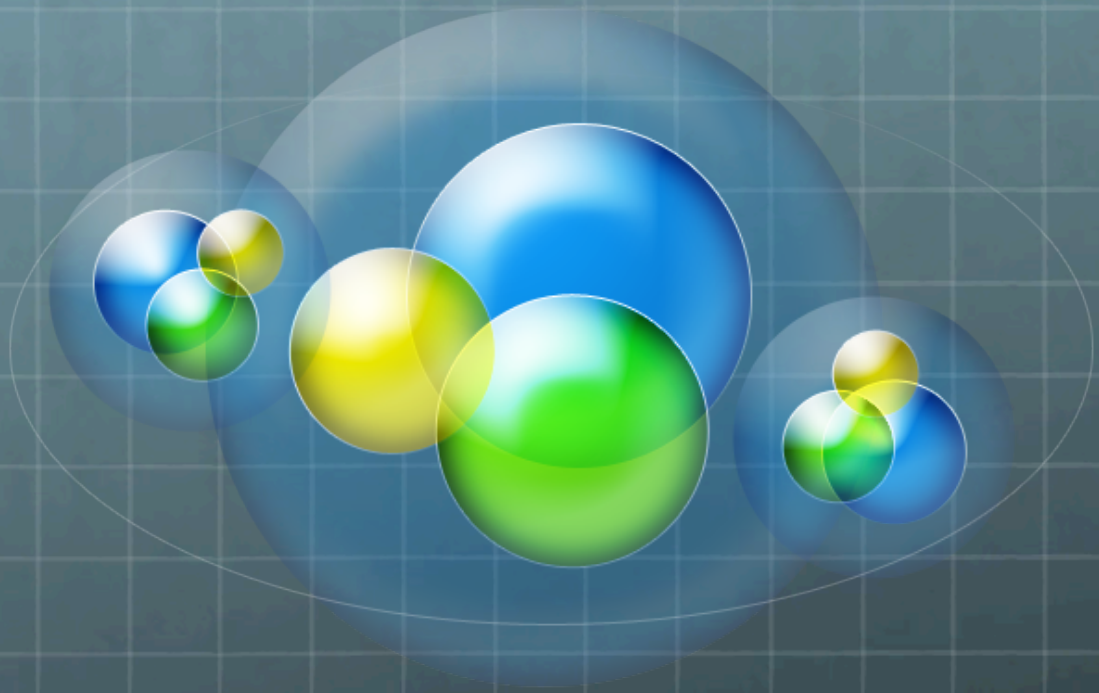
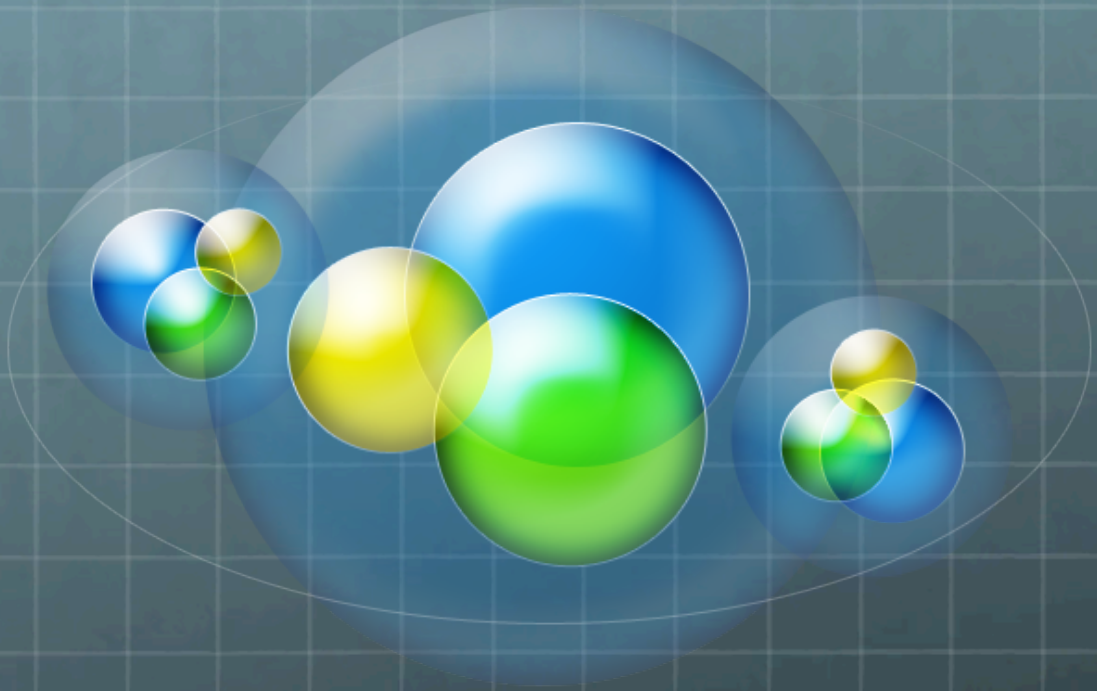


