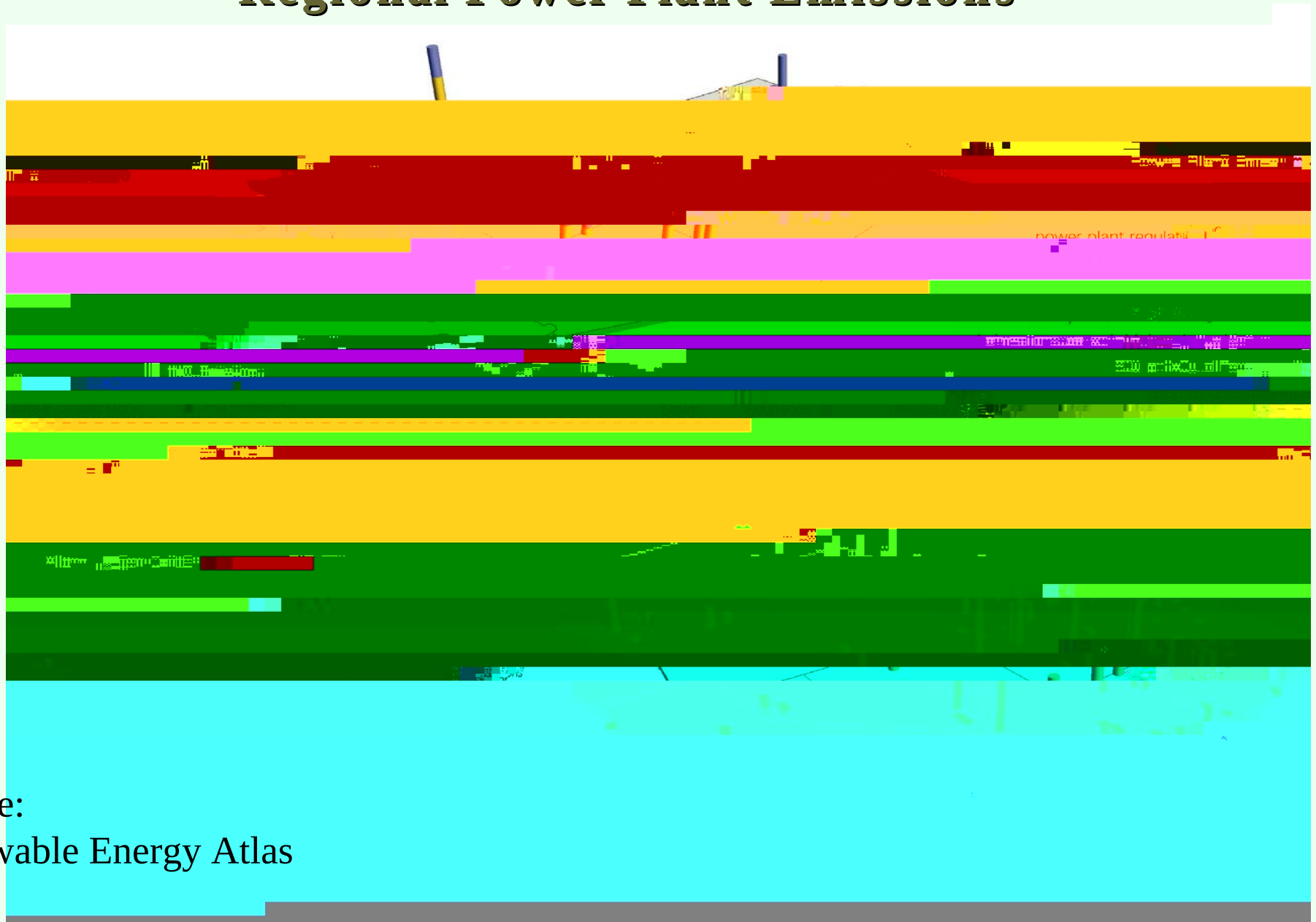


Source: Renewable Energy Atlas

Western US: Load Growth

Source: Renewable Energy Atlas

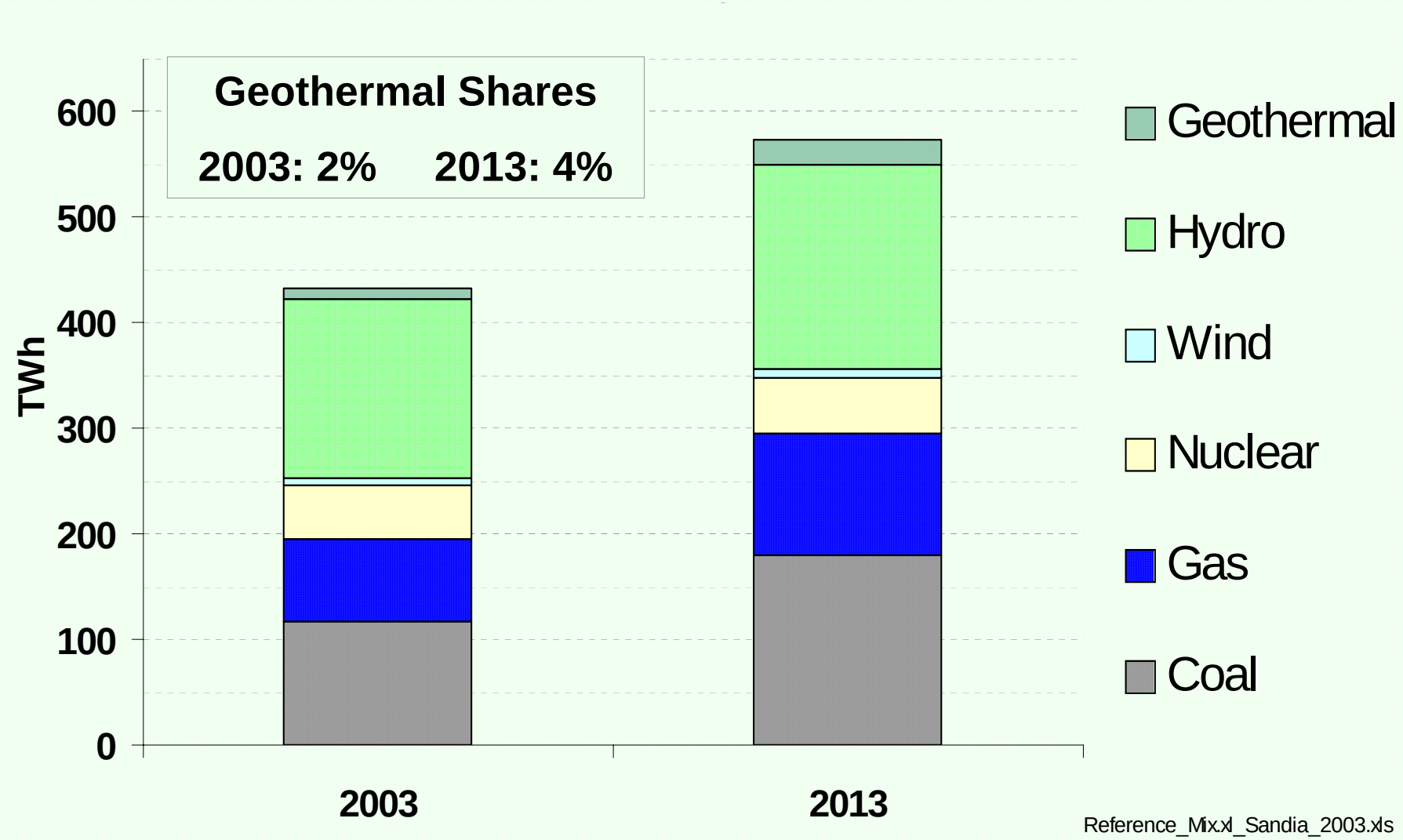
Regional Power Plant Emissions



Source:
