A Nuclear Wind/Solar Oil-Shale System for Variable Electricity and Liquid Fuels Production

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Outline

- Goals
- Nuclear Shale-Oil
- Nuclear Shale-Oil Renewable Electricity
- Environmental Impacts
- Challenges
- Conclusions

Nuclear Renewable Shale-Oil Goals

No Imported Oil

Reduce Trade Deficit

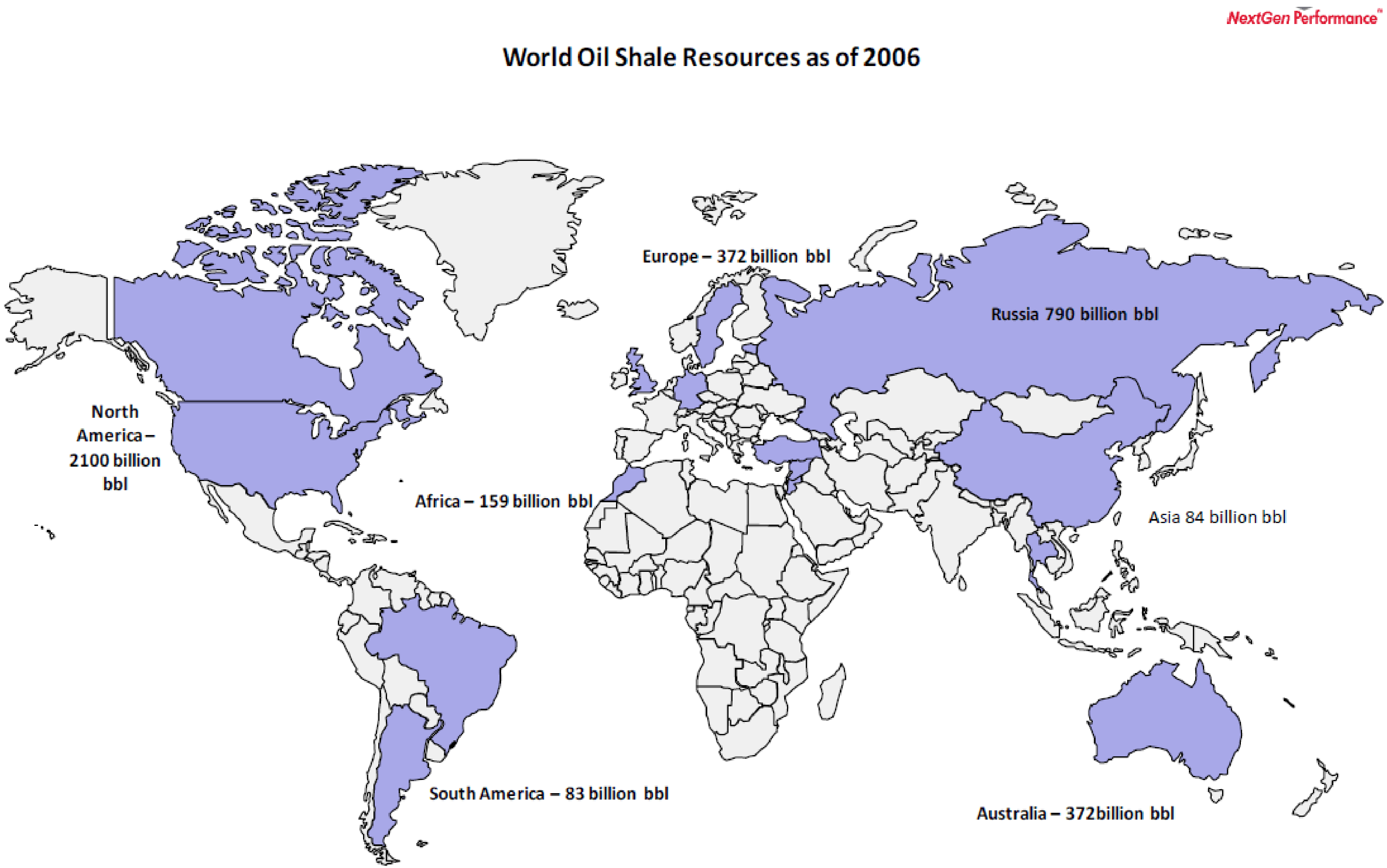
Reduce Greenhouse Gas Releases

Use Of America's Fossil Fuel

Enable Renewables

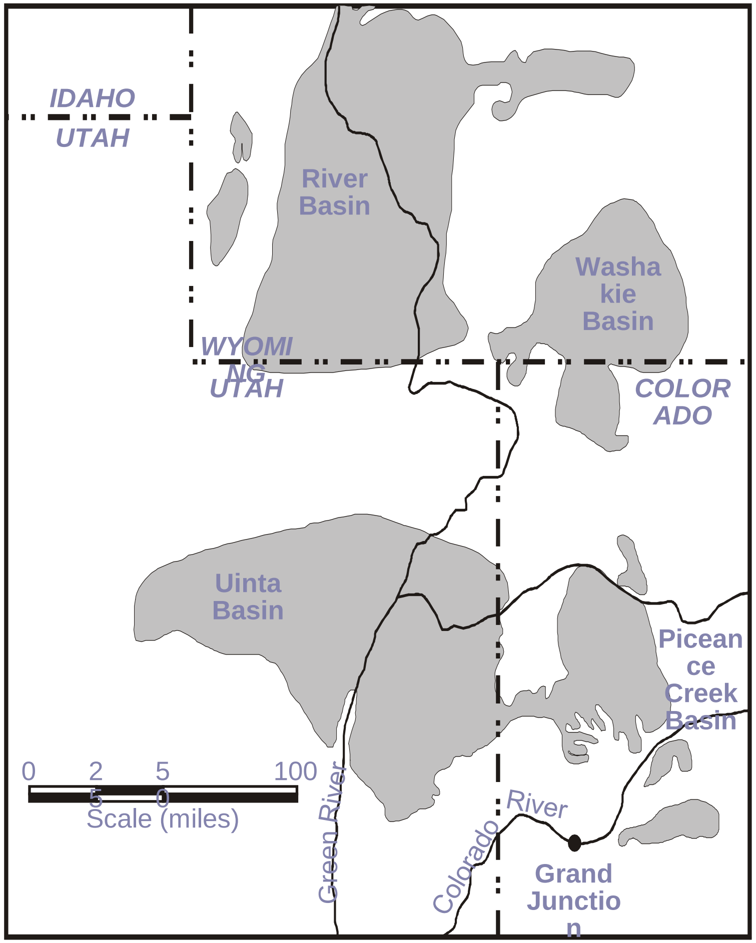
Nuclear Shale-Oil Systems

The U.S. Has 60% of Global Shale Oil



U.S. Oil Shale Could Replace Conventional Oil

- Green River recoverable reserves ~1.4 trillion barrels of oil
- Total world production of oil to date is 1.1 trillion barrels
- ~1 million barrels of oil per acre; Most concentrated fossil fuel on earth
- Pilot plants in operation