Nuclear Energy

Gabrielle Reese, Sri Pisupati, Emily Phipps



A Brief History

Nuclear Energy

1895-1945

- Atomic radiation, atomic changes, and nuclear fission
- 1939- Hahn and Strassman
  - Fission released a lot of energy
  - Released additional neutrons causing fission in Uranium nuclei
  - Possible self-sustaining chain reaction
- 1942-World's first nuclear chain reaction

1939-1945

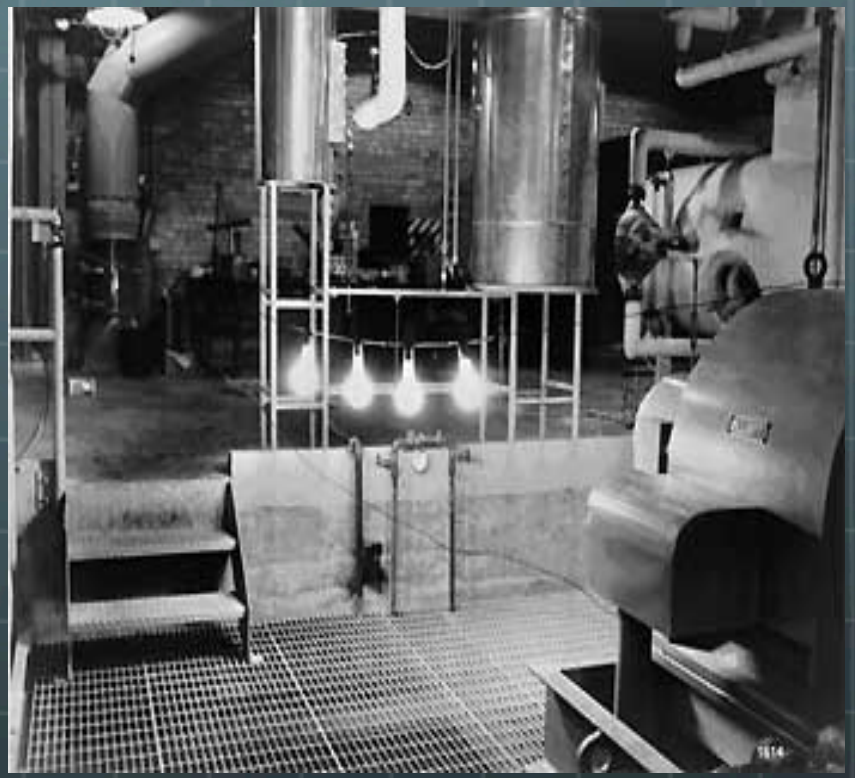
- Atomic bomb
- Physicists Peierls and Frisch
  - Concepts of atomic bomb
  - How bomb can be denotated, how U-235 can be produced, radiation effects
- Agreement between Britain and US

First Atomic Device

- http://www.youtube.com/watch?v=Ru2PWmGIoB8
- July 16, 1945
  - Alamogordo, New Mexico
- Used Platonium

1945- Attention Shift

- Focused on harnessing energy for naval purposes and making electricity
- 1951
  - An experimental breeder reaction in Idaho produces world's first electric power from nuclear energy