Renewable Energy Atlas

Optimization Defines Four Bands for New Geothermal Based es Tc -0inB 5x25Bi for

EIA 2003 and 2013 Generating Mixes



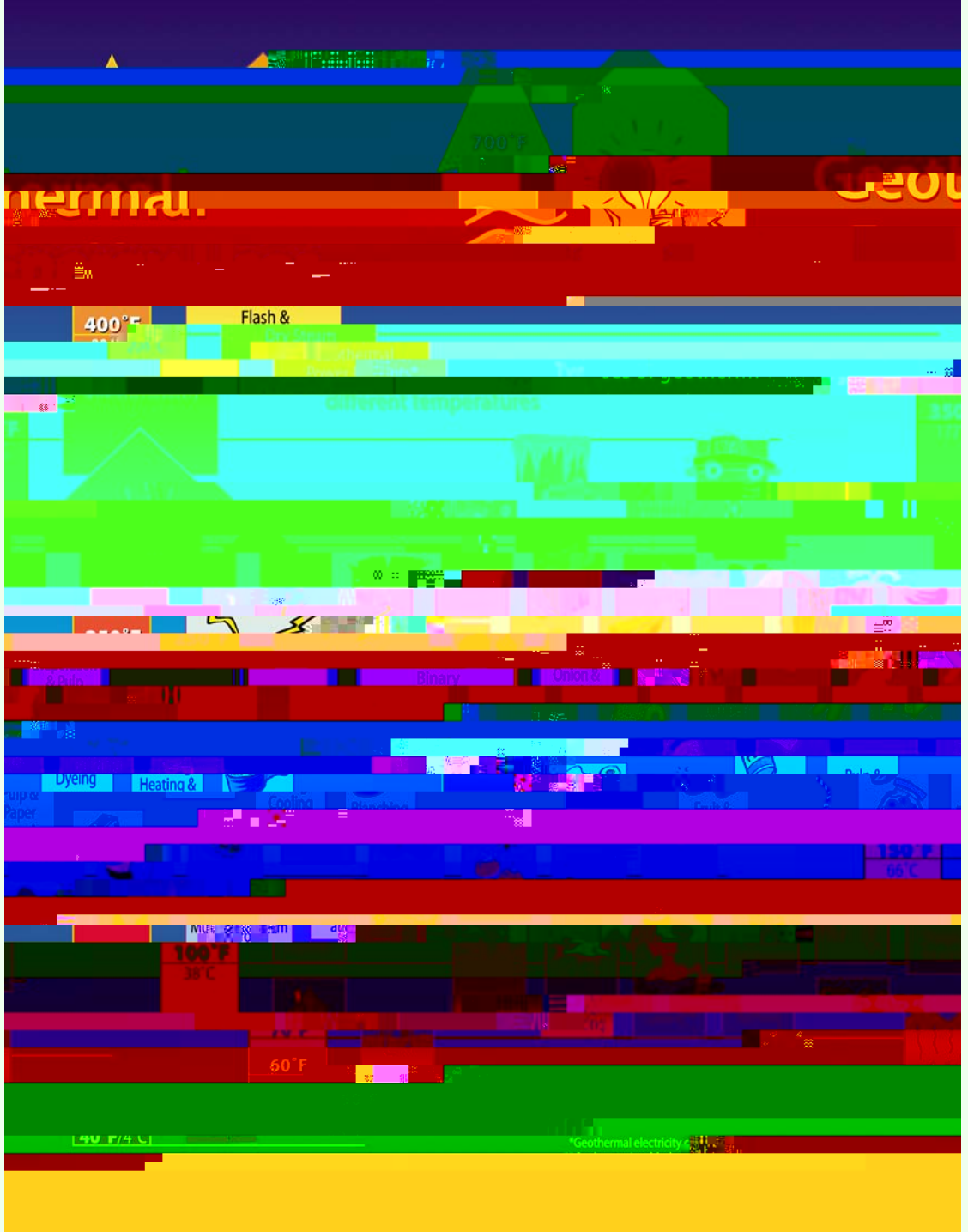
Generating Cost Inputs: Nominal $/kWh

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

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


700˚F
400˚F
Flash &
Binary
Dyeing
Heating &
Cooling
150˚F
65˚C
100˚F
38˚C
50˚F
40˚F/4˚C
*Geothermal electricity c