

Nuclear Energy and Nuclear Futures

Dr. Charles Forsberg

Oak Ridge National Laboratory
P.O. Box 2008; Oak Ridge, TN 37831-6165
Tel: (865) 574-6783; E-mail: forsbergcw@ornl.gov

Environmental Writing Class
University of Tennessee
Knoxville, Tennessee
Tuesday; October 12, 2004

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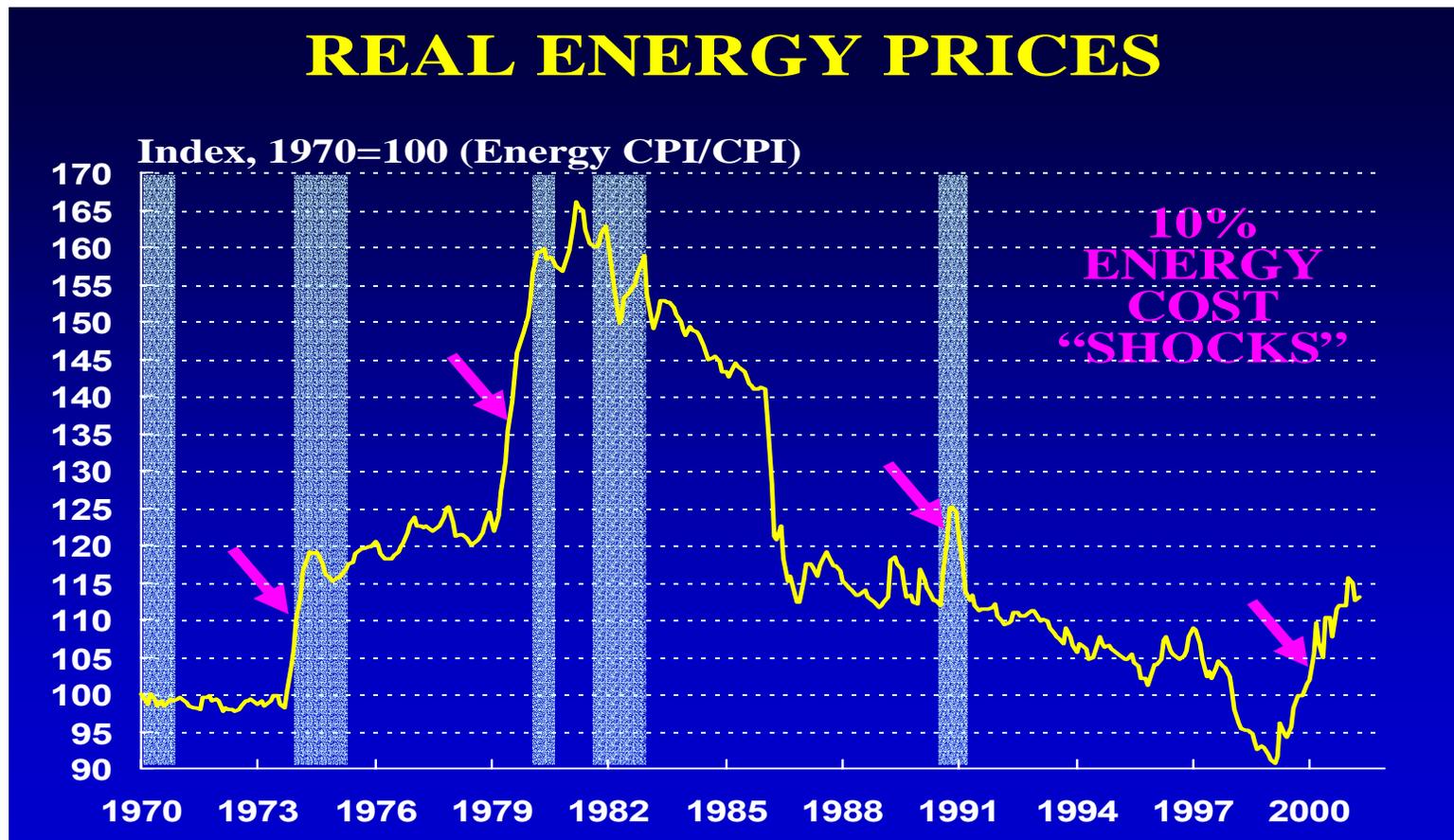
Our Society Requires Energy



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UT-BATTELLE

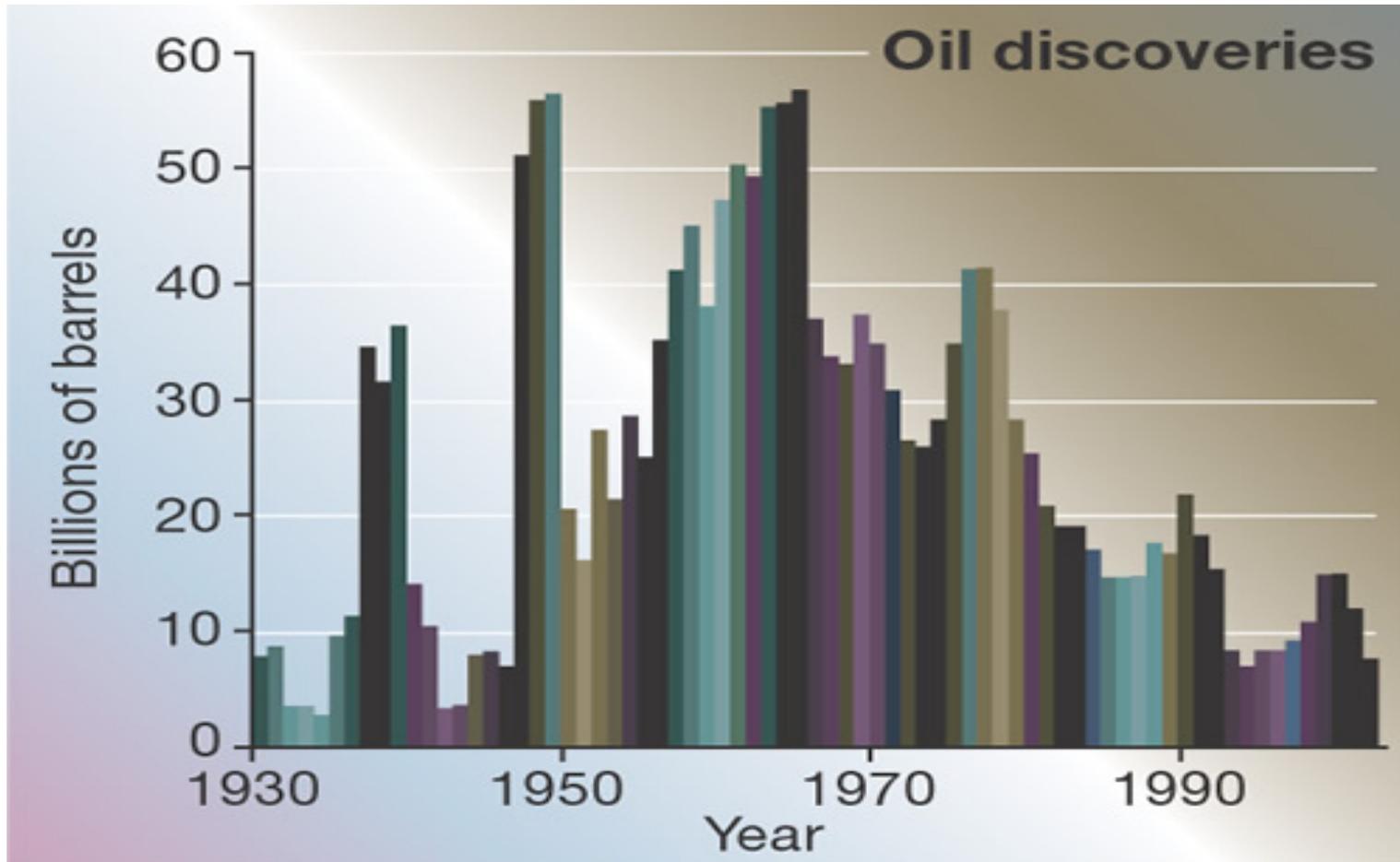
Rising Energy Costs have Often Preceded Economic Recessions



Energy Realities

No Free Lunch

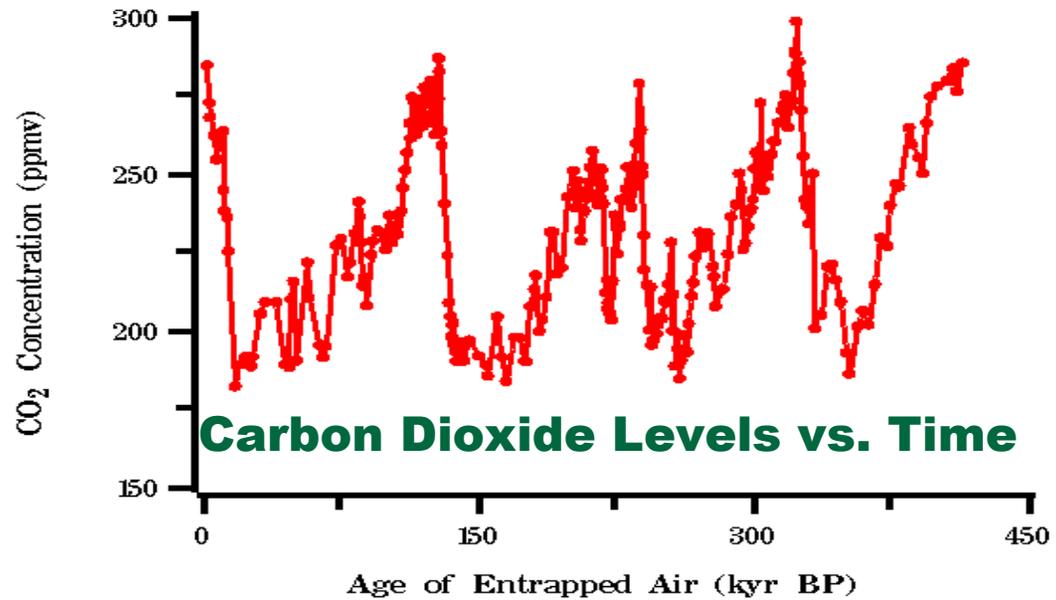
Oil Discoveries and Common Sense – Oil is Limited