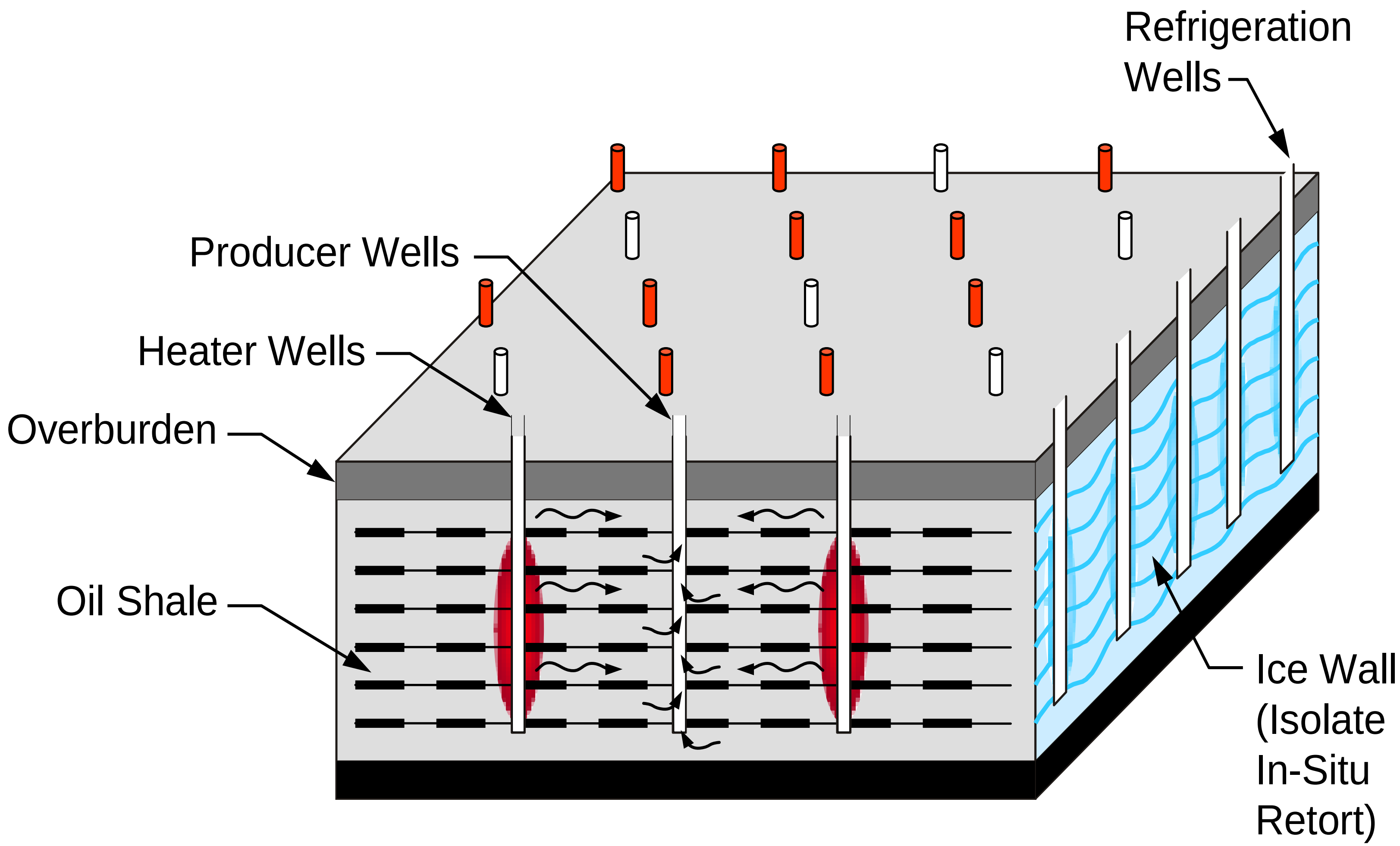
Conventional Shale Oil Production

Reserves Exceed Mideast Oil

- Oil shale contains no oil but instead kerogen
- Heat kerogen to 370°C underground to produce oil, gas, and carbon char
- Current strategy
  - Burn one quarter of oil and gas product to heat shale
  - Large carbon dioxide release during production
- Slow underground heating process over a year—can add heat at a variable rate

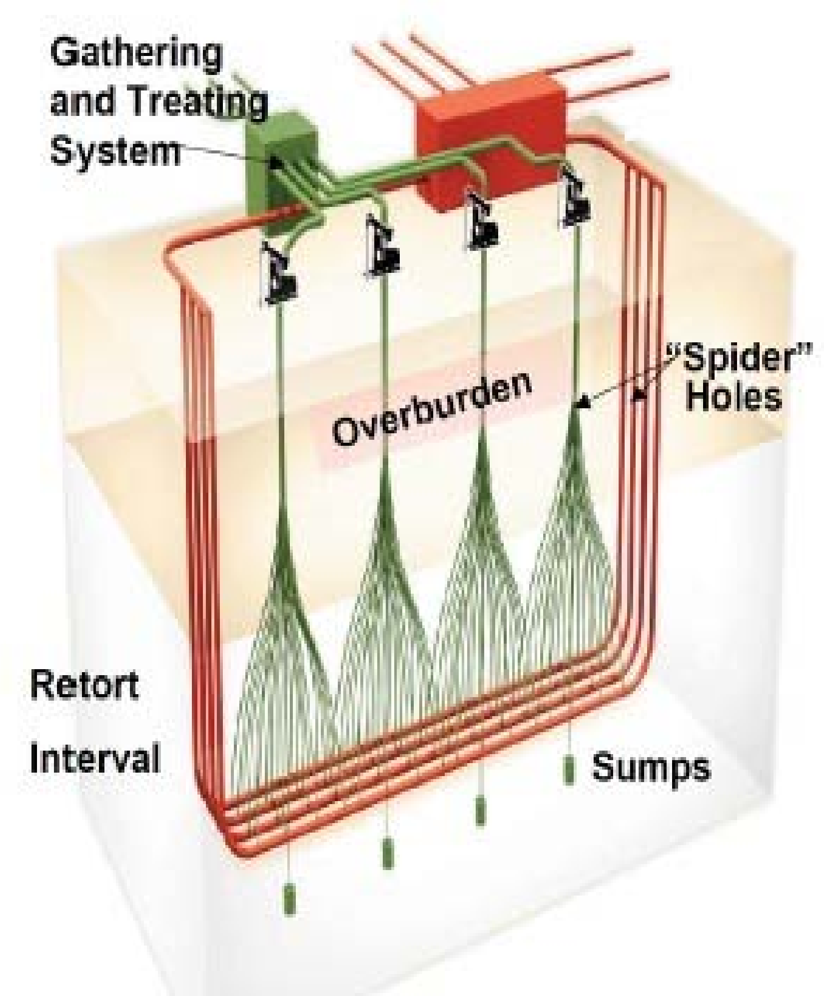
The Shell In Situ Conversion Process:

Heat Oil Shale Electrically to Release Liquid Fuel



Can Use Nuclear Heat (Steam in Pipes) For In-Situ Oil Shale Retorting

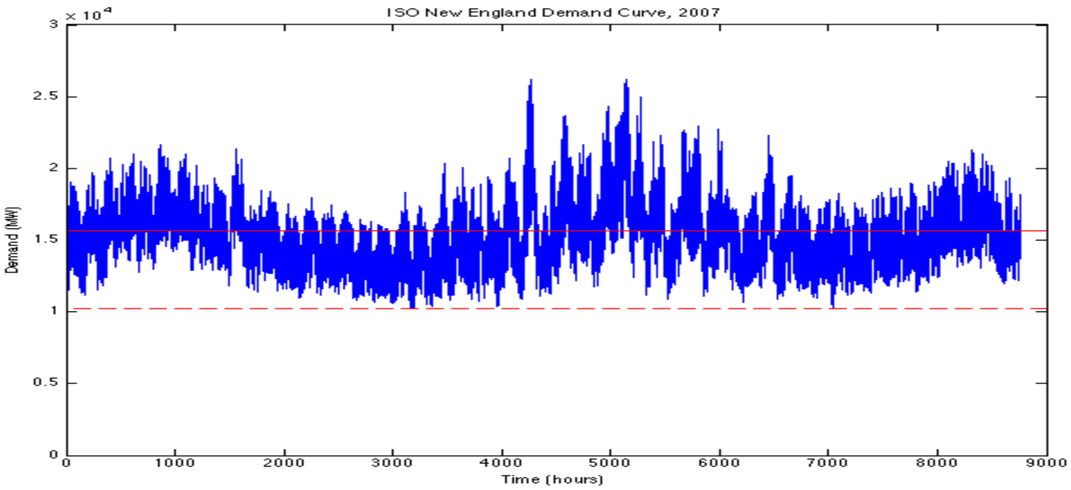
- Heat kerogen in oil shale rock to 370°C
  - Very slow heating process
  - Several years
- Avoids burning fossil fuels to produce heat
- Low-greenhouse-gas fossil liquid-fuels option



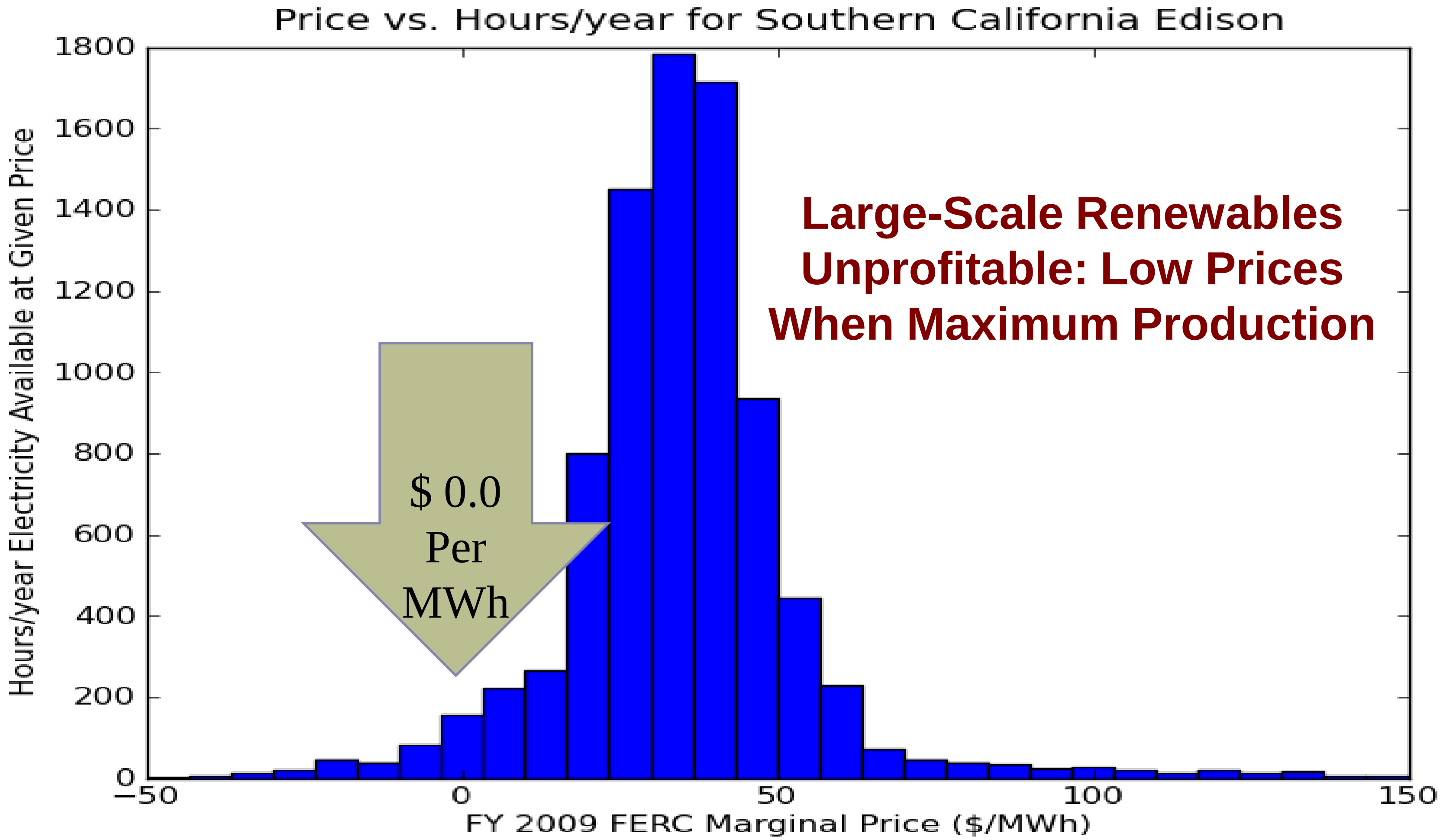
Nuclear Shale-Oil
Renewable Electricity Systems

The Renewables Challenge

- Wind and solar do not match electricity demand
- Variable backup power from fossil power plants with large greenhouse gas releases