http://www.euronuclear.org/

1957

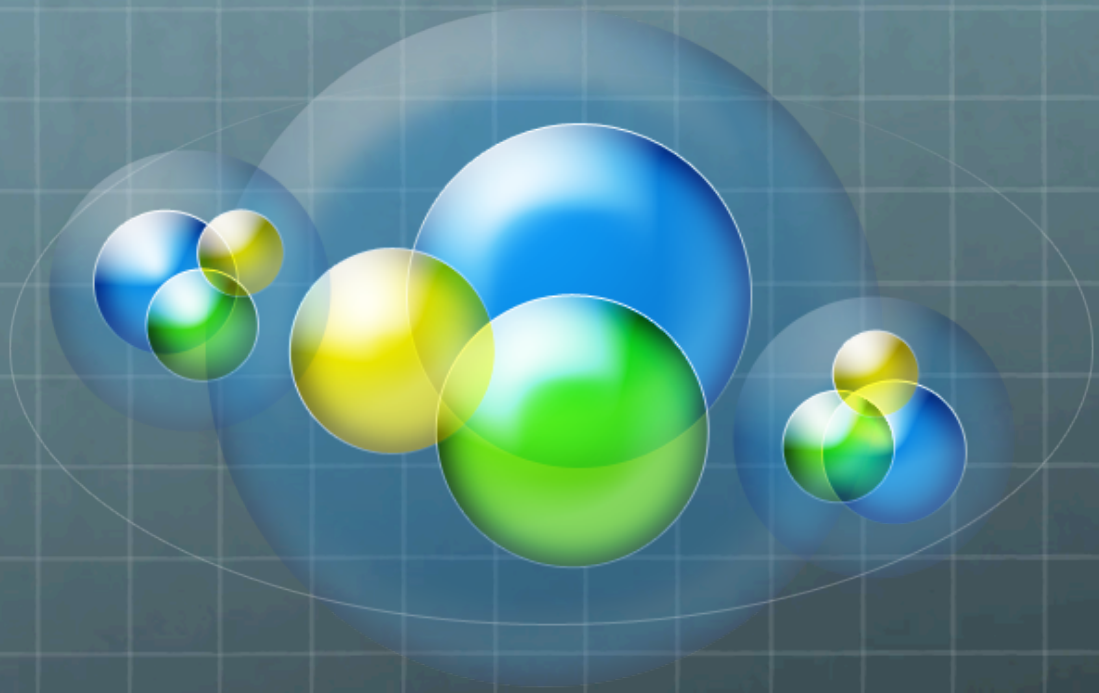
- First large scale nuclear power plant in the US
- Shippingport, PA

http://www.eoearth.org/

Since 1965

- Focus on technological evolution of reliable power plants
- Westinghouse designed first pressurized water reactor
  - Started in 1960 and operated until 1992

http://www.storenuclearfuel.com/



Nuclear Technology

Fun Facts

- Generally, nuclear electricity is generated using two types of reactors (developed in the 1950s)
- Four generations of nuclear reactors – first has been phased out
- 13% of worldwide electricity production comes from nuclear sources

Components of Nuclear Reactors

- Fuel: Uranium – Uranium oxide rods form fuel rods
- Moderator: Slows down the neutrons in the reaction so that more fission occurs
  - Water, heavy water, and graphite
- Control Rods: control the rate of reaction/stop the reaction.
- Coolant: fluid that circulates around the core
  - LWR – moderator also is primary coolant
  - Secondary coolant where water becomes steam (except BWR)

Components of Nuclear Reactors

- Pressure Vessel/Tubes: steel vessel that contains the core and moderator
- Steam Generator: part of the cooling system where the primary coolant is used to make steam for the turbine
- Containment: structure around the reactor and protects it from the surroundings and contains radiation is there is a malfunction

Types of Reactors

- Pressurized Water Reactor (PWR):
  - Used in the US, France, Japan, Russia, and China
  - Coolant: Water
  - Moderator: Water
- Boiling Water Reactor (BWR):
  - Used in US, Japan, Sweden
  - Coolant: Water
  - Moderator: Water
- Pressurized Heavy Water Reactor (PHWR)
  - Used in Canada
  - Coolant: Heavy Water
  - Moderator: Heavy Water

Types of Reactors

- Gas- Cooled Reactor (AGR, MAGNOX)
  - Used in UK
  - Coolant: CO_2
  - Moderator: Graphite
- Light Water (RBMK, EGP)
  - Used in Russia
  - Coolant: Water
  - Moderator: Graphite
- Fast Neutron Reactor (FBR)
  - Used in Russia
  - Coolant: Liquid Sodium
  - Moderator: None

PWR vs. BWR

- In a BWR, the reactor core heats water, which turns to steam and then drives a steam turbine
- In a PWR, the reactor core heats water, which does not boil. This hot water then exchanges heat with a lower pressure water system, which turns to steam and drives the turbine.
  - Safest – water leaving the reactor does not touch nuclear components
  - Built in safety system (water is a moderator, steam is not)

Moderation

- Graphite Moderators: use carbon as a neutron moderator
  - Most famously known because of Chernobyl
- Heavy Water Moderation: Heavy water, D^2O, is water in which both hydrogen atoms have been replaced with deuterium, the isotope of hydrogen containing one proton and one neutron
  - Allows for natural uranium to be used (eliminates need for expensive enrichment facilities)
  - Heavy Water is expensive
  - Risk of nuclear proliferation due to byproducts
- Light Water Moderation
  - Uses normal water as a coolant and for moderation
  - The most common type of moderation
  - Requires enriched fuels (expensive enrichment facilities required)