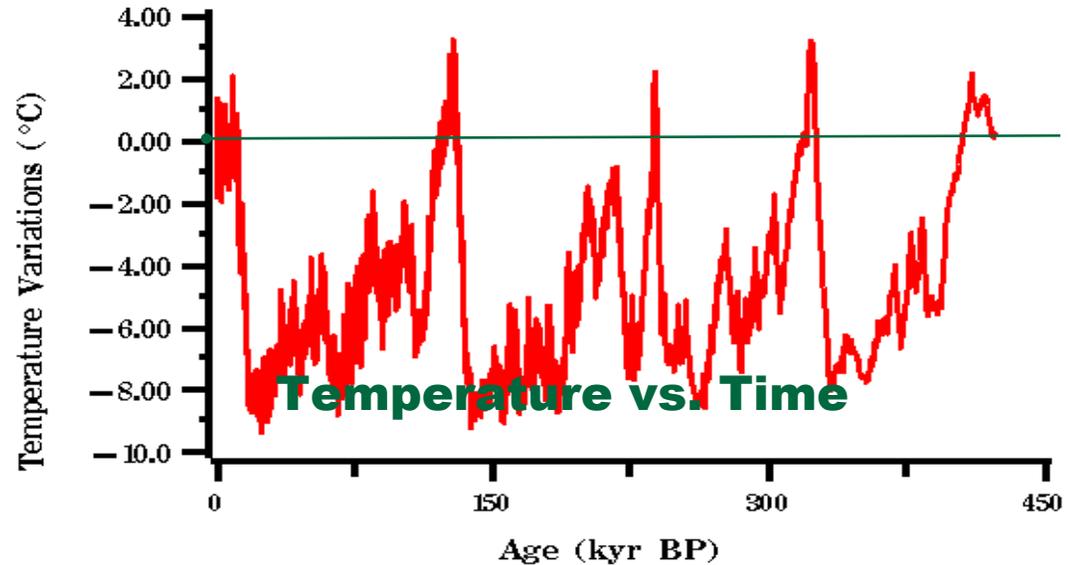
The Earth's Temperature is Coupled to the Atmospheric Carbon Dioxide Content

Burning Fossil Fuels Increases the Carbon Dioxide Content of the Atmosphere

Vostok, Antarctica Ice Core Atmospheric Carbon Dioxide Record



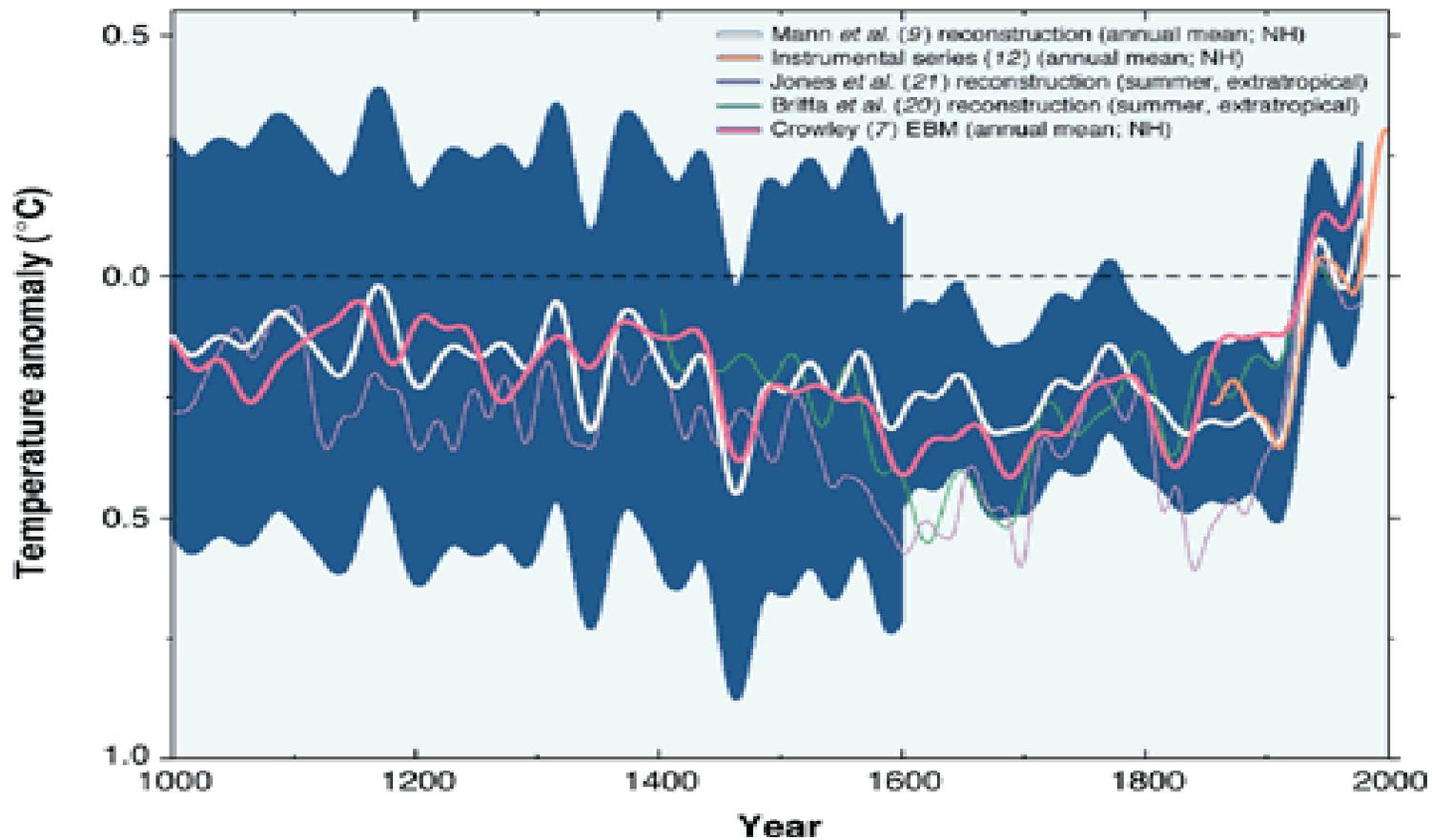
Source: Jean-Marc Barnola et al.



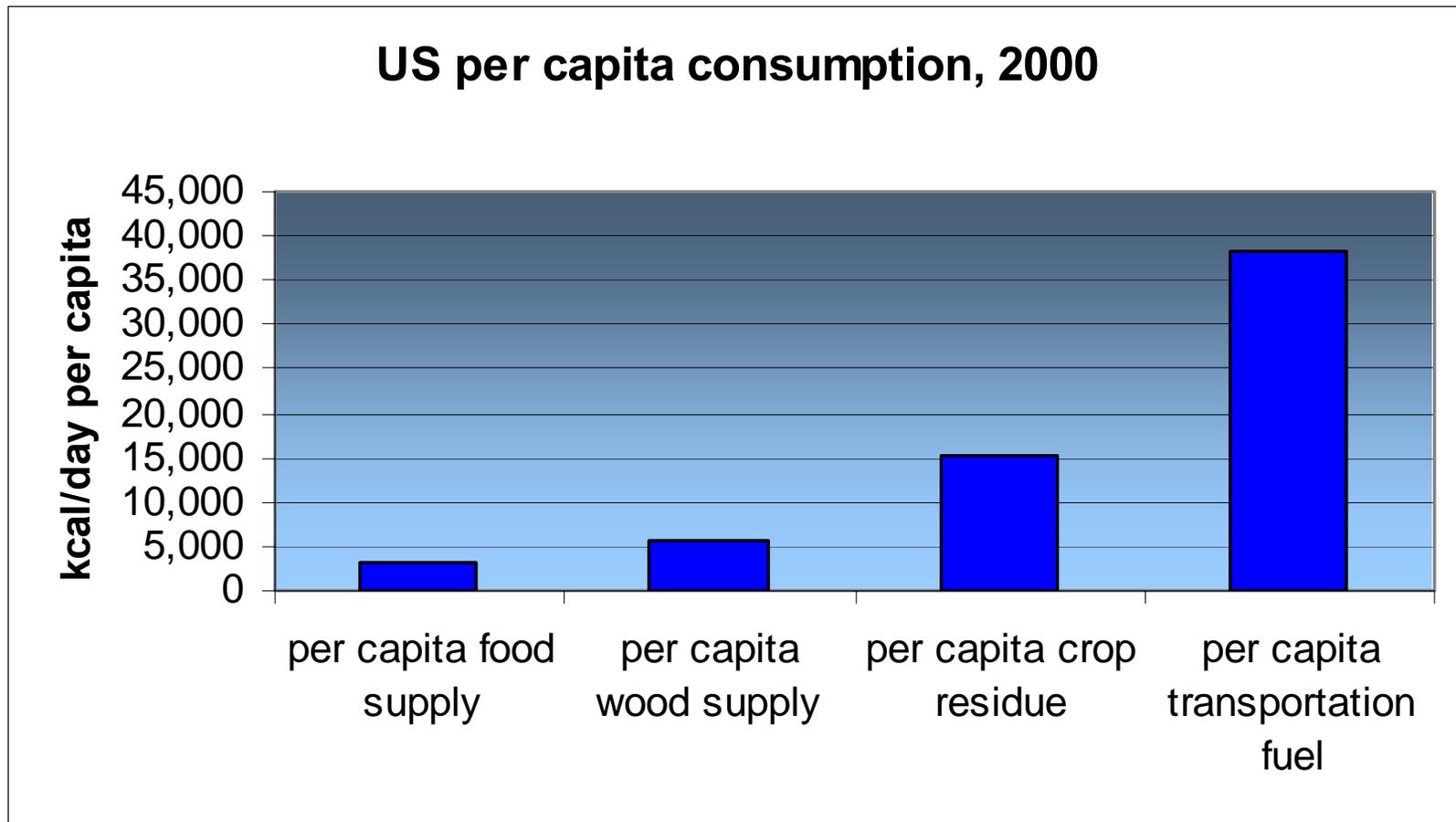
Variation with time of the Vostok isotope temperature record as a difference from the modern surface temperature value of -55.5°C .

Source: Petit et al.

Global Temperatures Reconstructed by Several Groups Suggest that Man is Changing the Climate



The Energy Potential of Biomass is Limited

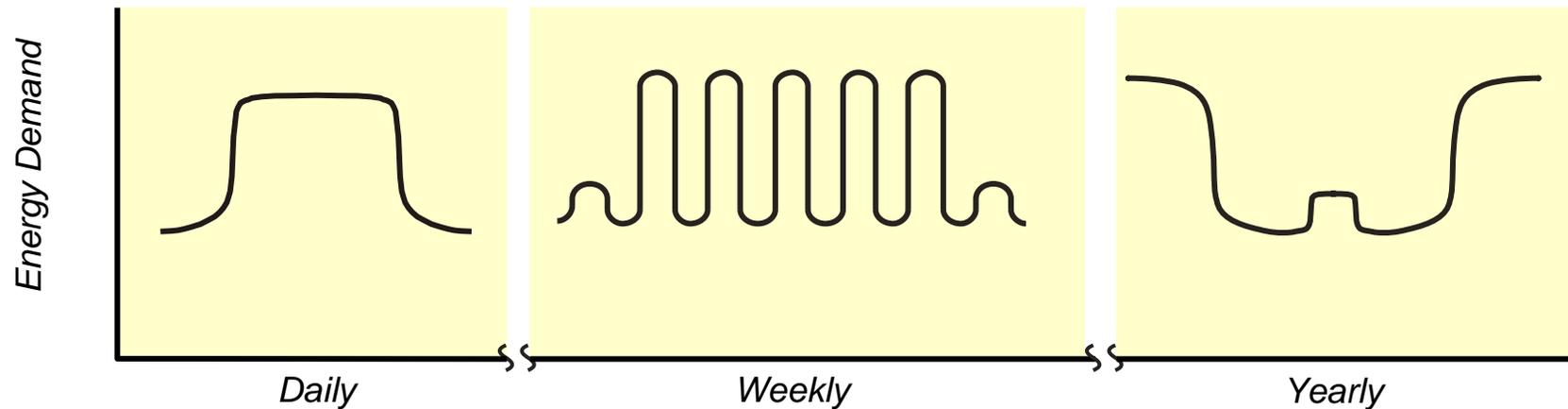


Land Area is Sufficient for Solar to Meet Energy Requirements, but High Costs (Environmental Impacts in Manufacturing the Energy Systems)