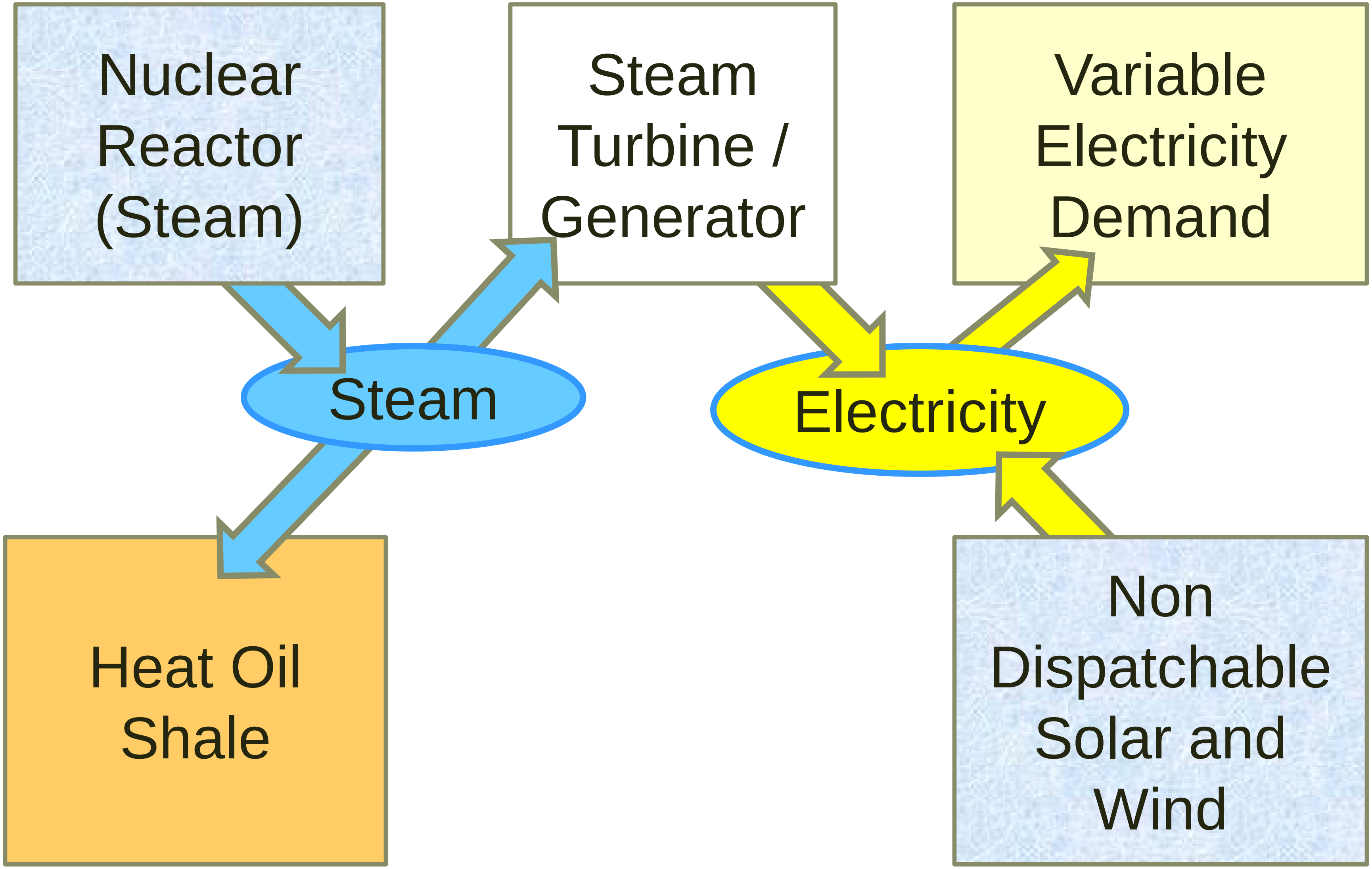


Deregulated Electricity Markets Have Low- and Negative-Priced Electricity

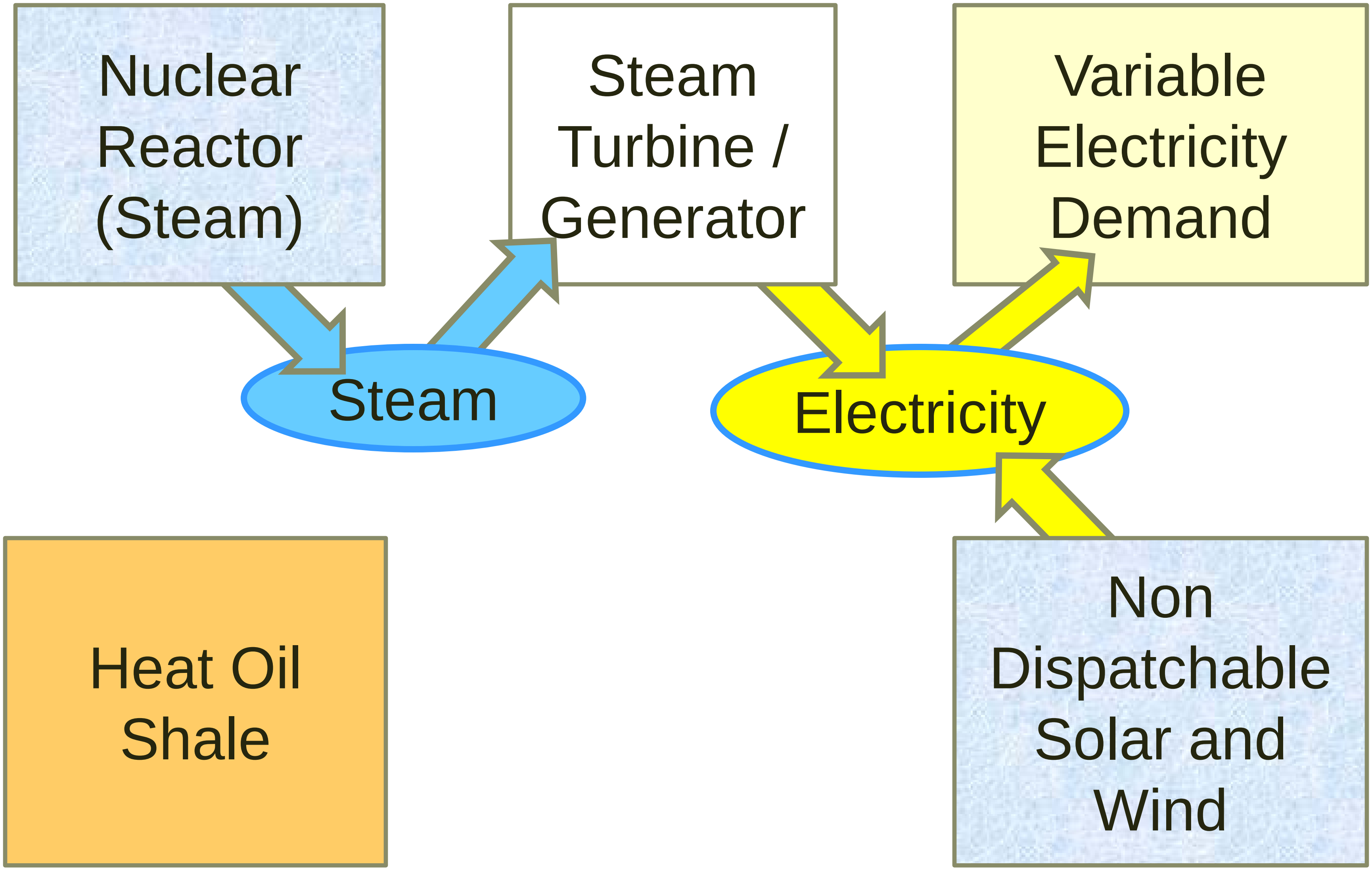


Nuclear Shale-Oil System for Variable Electricity

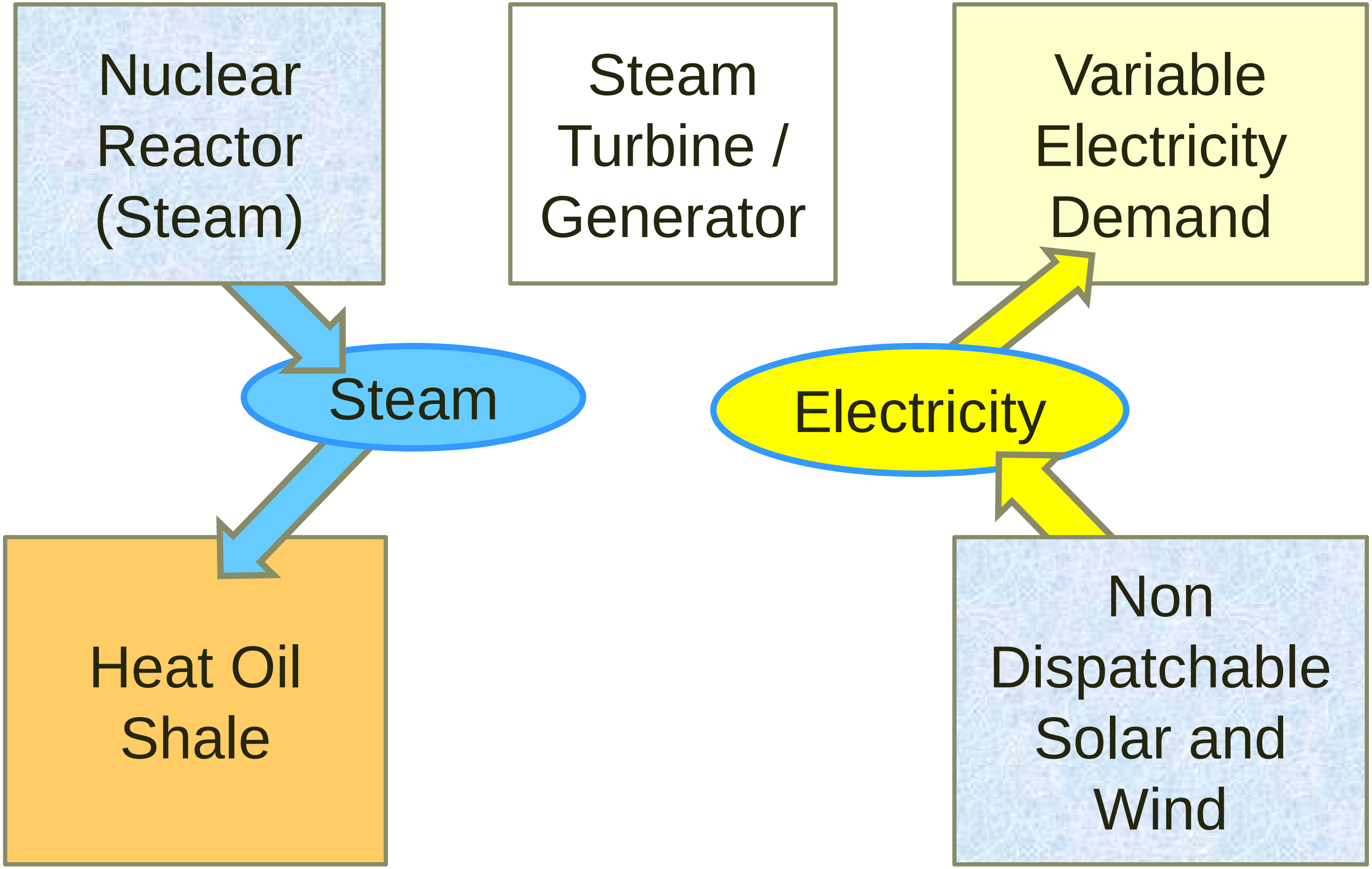
Nuclear Plant Base-Load Operations



Ideal Operations When High Electricity Prices