Generations

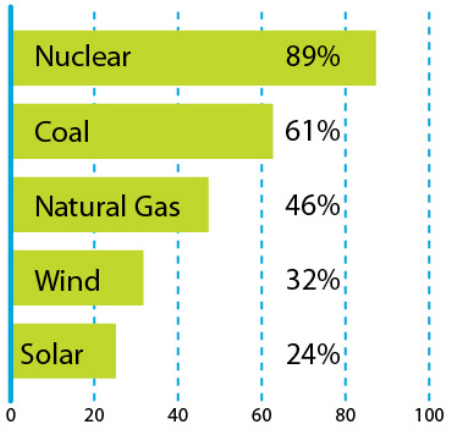
- Generation 1:
  - Early power plant designs
  - Have been decommissioned
- Generation 2:
  - Built until the beginning of the 1990s
  - Original design life of 30-40 years – extended to 50-60 years
  - Most current reactors
- Generation 3:
  - Improved fuel technology, thermal efficiency, safety systems, and reduced maintenance and capital costs
  - 60-120 year lifespan
- Generation 4+:
  - Mostly prototypes

Nuclear Fuel

- Preparing uranium for use in a nuclear reactor involves mining and milling, conversion, enrichment and fuel fabrication
- Used fuel still contains about 96% of its original uranium
- Reprocessing separates uranium and plutonium from waste products
- There are no disposal facilities (as opposed to storage facilities) in operation in which used fuel, not destined for reprocessing, and the waste from reprocessing, can be placed
- The general consensus favors its placement into deep geological repositories, about 500 meters down

Efficiency

Average Operating Efficiency* by Source of Electricity, 2011

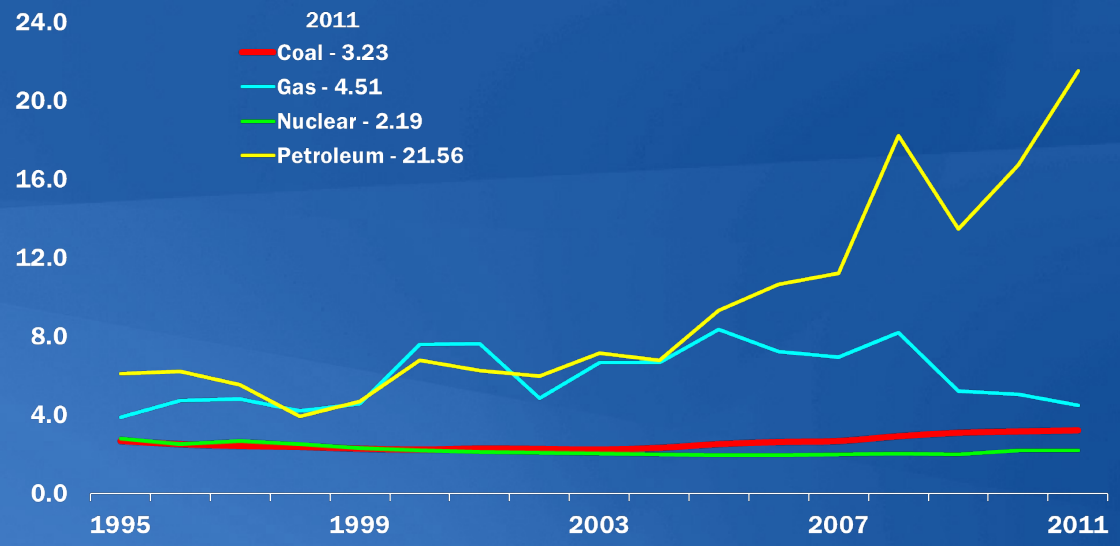


Source: Ventyx / U.S. Energy Information Administration

**Operating efficiency is measured by capacity factor, the ratio of the amount of electricity produced by a plant to the amount of eletricity that could have been produced if the plant operated all year at full power.*