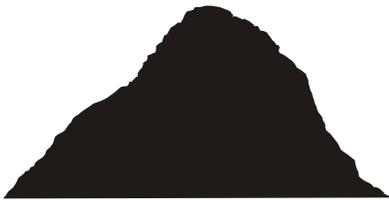
For All Renewables, the Major Long-Term Challenge is that Energy Demand Varies

Energy Demand Vs. Time

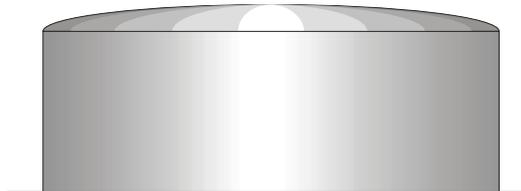


Current Energy Storage Systems

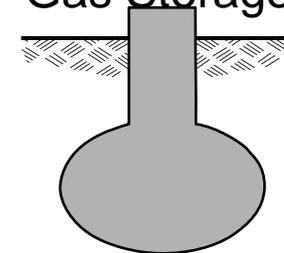
Coal Piles



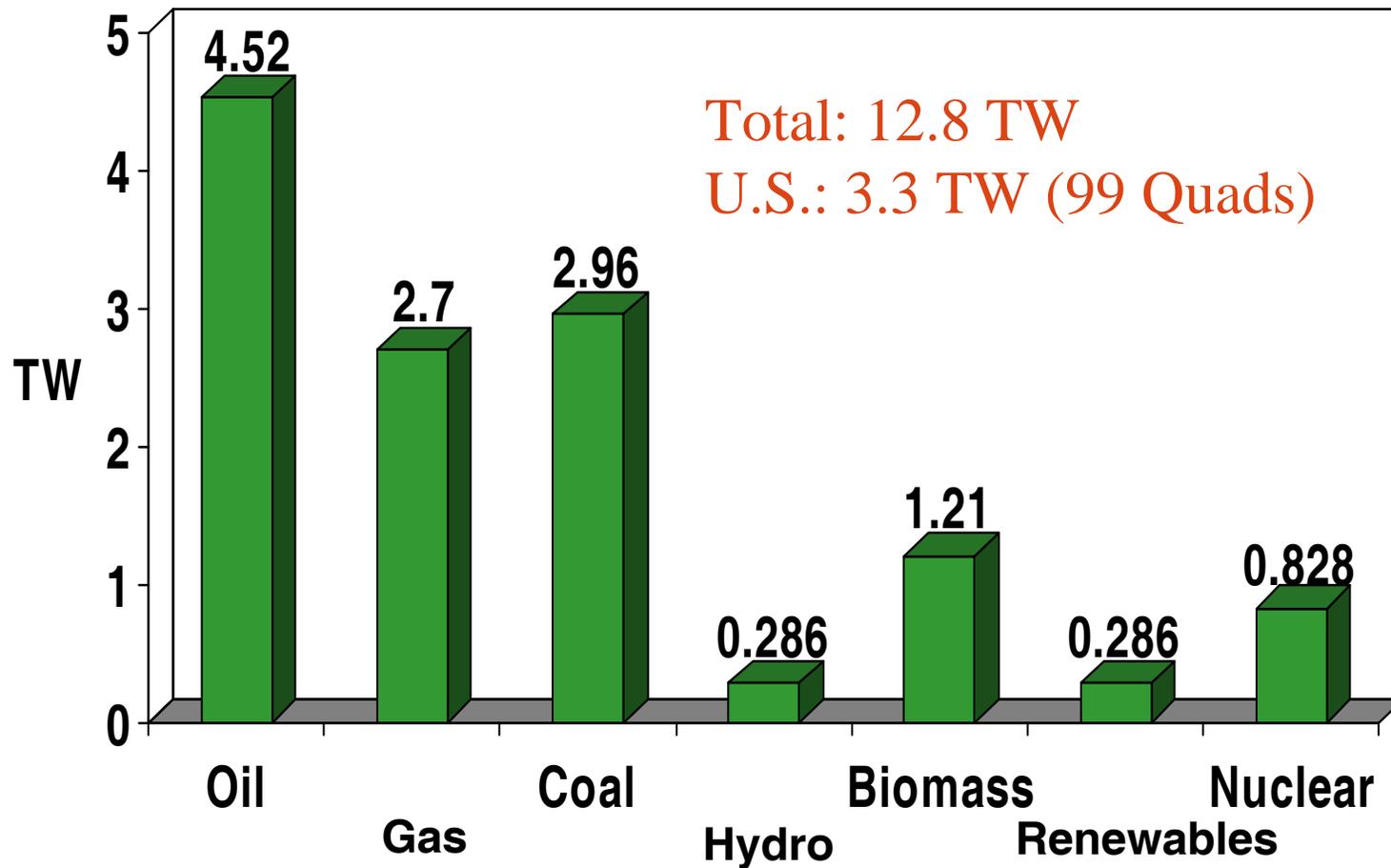
Oil Storage



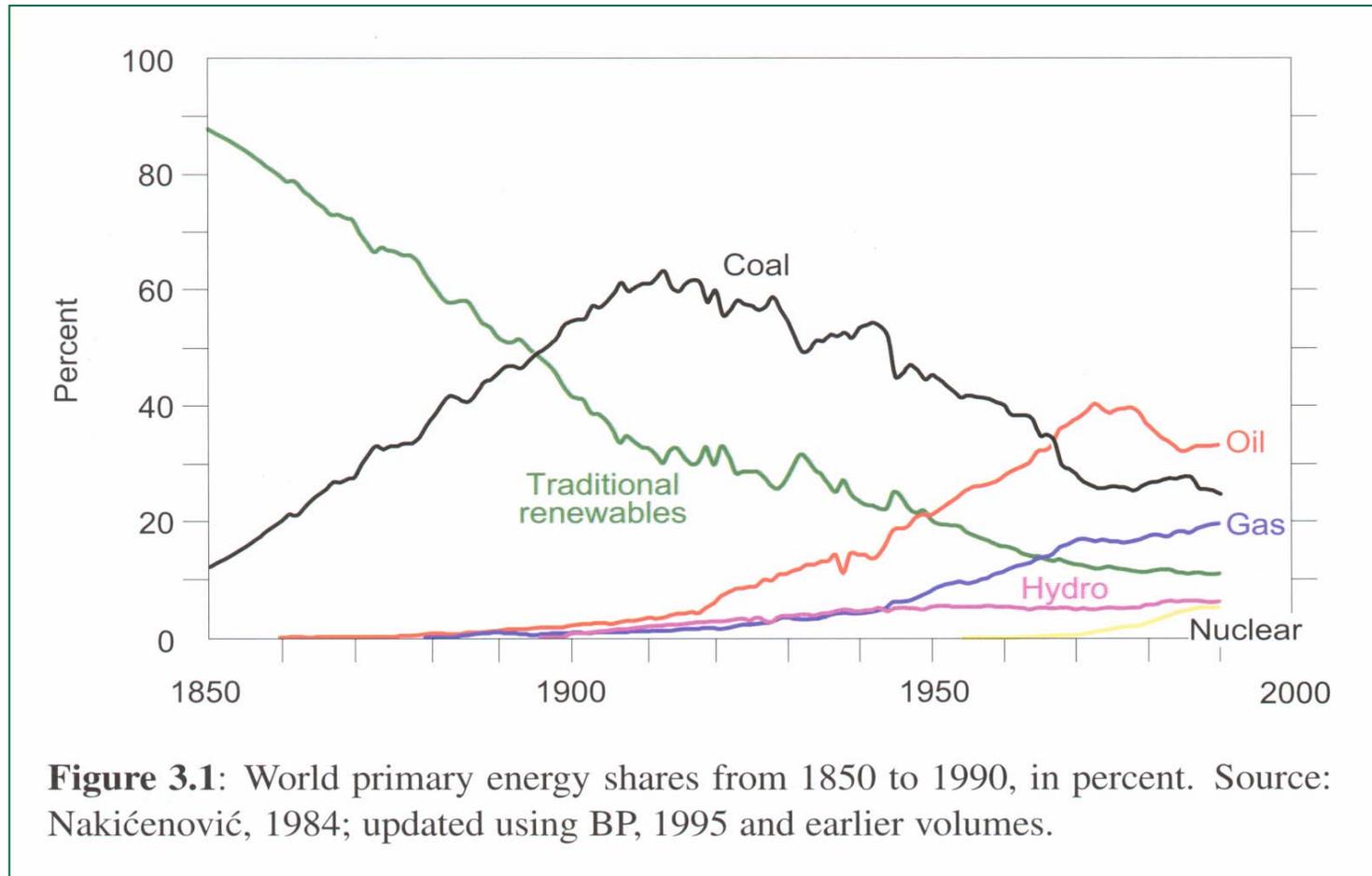
Underground Natural Gas Storage