Ideal Operations When Low Electricity Prices



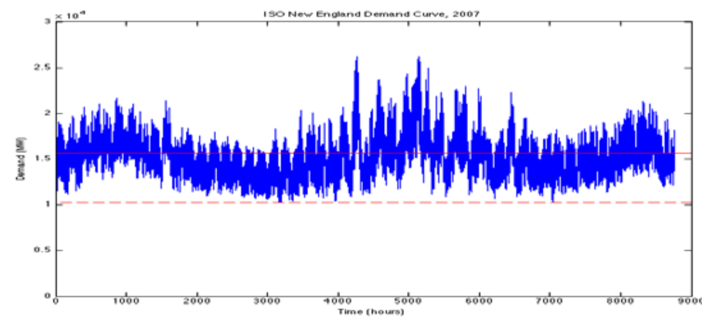
Nuclear Shale-Oil Renewable System

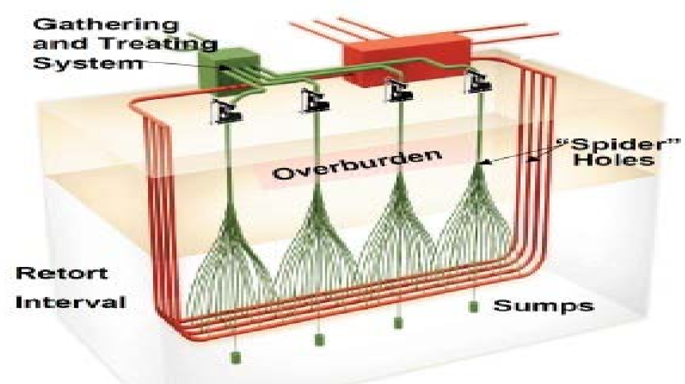
- Base-load nuclear: Maximize revenue by avoiding sale of low-priced electricity
- Enables renewables—Cheaper backup electricity
- No fossil fuels for variable electricity production