U.S. Electricity Production Costs

1995-2011, *In 2011 cents per kilowatt-hour*



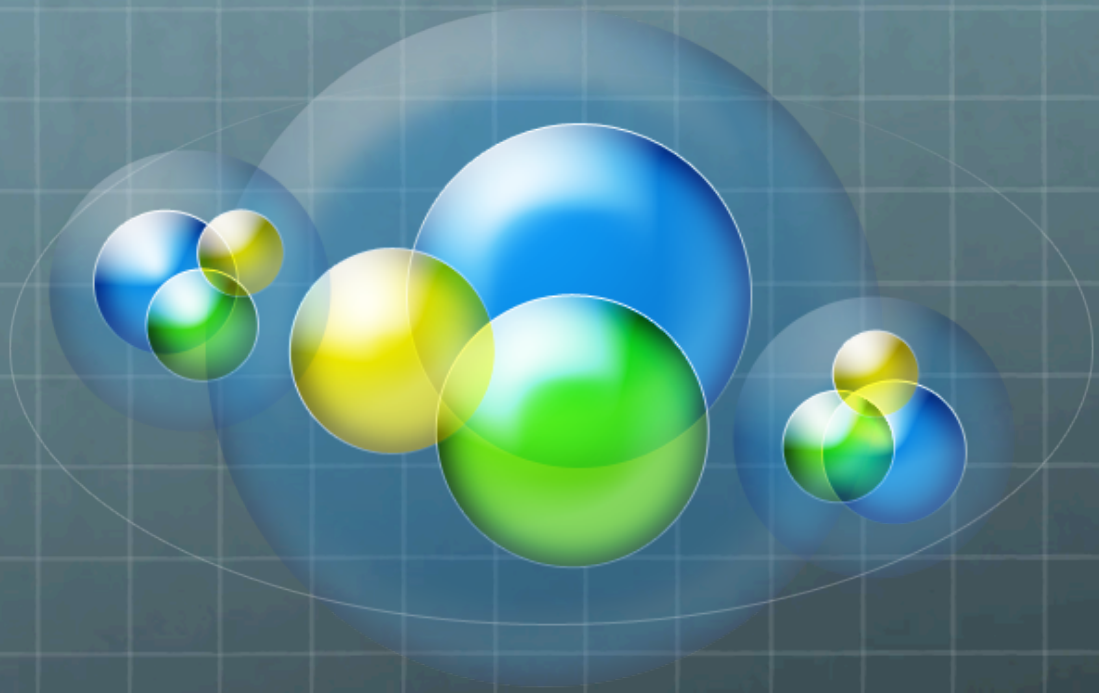
Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs do not include indirect costs and are based on FERC Form 1 filings submitted by regulated utilities. Production costs are modeled for utilities that are not regulated.