Global Energy Consumption, 1998



World Primary Energy Shares

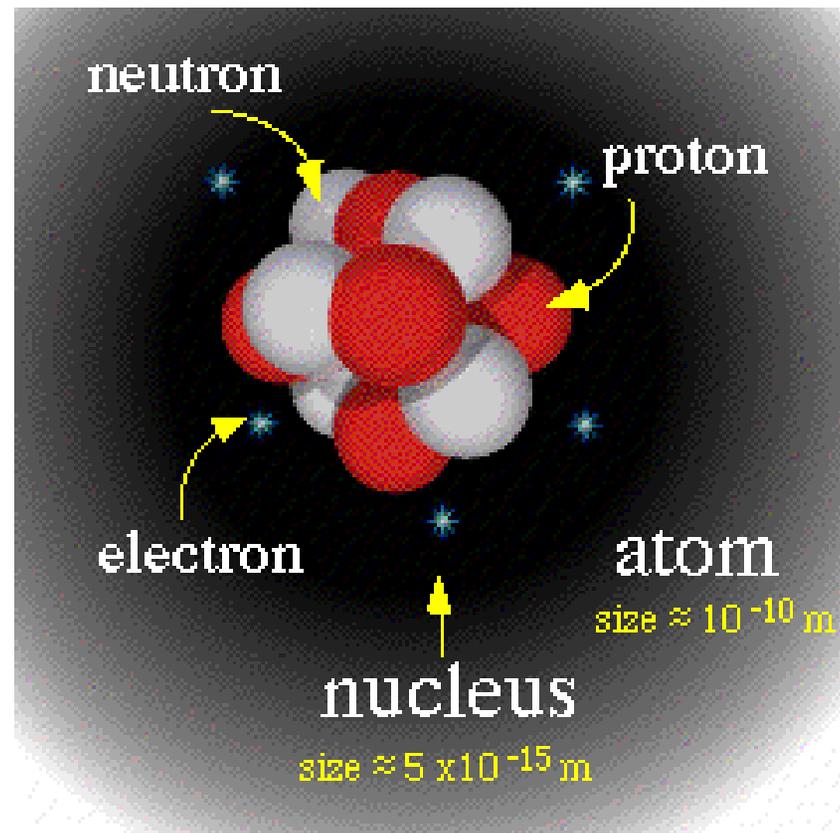


Nuclear Energy Primer

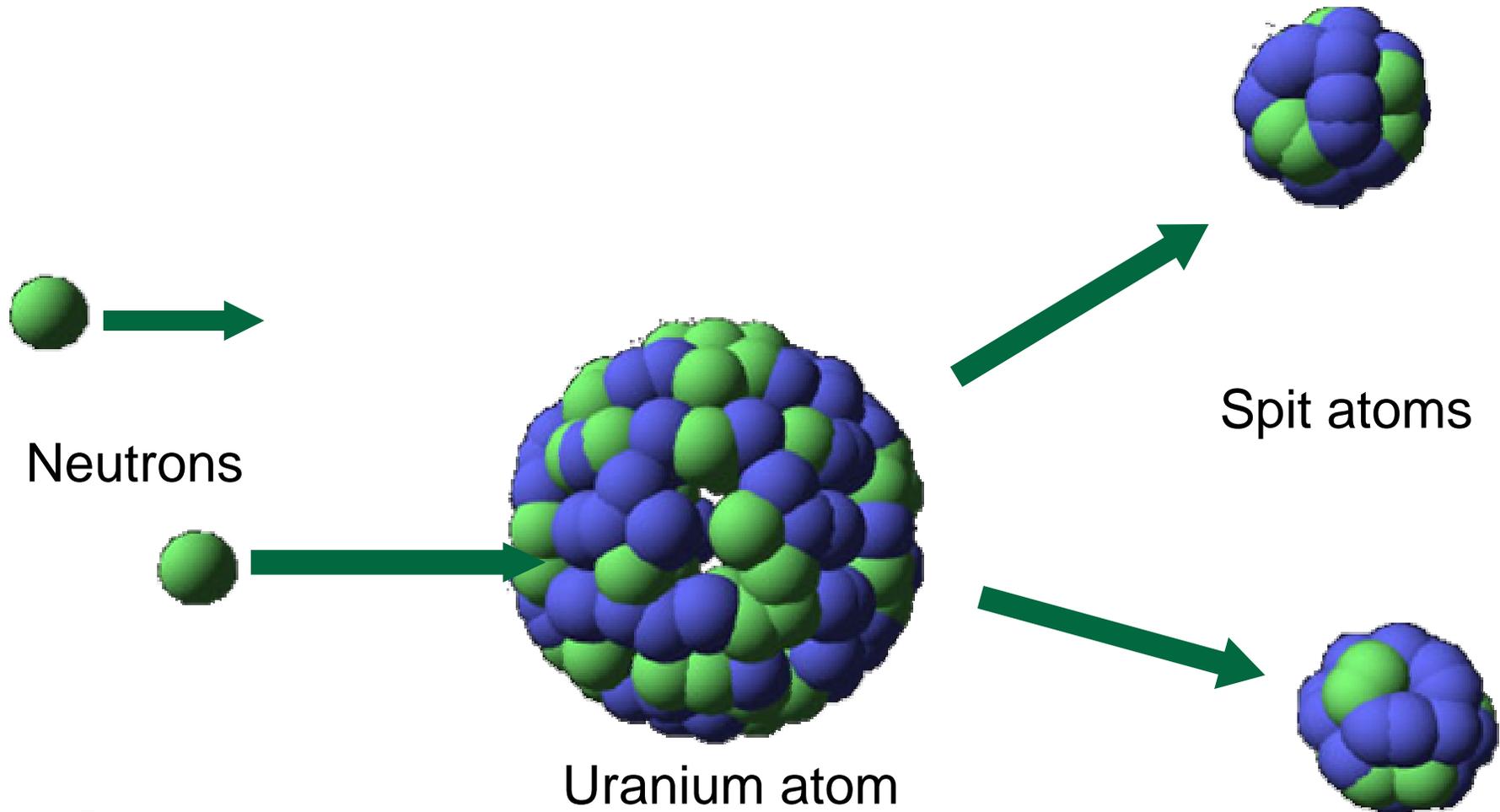
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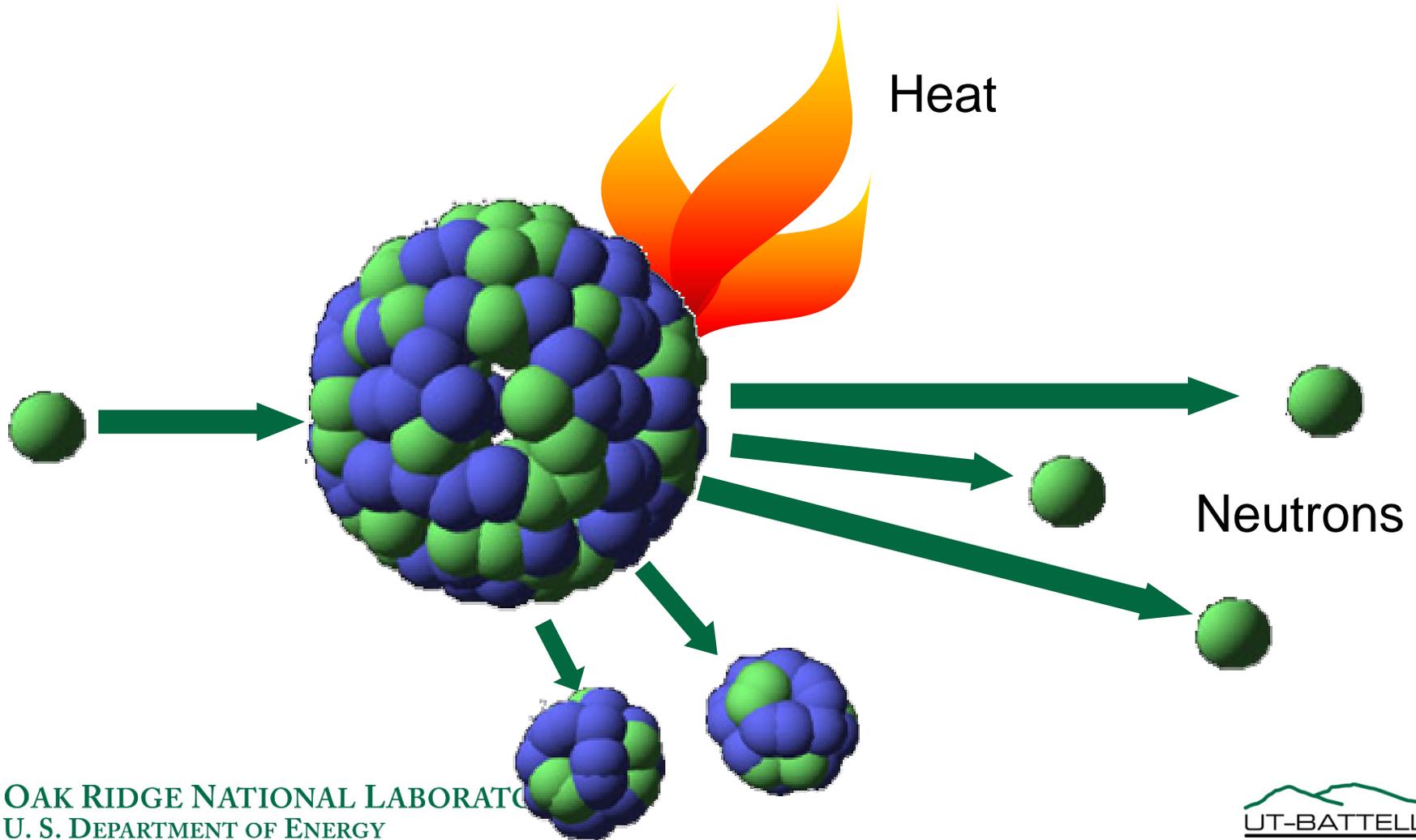
What is an Atom?



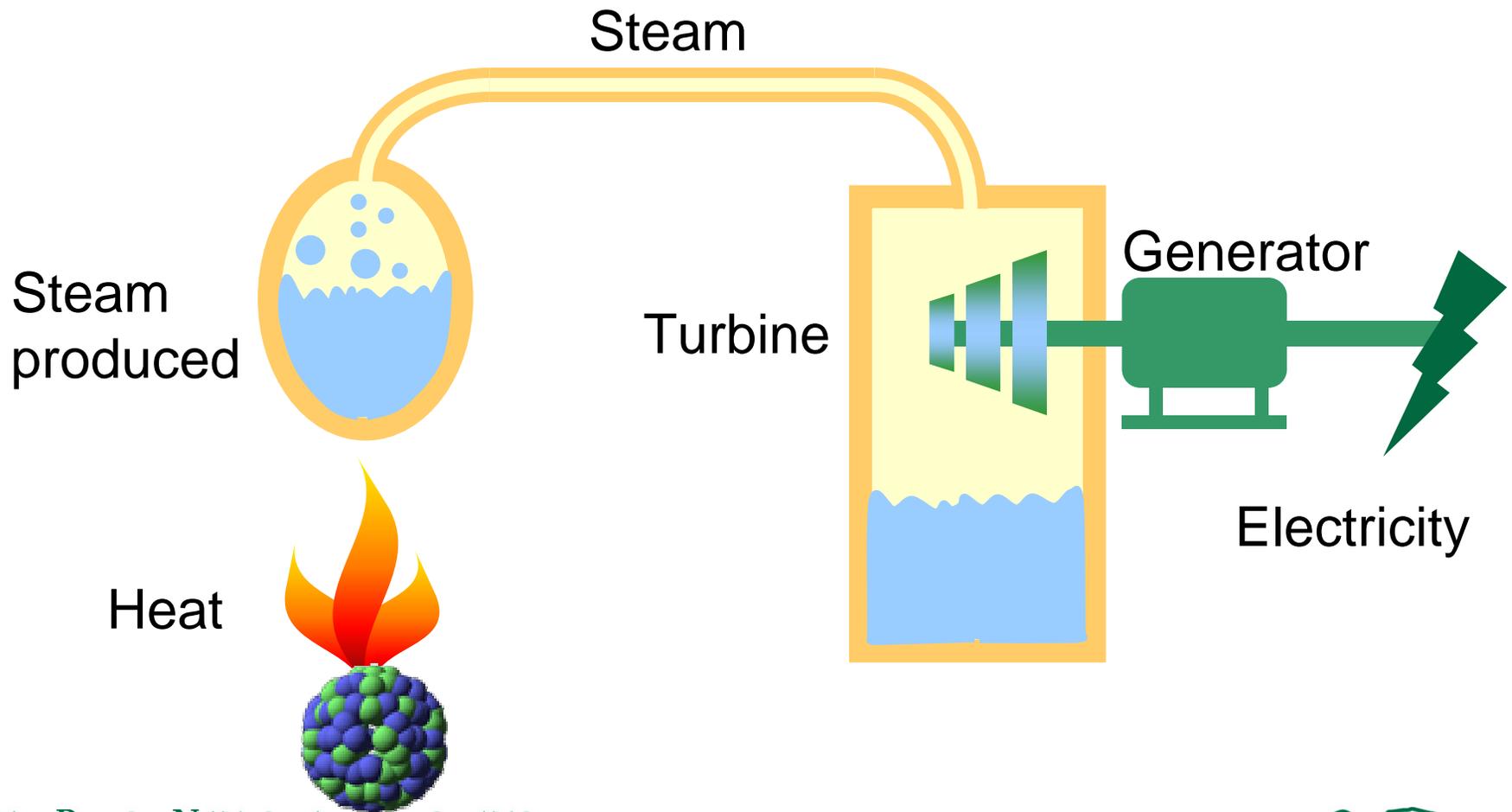
Nuclear Energy Comes from Fission: Breaking Apart Uranium Atoms