Electricity

Electricity

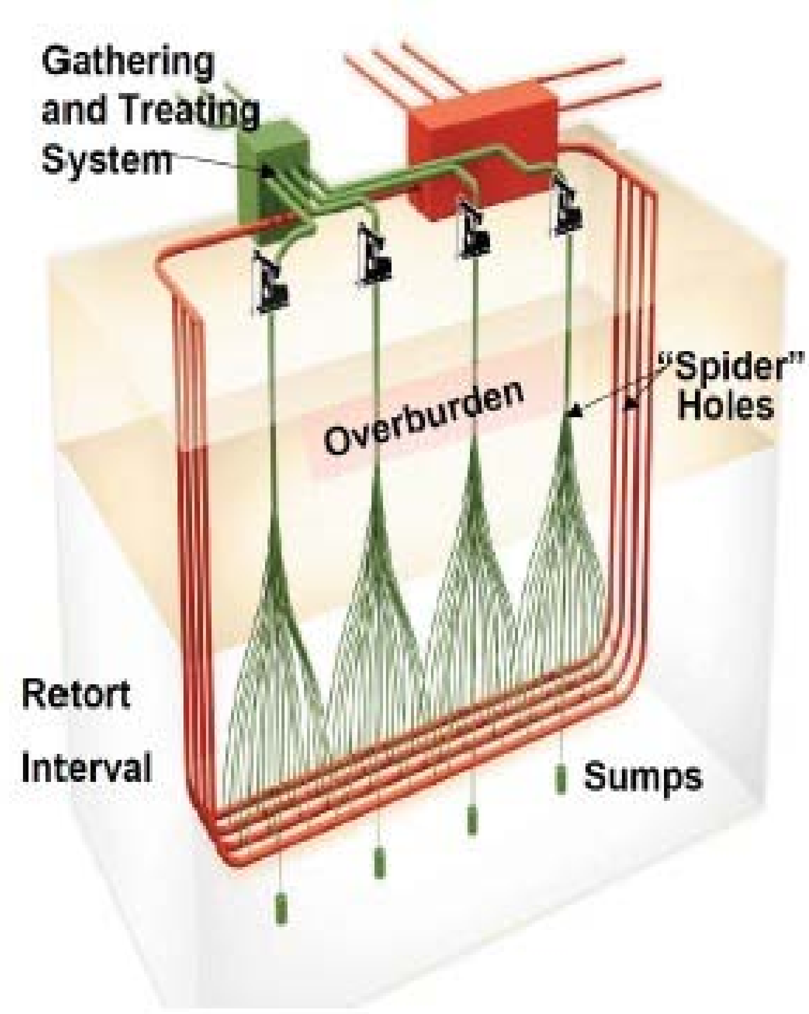
Heat





Unique Characteristics of System

- Heating oil shale is slow
  - 1 to 2 years
  - Almost no economic penalty for variable heat input
- Total heat input to replace 10 million barrels of oil per day: 200 GWt
- Only large process heat market where variable heat input is economically viable



Nuclear Renewable Shale-Oil Can Cut CO_2 Footprint per Vehicle Mile in Half

- Example: 3-GWy nuclear heat
  - 1-GWy to oil shale yielding **4 GWy** shale oil and gas
  - 2-GWy to variable electricity production
- Nuclear heat replaces 2-GWy fossil fuels for variable electricity production
- CO_2 credit from avoided fossil fuels for variable electricity (**2-GWy**) applied to shale oil
- Cut greenhouse liquid-fuel footprint in half with variable electricity that enables renewables

Has Lowest Environmental Impact of Any Liquid Fossil Fuel Option

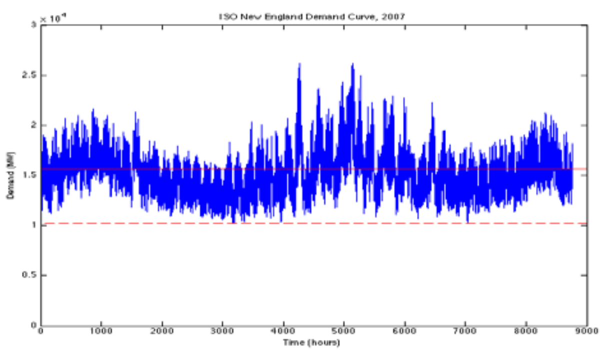
The Clean Fossil Fuel

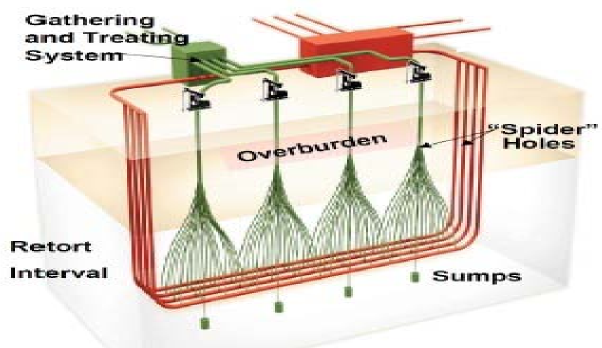
- Lowest greenhouse gas emissions per liter gasoline
- Most concentrated fossil fuel deposits on earth: 1 to 3 million barrels oil per acre
- Lowest environmental impacts per liter gasoline
  - Minimize land use
  - Minimize oil and gas transport from production system
  - Minimize equipment inputs per barrel of oil

Technical / Institutional Challenges

- Technical: Limited Studies
  - Shale oil technology in pilot state
  - Nuclear not adapted for shale oil production today
- Institutional
  - Stove-piped R&D, regulations, and energy companies
  - U.S. political divided
  - Rethink of entire energy system

Questions





http://canes.mit.edu/sites/default/files/pdf/NES-115.pdf

Backup Information

A Nuclear Wind/Solar Oil-Shale System for Variable Electricity and Liquid Fuels Production

Abstract – *The recoverable reserves of oil shale in the United States exceed the total quantity of oil produced to date worldwide. Oil shale contains no oil, rather it contains kerogen which when heated decomposes into oil, gases, and a carbon char. The energy required to heat the kerogen-containing rock to produce the oil is about a quarter of the energy value of the recovered products. If fossil fuels are burned to supply this energy, the greenhouse gas releases are large relative to producing gasoline and diesel from crude oil.*

The oil shale can be heated underground with steam from nuclear reactors leaving the carbon char underground—a form of carbon sequestration. Because the thermal conductivity of the oil shale is low, the heating process takes months to years. This process characteristic in a system where the reactor dominates the capital costs creates the option to operate the nuclear reactor at base load while providing variable electricity to meet peak electricity demand and heat for the shale oil at times of low electricity demand. This, in turn, may enable the large scale use of renewables such as wind and solar for electricity production because the base-load nuclear plants can provide lower-cost variable backup electricity.

Nuclear shale oil may reduce the greenhouse gas releases from using gasoline and diesel in half relative to gasoline and diesel produced from conventional oil. The variable electricity replaces electricity that would have been produced by fossil plants. The carbon credits from replacing fossil fuels for variable electricity production, if assigned to shale oil production, results in a carbon footprint from burning gasoline or diesel from shale oil that may half that of conventional crude oil. The U.S. imports about 10 million barrels of oil per day at a cost of a billion dollars per day. It would require about 200 GW of high-temperature nuclear heat to recover this quantity of shale oil—about two-thirds the thermal output of existing nuclear reactors in the United States. With the added variable electricity production to enable renewables, additional nuclear capacity would be required.