NEI

Source: Ventyx Velocity Suite
Updated: 5/12

Video

- http://www.youtube.com/watch?v=MSFgmLW1Crw



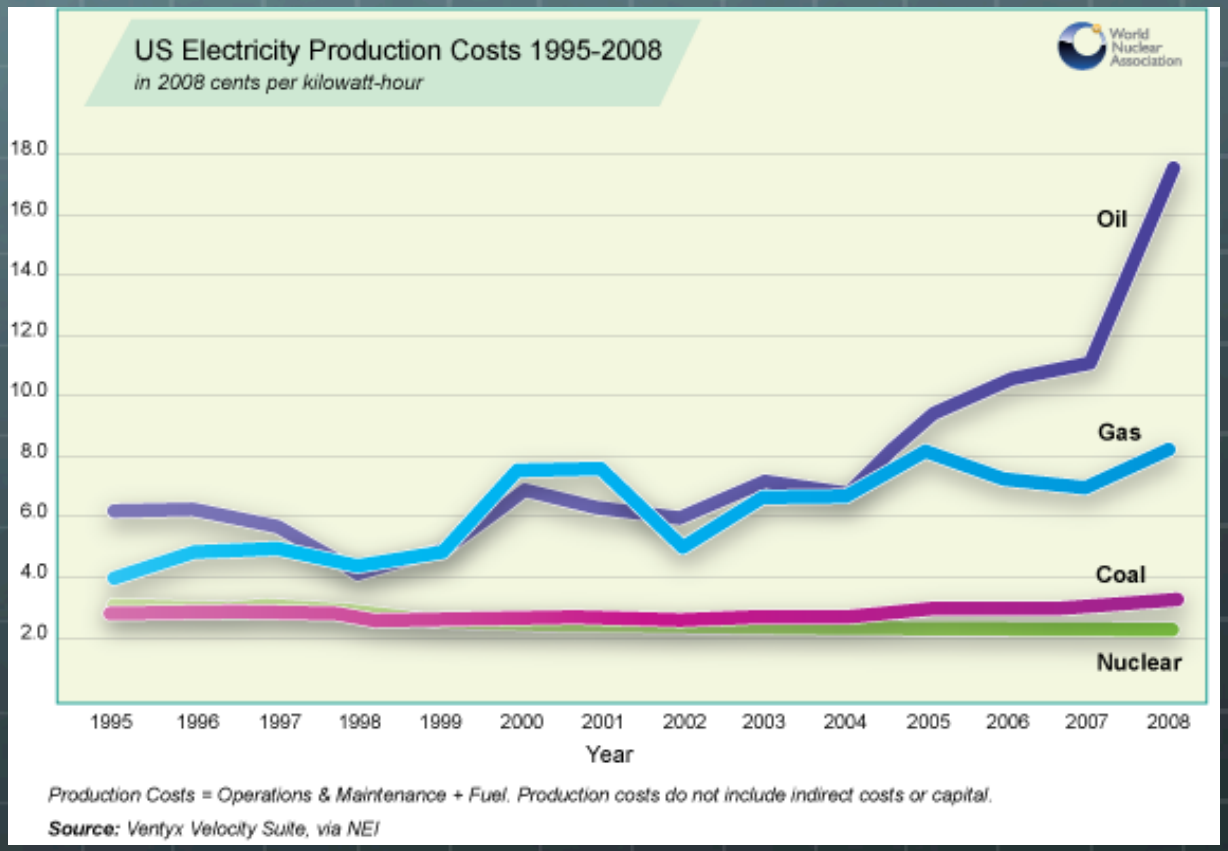
Utilization

Nuclear Energy

Economics

- Cost of Fuel
  - Uranium must be processed , enriched & fabricated into fuel elements
    - *About half the cost is due to enrichment and fabrication
  - Total fuel costs are about 1/3 that for coal fired power plants, and 1/4-1/5 for a gas combined-cycle plant
  - Advantage: Uranium is a highly concentrated source of energy
    - Easily & cheaply transportable
    - 1 kg of natural uranium will yield about 20,000 x as must energy as same amount of coal
    - If fuel is reprocessed and the recovered plutonium and uranium is used in mixed oxide fuel (MOX), more energy can be obtained
      - Costs for this can be large but are also offset by not needing enrichment, and by there being smaller amounts of high level wastes

- Important to distinguish between the economics of nuclear plants already in operation and those at the planning stage
  - Existing plants operate at a very low cost
    - operations, maintenance, fuel costs, used fuel management



http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/

New Generating Capacity

- Understanding Costs
  - Capital costs: the bare plant cost, the owner's costs, cost escalation and inflation
  - Financing costs: depends on rate of interest on debt-equity ratio, how capital costs are recovered
  - Operating costs: include operating and maintenance, fuel costs (includes used fuel management) and final waste disposal
    - These costs are internal for nuclear power, usually external for other technologies.

- An update in 2009 by MIT (of a 2003 study) says that “The estimated cost of constructing a nuclear power plant has increased at a rate of 15% per year heading into the current economic downturn. “
  - This is based off of actual builds in Japan and Korea
  - Capital costs for coal and natural gas have increased as well, but no as much
- US Energy Information Administration 2010 report “Updated Capital Cost Estimates for Electricity Generation Plants“.
  - The US cost estimate for new nuclear was revised to a value of $5339/kW for 2011
- Construction costs vs operation costs, do the very low operation costs for nuclear outweigh production costs of new facilities?
  - Current facilities along with other combinations of energy (natural gas + renewables)

Reserves/ Resources

- Uranium is a relatively common metal, found in rocks and seawater
  - The world's known uranium resources increased 15% in two years due to increased mineral exploration
  - It is a common metal in the Earth's crust
    - Constituent of most rocks and the sea
    - Typical concentrations..

Very high-grade ore (Canada) - 20% U	200,000 ppm U
High-grade ore - 2% U,	20,000 ppm U
Low-grade ore - 0.1% U,	1,000 ppm U
Very low-grade ore* (Namibia) - 0.01% U	100 ppm U
Granite	3-5 ppm U
Sedimentary rock	2-3 ppm U
Earth's continental crust (av)	2.8 ppm U
Seawater	0.003 ppm U

http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Uranium-Resources/Supply-of-Uranium/

- Orebody: an occurrence of mineralisation from which the metal is economically recoverable
  - Relative to both costs of extraction and market prices

- Measured resources of uranium (the amount known to be economically recoverable from orebodies) are relative to costs & prices
  - Also dependent on past exploration and what is known about what is in the Earth's crust
    - "Epistemology rather then geology"