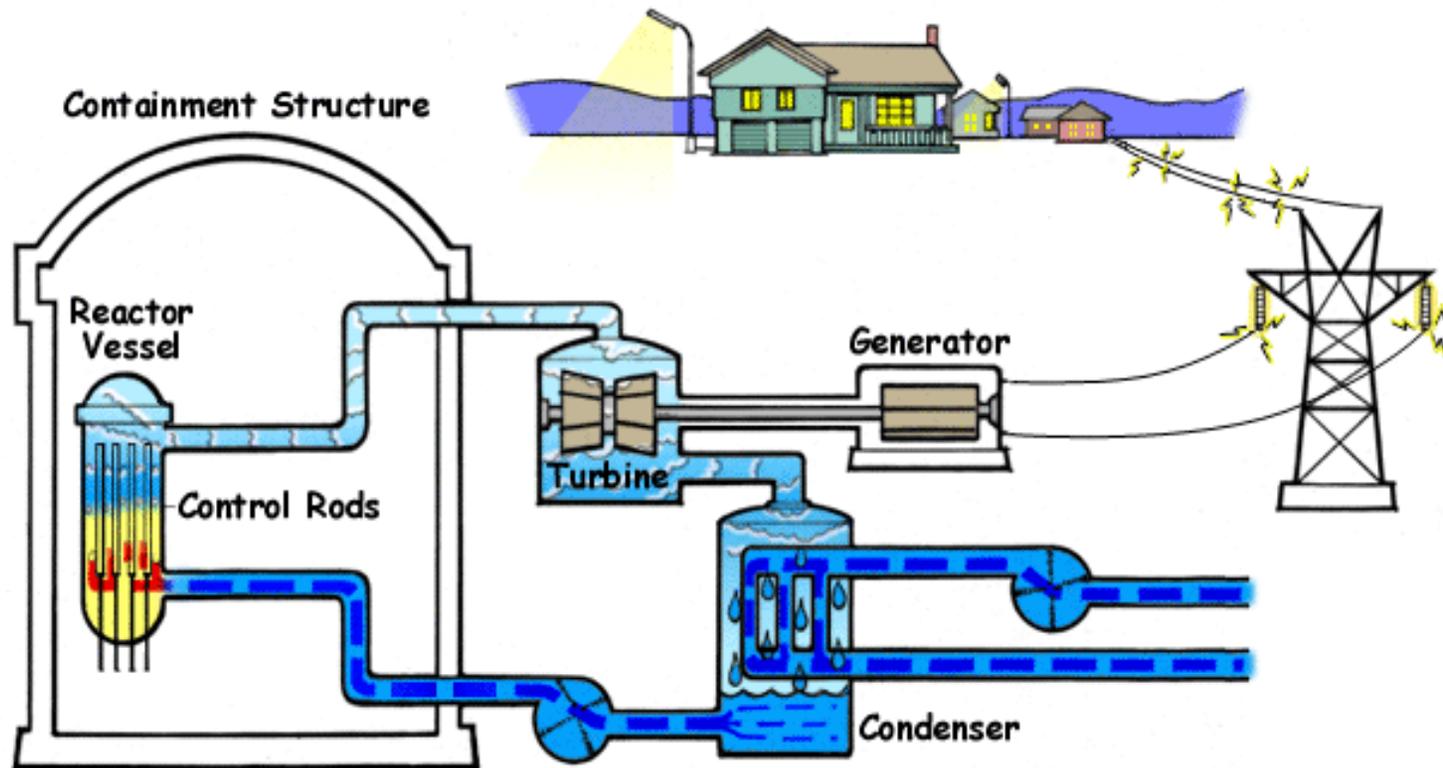
Splitting Atoms Releases Neutrons, Making Heat



Heat Produces Steam, Generating Electricity



Heat Produces Steam, Generating Electricity



Uranium is Mined and Refined



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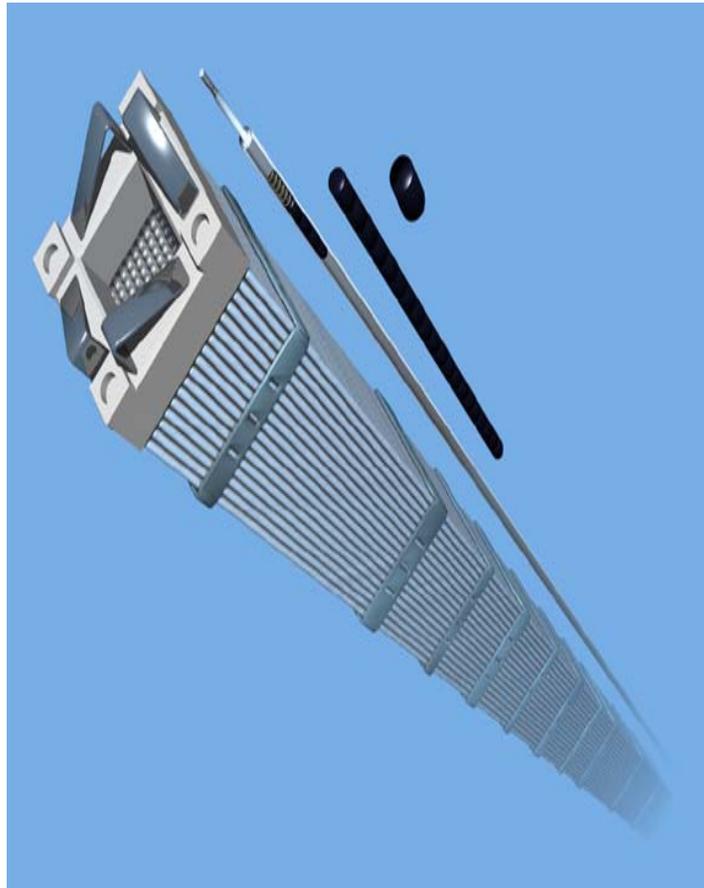
Uranium is Converted into Uranium Dioxide Ceramic Pellets



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Fuel Rods Filled with Pellets are Grouped into Fuel Assemblies



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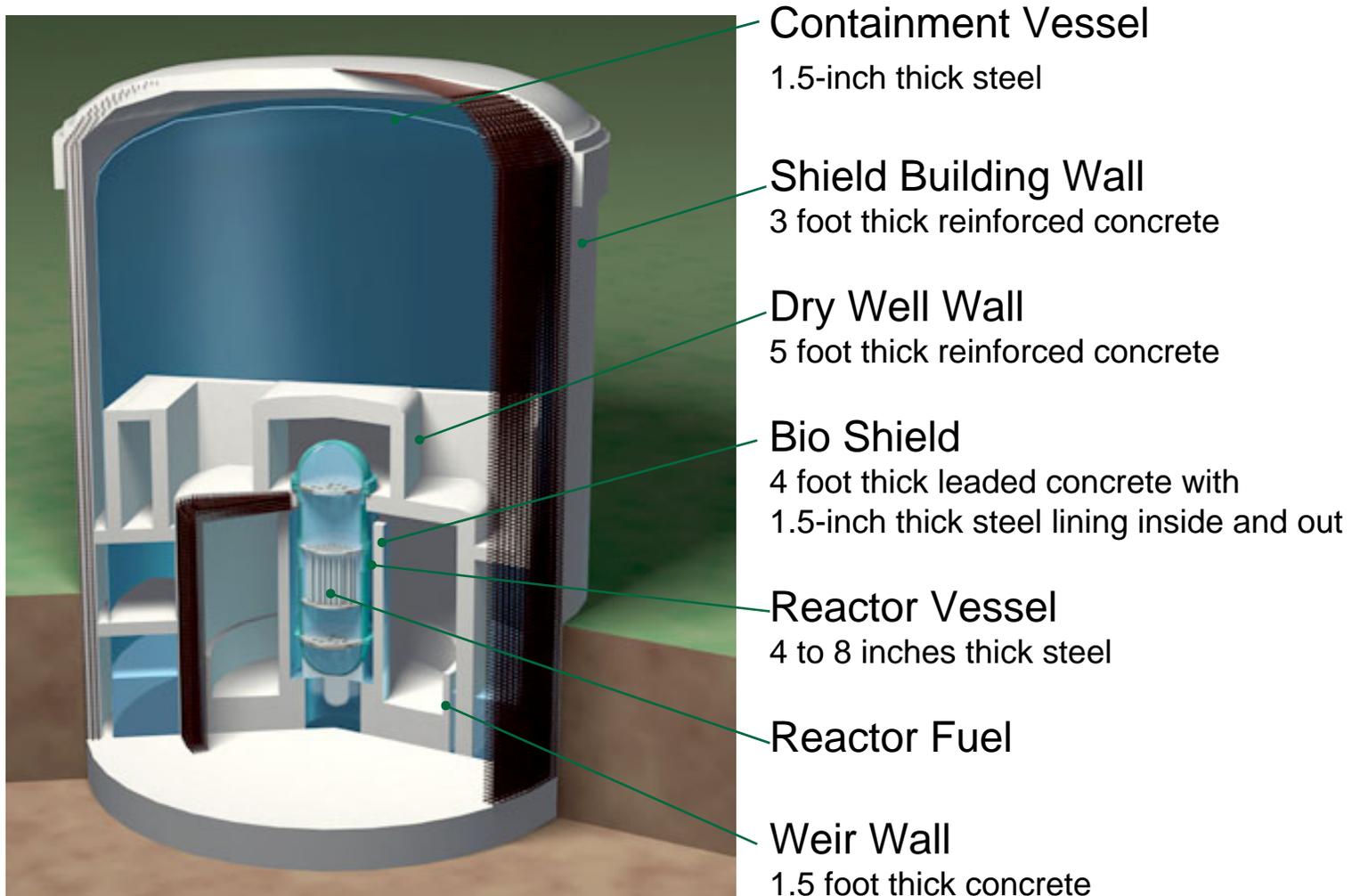
The Important Characteristic of Nuclear Energy