Biography: Charles Forsberg

Dr. Charles Forsberg is the Executive Director of the Massachusetts Institute of Technology Nuclear Fuel Cycle Study, Director and principle investigator of the High-Temperature Salt-Cooled Reactor Project, and University Lead for Idaho National Laboratory Institute for Nuclear Energy and Science (INEST) Nuclear Hybrid Energy Systems program. Before joining MIT, he was a Corporate Fellow at Oak Ridge National Laboratory. He is a Fellow of the American Nuclear Society, a Fellow of the American Association for the Advancement of Science, and recipient of the 2005 Robert E. Wilson Award from the American Institute of Chemical Engineers for outstanding chemical engineering contributions to nuclear energy, including his work in hydrogen production and nuclear-renewable energy futures. He received the American Nuclear Society special award for innovative nuclear reactor design on salt-cooled reactors. Dr. Forsberg earned his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. He has been awarded 11 patents and has published over 200 papers.

http://web.mit.edu/nse/people/research/forsberg.html

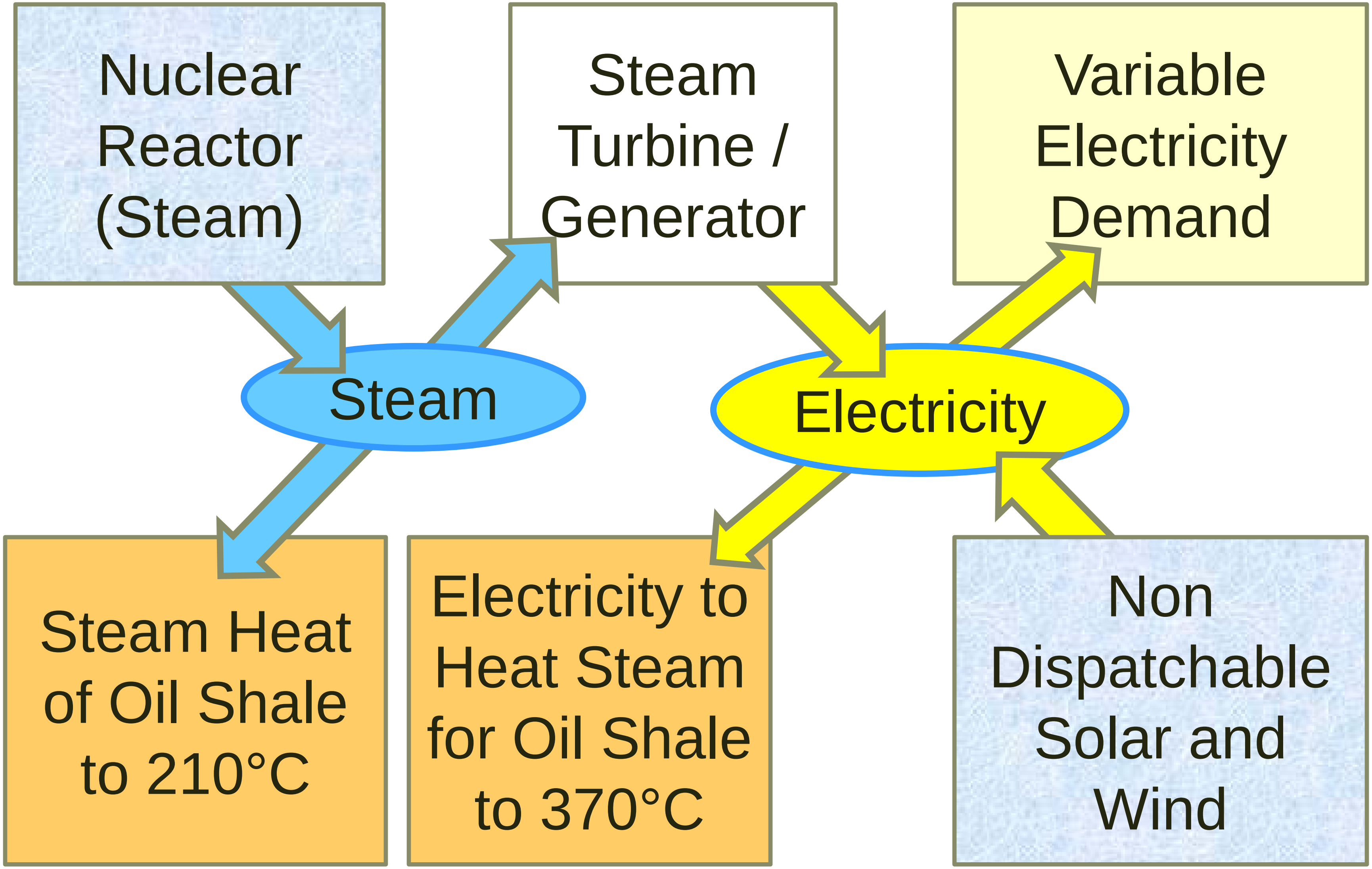
Light-Water Reactors for Nuclear Shale-Oil Renewable System

Is This the Market for Small Modular LWRs?