Known Recoverable Resources of Uranium 2011

	tonnes U	percentage of world
Australia	1,661,000	31%
Kazakhstan	629,000	12%
Russia	487,200	9%
Canada	468,700	9%
Niger	421,000	8%
South Africa	279,100	5%
Brazil	276,700	5%
Namibia	261,000	5%
USA	207,400	4%
China	166,100	3%
Ukraine	119,600	2%
Uzbekistan	96,200	2%
Mongolia	55,700	1%
Jordan	33,800	1%
other	164,000	3%
World total	**5,327,200**	

http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Uranium-Resources/Supply-of-Uranium/

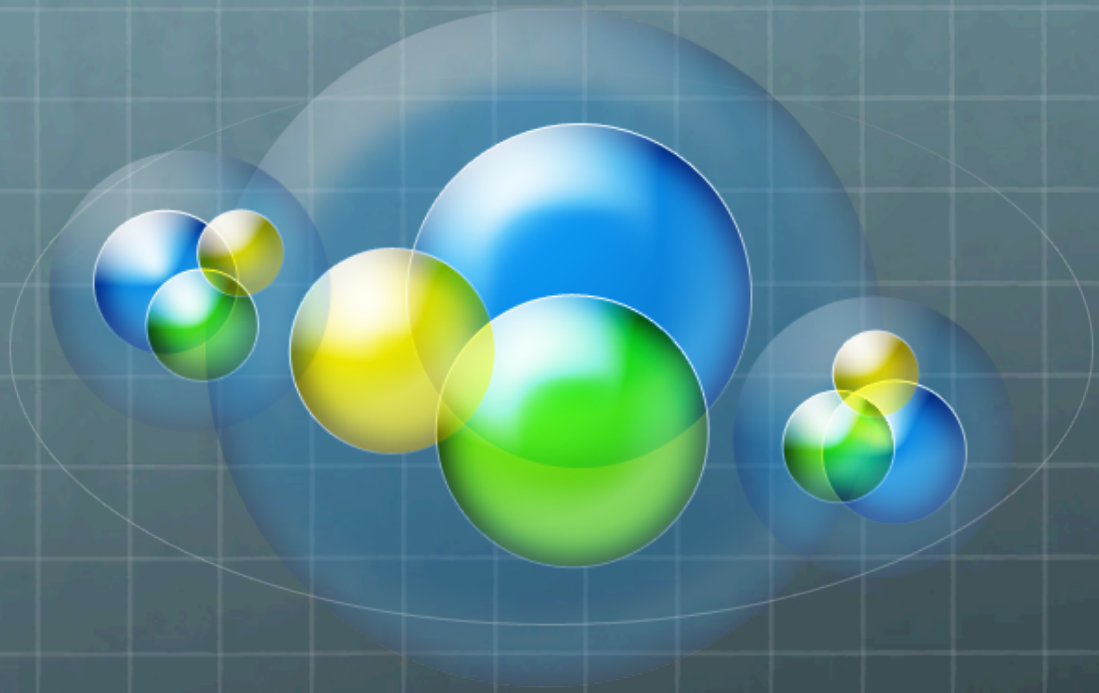
Australia

- Uranium has been mined since 1954, and four mines are currently operating. More are planned.
- Australia's known uranium resources are the world's largest - 31% of the world total.
- In 2011-12 Australia produced 7700 tonnes of uranium oxide concentrate. It is the world's third-ranking producer, behind Kazakhstan and Canada.
- Australia uses no nuclear power
- * Uranium has not been mined on a commercial scale in New Zealand

http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Australia--Uranium/

US Reserves

- The US Energy Information Administration came out with it's estimates in 2008 of US uranium reserves
  - At a maximum forward cost up to $100 / pound
    - Reserves totaled 1,227 million pounds
  - Up to $50/ pound
    - 539 million pounds
    - At 1999-2008 consumption rates, at $100/pound reserves estimated to last 23 years



Environmental Impacts

Nuclear Energy

Air Emissions

- DO NOT emit carbon dioxide, sulfur dioxide, or nitrogen oxides during power generation
- During mining, transport, fuel fabrication, enrichment, reactor construction, decommissioning & waste management fossil fuels are emitted
- Most power plant reactors are placed inside a containment building to contain all the radioactive elements that might be released

Clear Air Act

- Defines the EPA's responsibilities for protecting and improving the nation's air quality and the ozone layer
- Amendments that will prevent over 230,000 early deaths in 2020

http://green.autoblog.com/

Water Resource Use

- Use large quantities of water for steam production and cooling
- Remove water from lakes or rivers, which could affect fish & other aquatic life

http://www.cnn.com/

Water Discharges

- Heavy metals and salts build up in the water used
- Higher temperature discharged from the power plant can affect the water quality and aquatic life
- To cool water plants use cooling towers or cooling ponds
- A cooling pond has temperatures that are 30 degF larger where the water is discharged
  - Surface warming