**One Ton of Uranium
Equals 1,000,000 Tons
of Fossil Fuels**

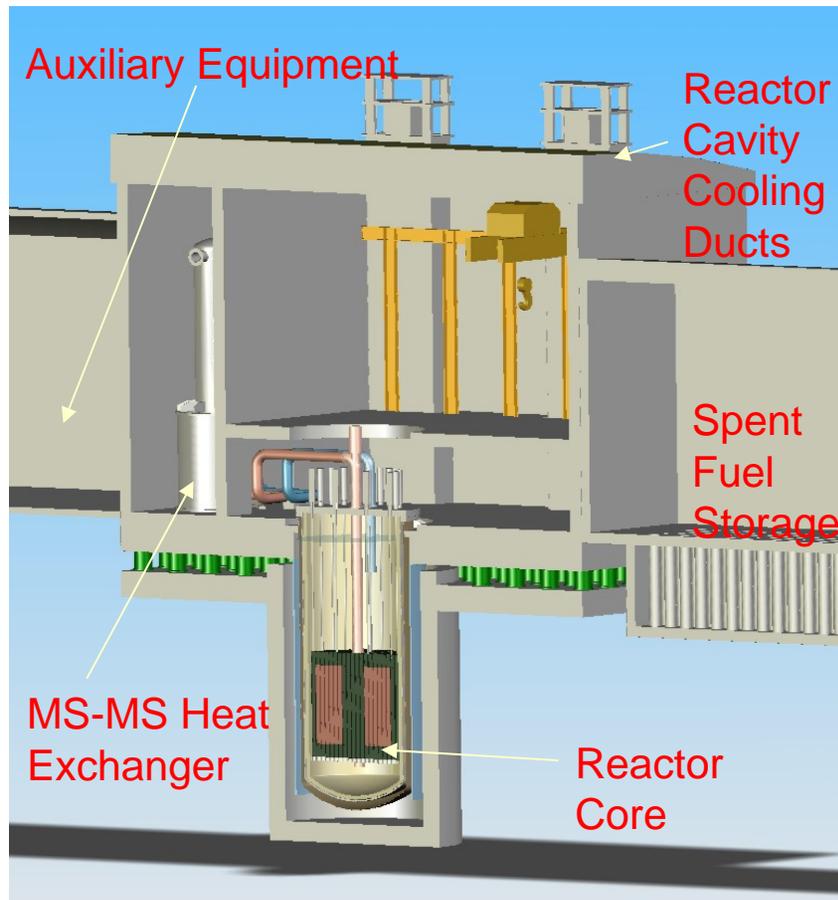
Implications of the High Energy Content of One Ton of Uranium

- **Resources available for millennia**
- **Small volumes allow all wastes to be contained**
 - Very small volumes
 - Allows very expensive per ton disposal methods without significantly impacting the cost of electricity
- **Nuclear energy is not dependent on location**
 - Large nuclear plant needs a few truckloads of fuel per year
 - Coal plant needs one-train per day
 - Renewables dependent upon location
- **Nuclear energy advantages and disadvantages are associated with the concentrated energy source**

Safety is Engineered into Reactor Designs with Multiple Barriers



Reactor Safety Technology is Evolving Toward Passive & Inherent Safety Systems



Advanced High-Temperature Reactor

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Example From Another Technology: Fire Protection

- Traditional approach
 - Fire detectors
 - Sprinklers
 - Fire department
- Passive/Inherent safety
 - Concrete building
 - No combustibles
- Such a strategy makes large accidents not credible

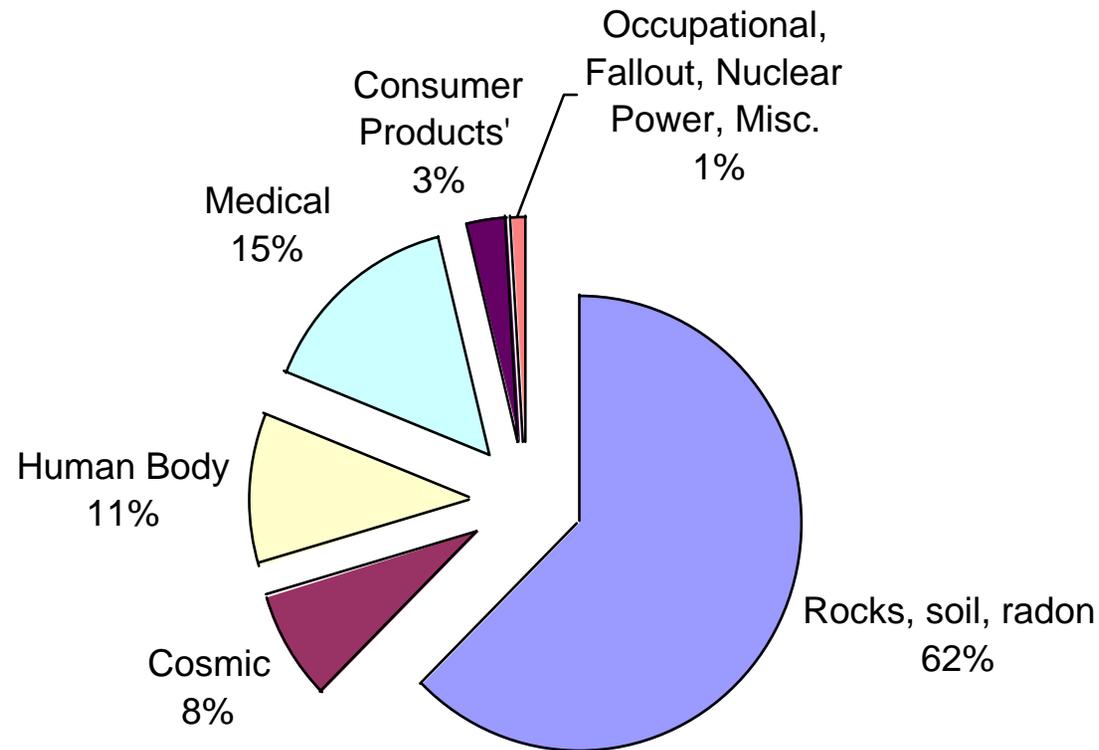
Environmental Benefits of Nuclear Energy: A Consequence of Small Waste Volumes

- No emissions of carbon monoxide, carbon dioxide or oxides of sulfur
- Can help reduce emission of greenhouse gases
- Can help reduce air pollution

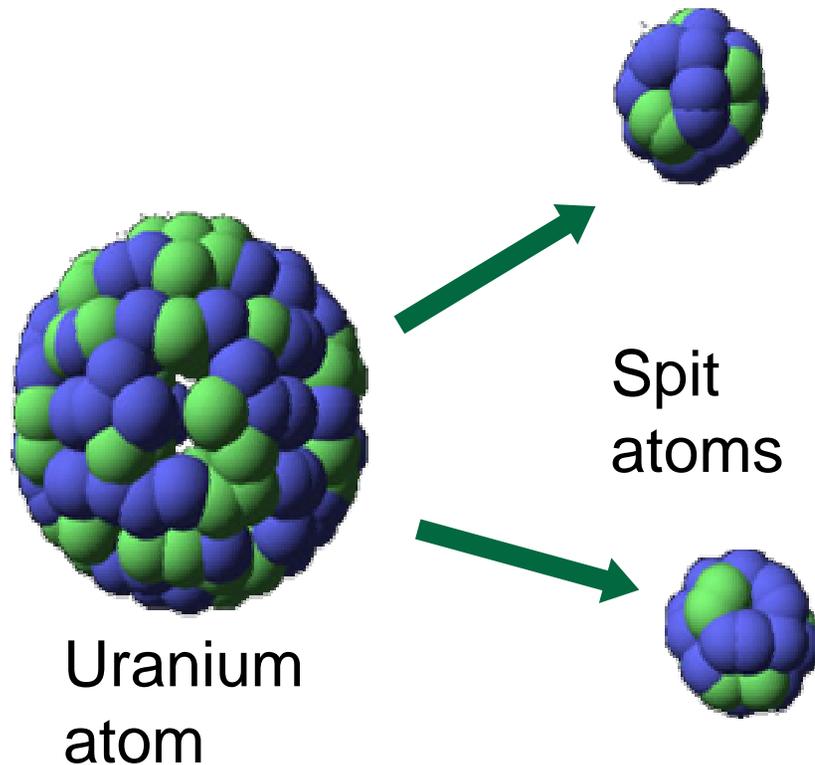


Sources of Background Radiation

(Releases of Radioactivity from Nuclear Power Plants is Small)

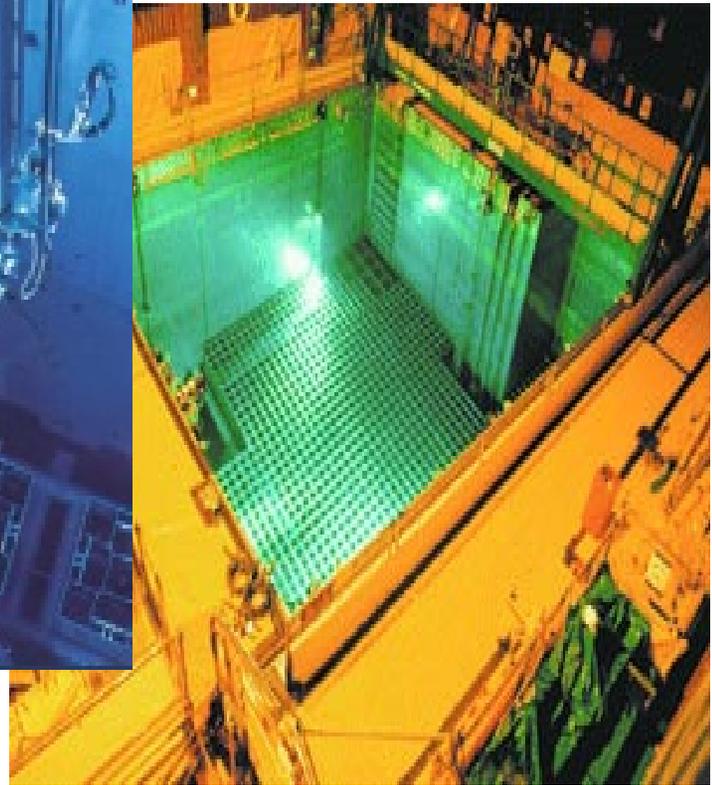


The Primary Nuclear Wastes are Fission Products and Actinides in Spent Fuel



- Radioactive atoms decay to non-radioactive atoms
- Different types of radioactive atoms become non-radioactive at different rates

Fresh Fuel is Relatively Non-Hazardous, Spent Fuel Highly Radioactive and Initially Stored in Water Pools