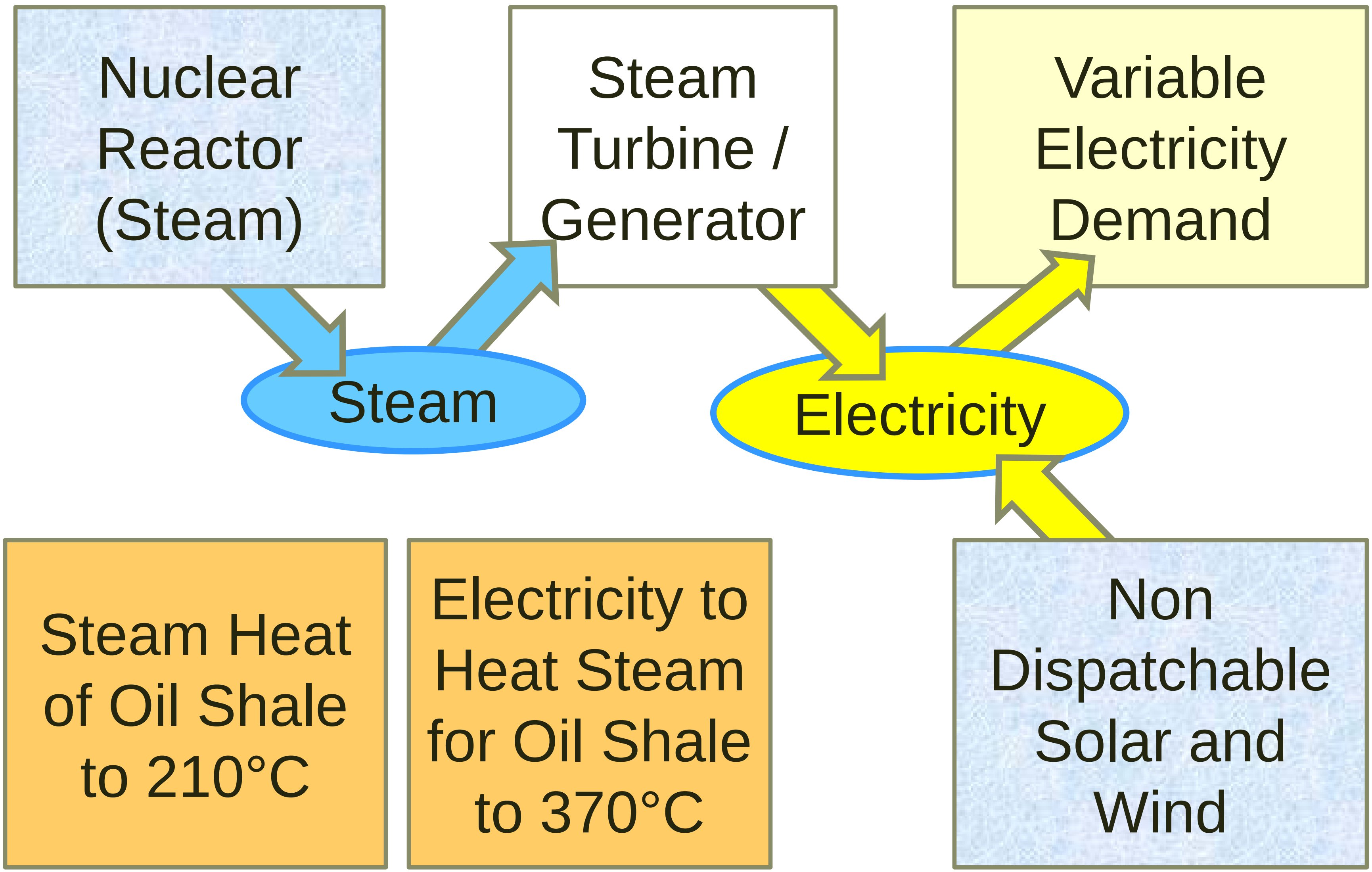
Challenges for Using LWRs
Need to Heat Oil Shale to 370°C

- Need 450°C when account for temperature drops
- Two stage process
  - Steam heat to 210°C
  - Electric heat to 370°C
- 2/3 steam requirements relative to electrical heat
  - One-sixth for steam heat
  - One-half for steam to make electricity to heat oil shale

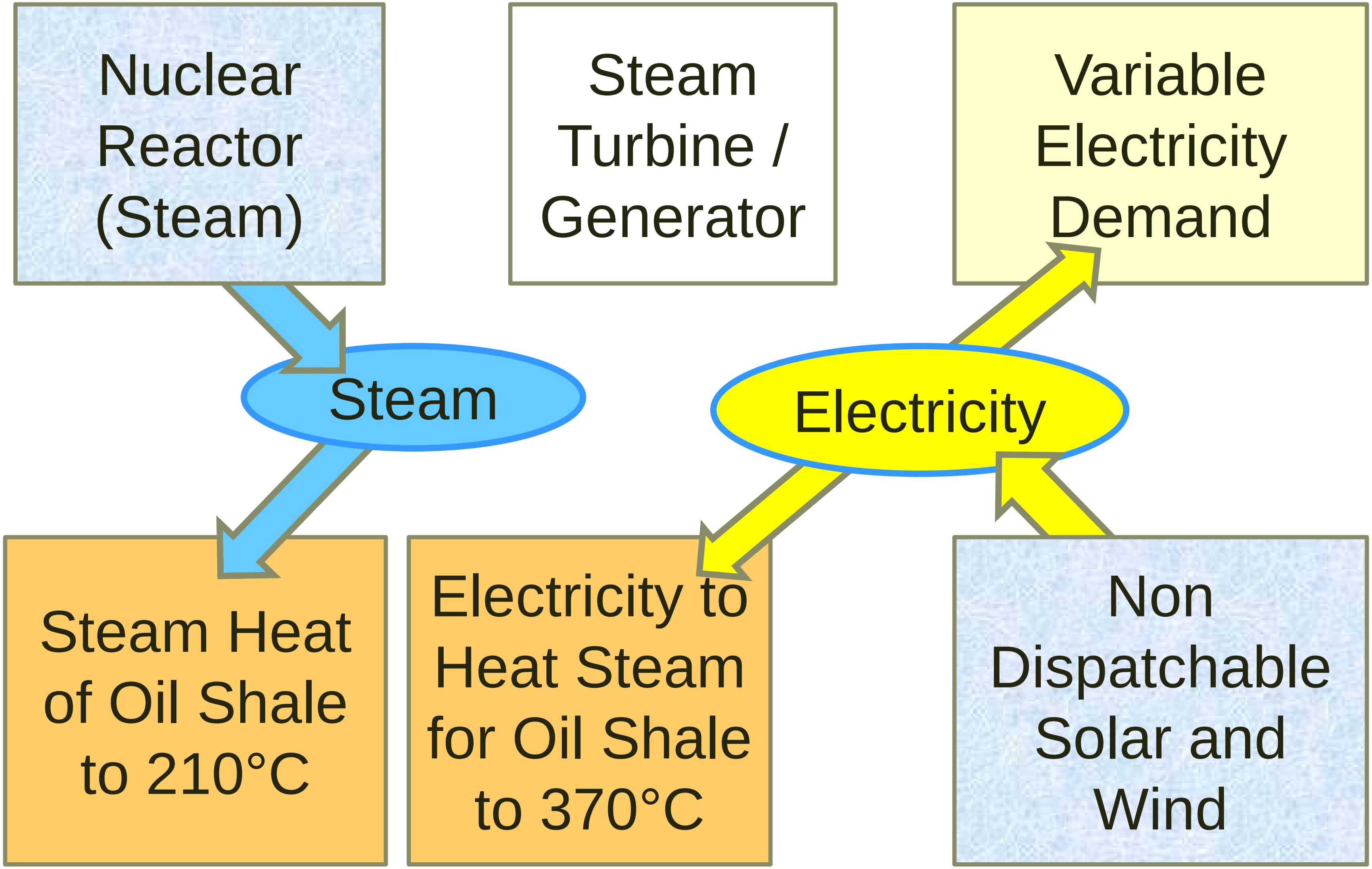
LWR Renewables Shale-Oil System



Operations When High-Electricity Prices



Operations When Low-Electricity Prices



Is This the Market for Small Modular Reactors?

- Steam lines to oil shale limited by distance
  - Some locations with 60-year 1000 MWe demand
  - Other locations 60-year steam demand is smaller
- Locations far from waterways but rail access
- May need dry cooling: Simpler with small reactors