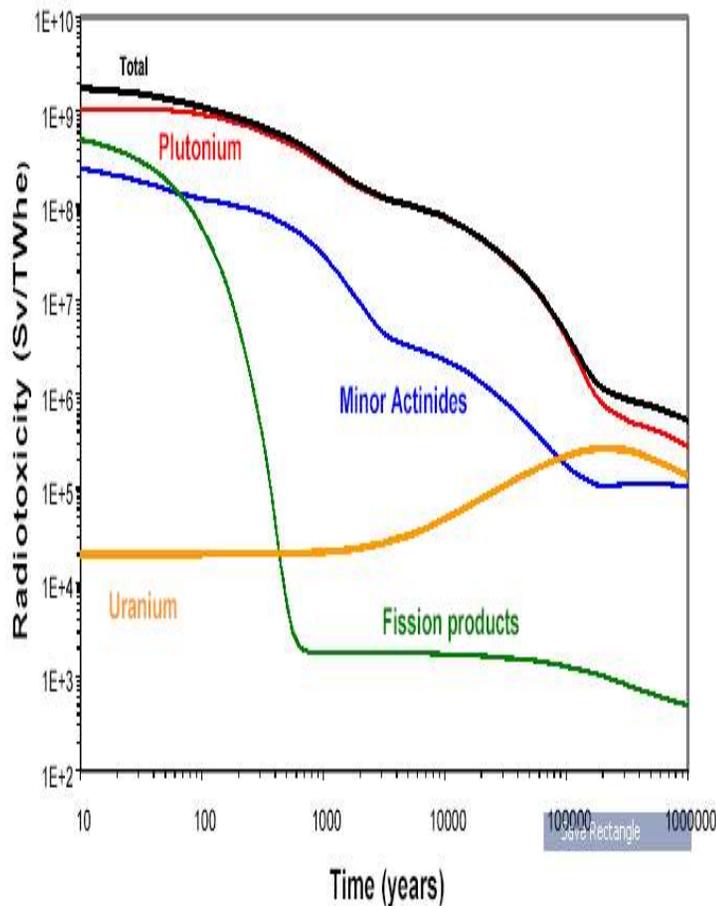


Spent Fuel Volumes are Incredibly Small: 30 Tons per Reactor Per Year



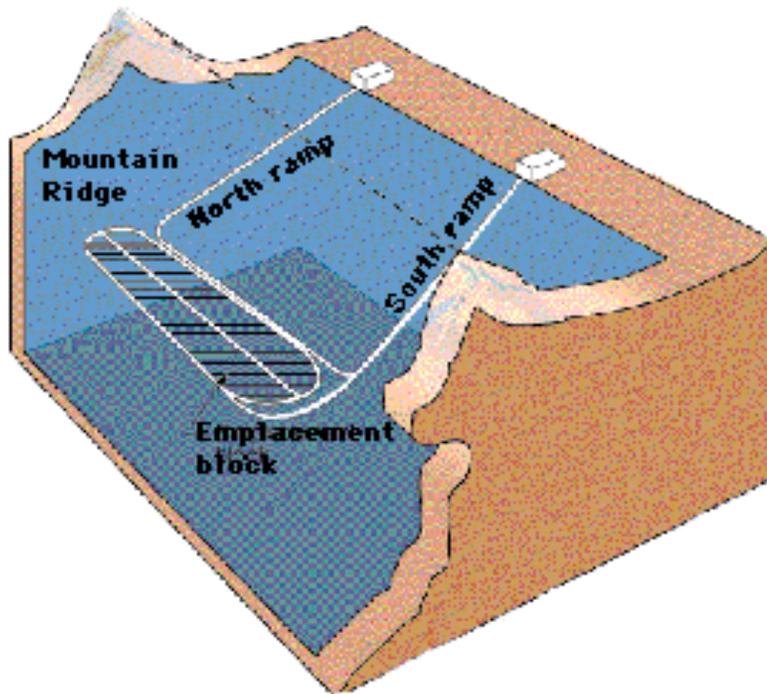
← **Three Casks per Year**

The Waste Management Approach is to Isolate Wastes from Man Until the Waste Toxicity is Low



- Wastes will be disposed of in deep mines
- Avoid long-term interactions with man
- Typical rocks are hundreds of millions of years old

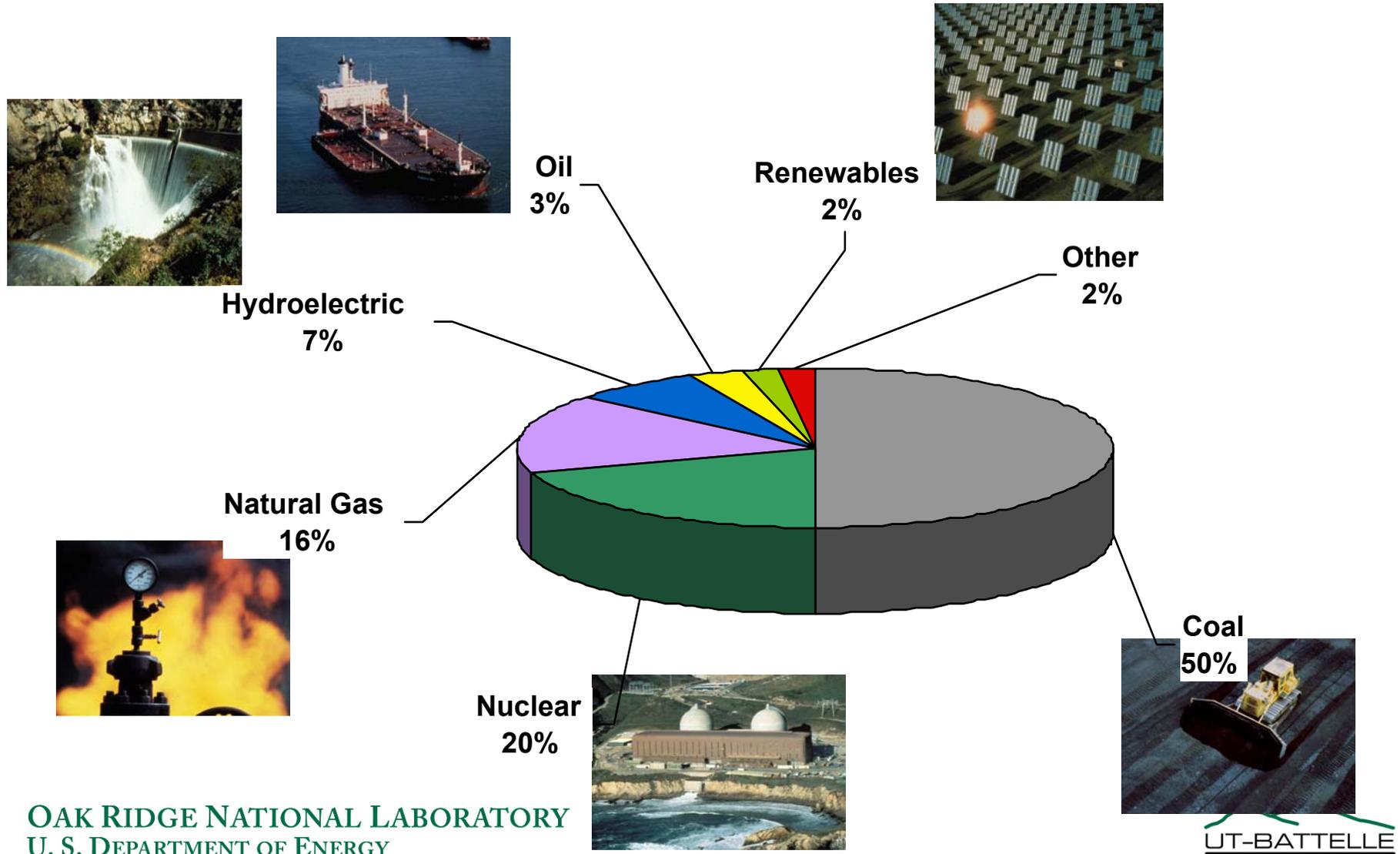
The United States is Planning Deep Underground Disposal at Yucca Mountain in Nevada for Spent Nuclear Fuel



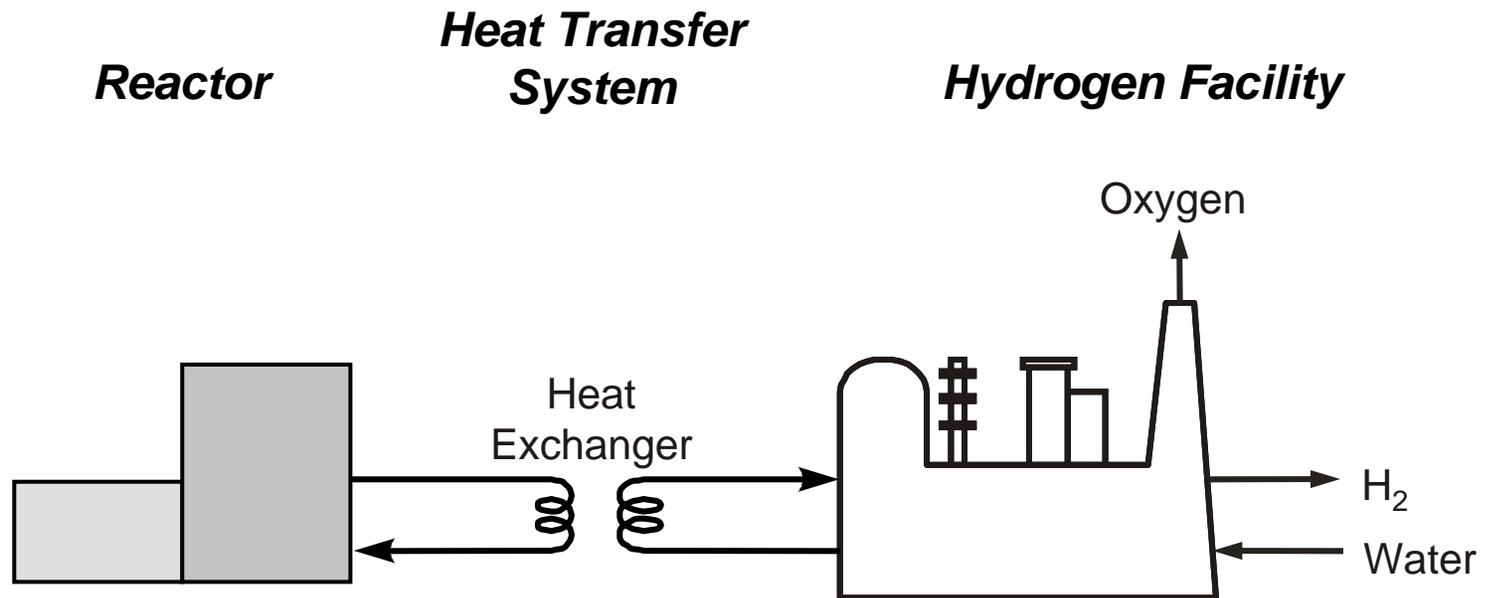
- Nuclear reactors have existed in nature and wastes have been contained
- Heavy metal ore deposits (lead, mercury, etc.) with similar toxicity are not a major hazard to man
- Same strategy as used in Europe for heavy metal disposal (toxic forever)

Nuclear Energy Futures

Nuclear Energy Can Replace Other Sources of Electricity



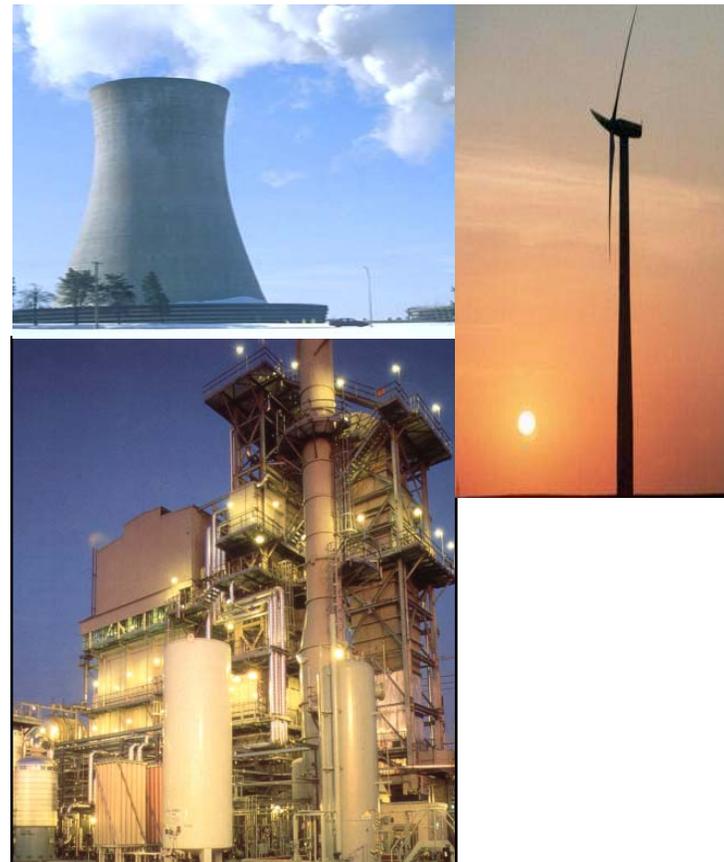
Methods are Being Developed to Produce Hydrogen Using Nuclear Energy



**High-Temperature Heat + Water
→ Hydrogen + Oxygen**

Nuclear Energy May be a Preferred Method for Hydrogen Production

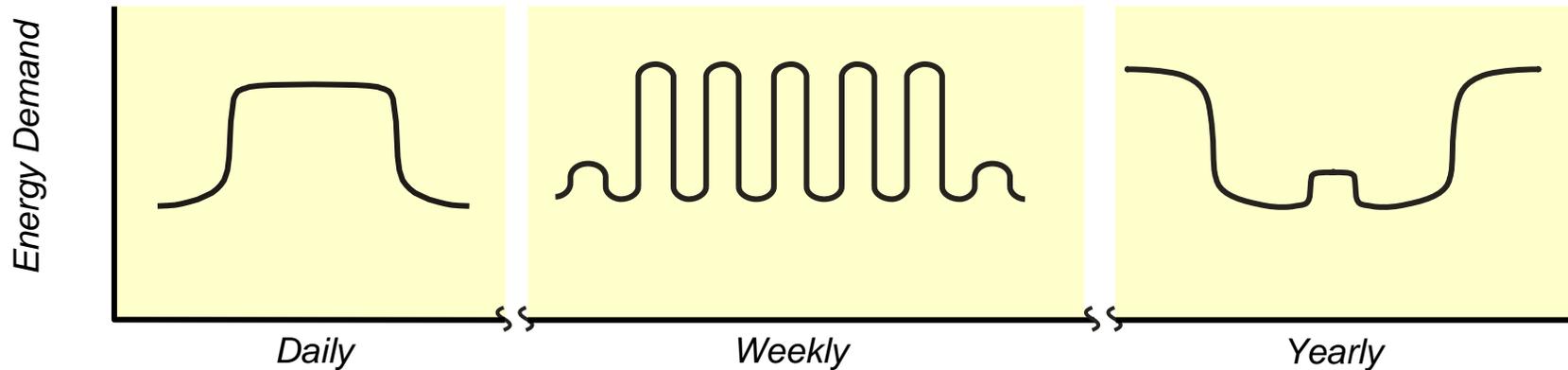
- Electricity can be economically generated on a large or small scale
 - Many generation options
 - **Moving electrons**
- Hydrogen is most efficiently generated on a large scale
 - Chemical industry experience with economics of scale
 - **Moving mass**
 - Favors hydrogen from nuclear energy



Hydrogen is a Way to Store Energy to Meet Variable Energy Demands

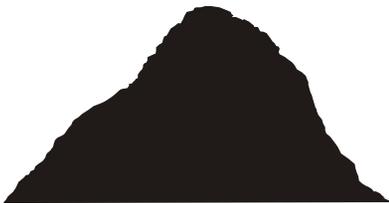
(An Alternative to Fossil Fuels)

Energy Demand Vs. Time

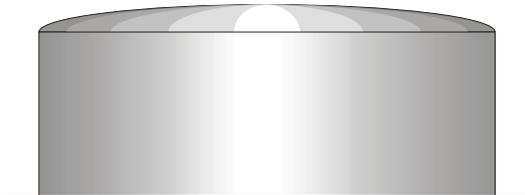


Current Energy Storage Systems

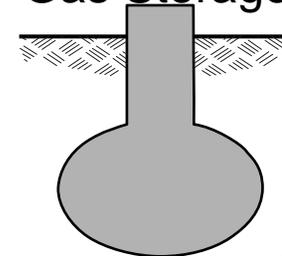
Coal Piles



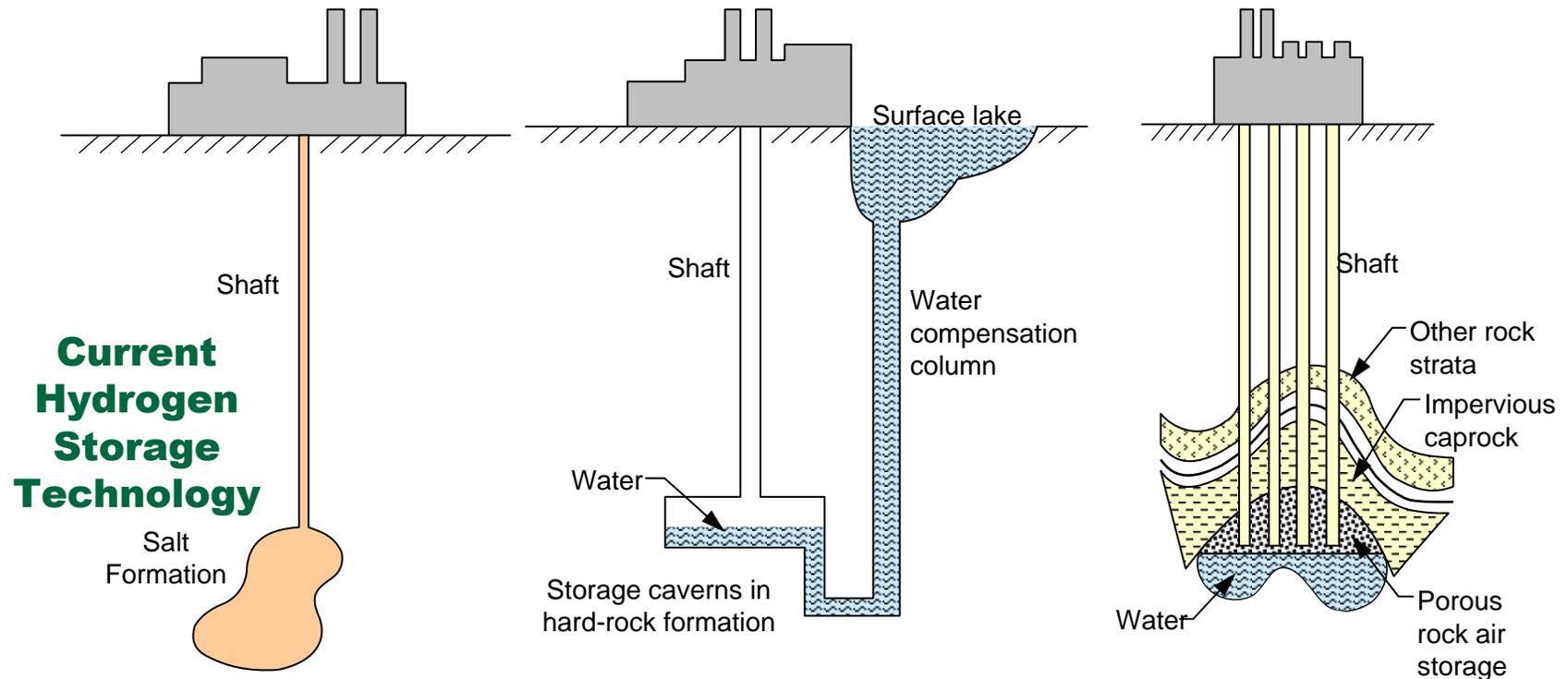
Oil Storage



Underground Natural Gas Storage



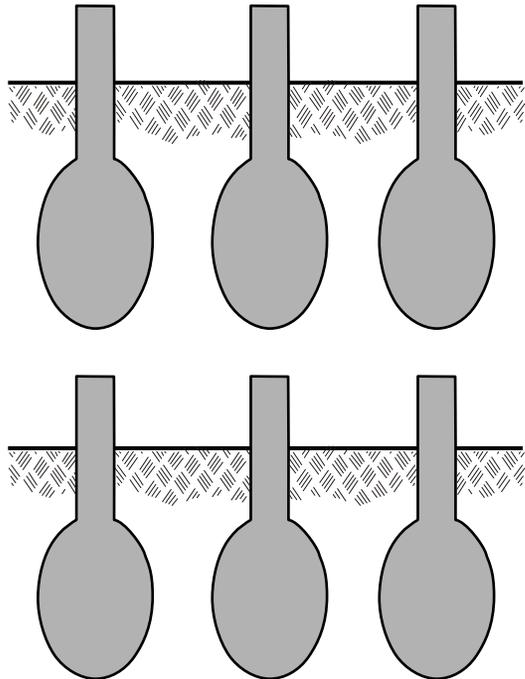
Hydrogen can be Economically Stored in Underground Facilities



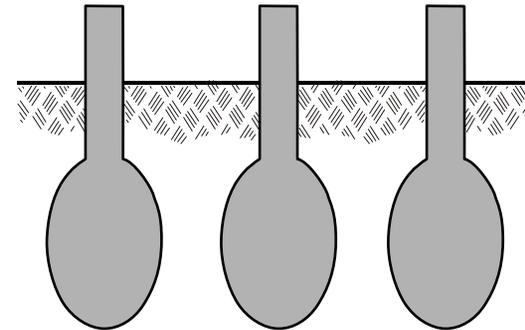
Stored Natural Gas In the U.S. Equals 1/3 of Annual Consumption

Hydrogen Storage Requirements Depend Upon the Match Between Seasonal Energy Demand and Energy Production

Renewable Energy Sources Do Not Match Seasonal Energy Demands
→ Large Storage Needs



Nuclear Energy Can More Closely Match Energy Demands
→ Smaller Storage Needs



Nuclear-Generated Hydrogen May Minimize Hydrogen Storage Volumes and Costs

Nuclear Energy May be the Enabling Technology Large-Scale Renewable Energy

- **Two challenges for renewables**
 - High energy generating costs
 - Energy storage
- **Technology may ultimately develop low-cost renewable energy sources**
- **Without energy storage, renewables need expensive backup power sources that make large-scale renewables uneconomic**
- **Nuclear hydrogen may eliminate the energy storage challenge and thus become the enabling technology for a nuclear-hydrogen renewables economy**



Conclusions

- **Energy options: no free lunch**
- **The unique characteristic of nuclear energy is that 1 ton of uranium equals 1,000,000 tons of fossil fuels**
 - Small volumes allow full containment of wastes
 - Energy source is not dependent on location
- **Future energy options depend upon how the different technologies advance**
- **Hydrogen from nuclear energy may be the enabling technology for long-term renewables because it may eliminate the biggest challenge to renewables: energy storage**