Water Discharges

- Can discharge small amounts of tritium and other radioactive elements
  - Tritium: a radioactive isotope of hydrogen that emits a low-energy beta particle (drinking water)
- Waste from uranium mining operations and water runoff
  - contaminate groundwater and surface water with heavy metals and traces of radioactive uranium

Spent Fuel

- Every 18-24 months plants must shut down to remove and replace “spent” uranium fuel
- Waste is stored in steel-lined, concrete vaults filled with water
  - OR aboveground steel or steel-reinforced concrete containers with steel inner canisters

http://www.nacintl.com/

Spent Fuel

- Methods for final burial in deep stable geological structures have been suggested
  - No country has been successful
    - Too expensive
    - Yucca Mountain- years of controversy and legal problems
- Fuel can be reprocessed at a reprocessing plant
  - Major source of radioactive environmental contamination
- Obama administration has disallowed reprocessing of nuclear waste due to proliferation concerns

Radioactive Waste Types

- Regulated waste types:
  - Low-level waste: radioactivity contaminating protective clothing, tools, etc produced through the process of purifying the water
  - Waste secondary to reprocessing refers to certain waste byproducts that result from spent fuel
  - High-level waste: nuclear reactor fuel
  - Uranium left behind after the processing of natural ore to extract uranium and thorium

Radioactive Waste Generation

- During an accident, plant releases large amounts of radioactive material
  - Radiation sickness
  - Three Mile Island, Chernobyl
- Closed plant
  - Waste stored for 20-30 years

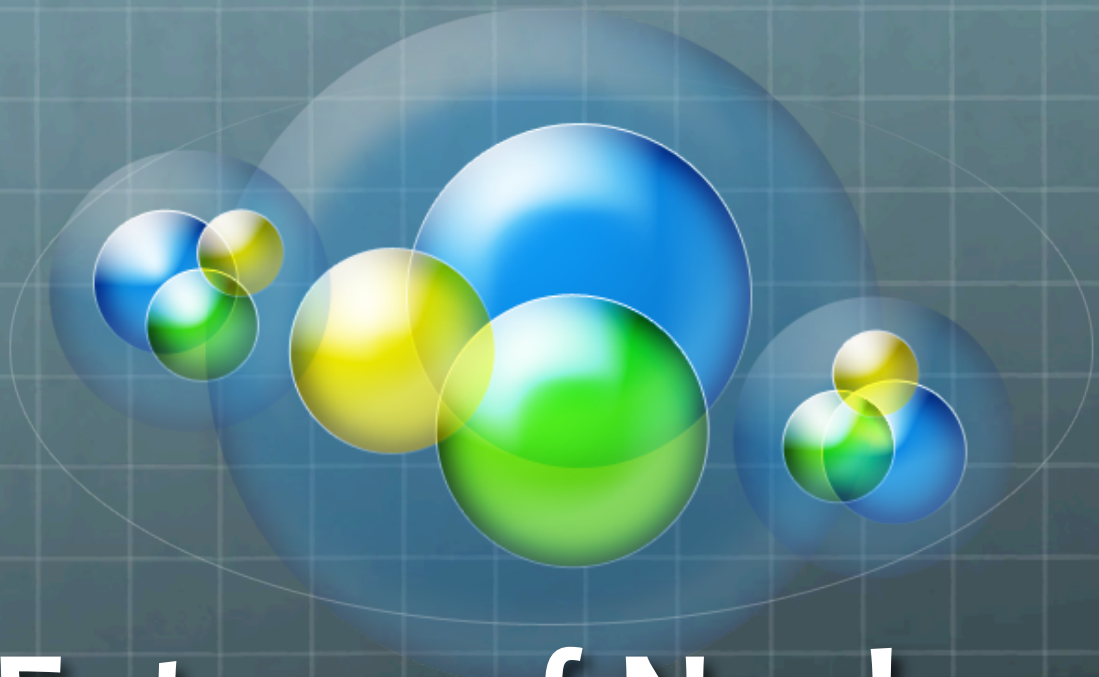
Thermal Pollution

- Nuclear power plant discharges 50% more waste heat than fossil-fuel plant

http://en.wikipedia.org/

Within United States

- As of February 2009, NRC requires:
  - Design of new power plants ensure that reactor containment would remain intact, cooling systems could still operate, and spent fuels still protected if an aircraft attacked



Future of Nuclear Energy

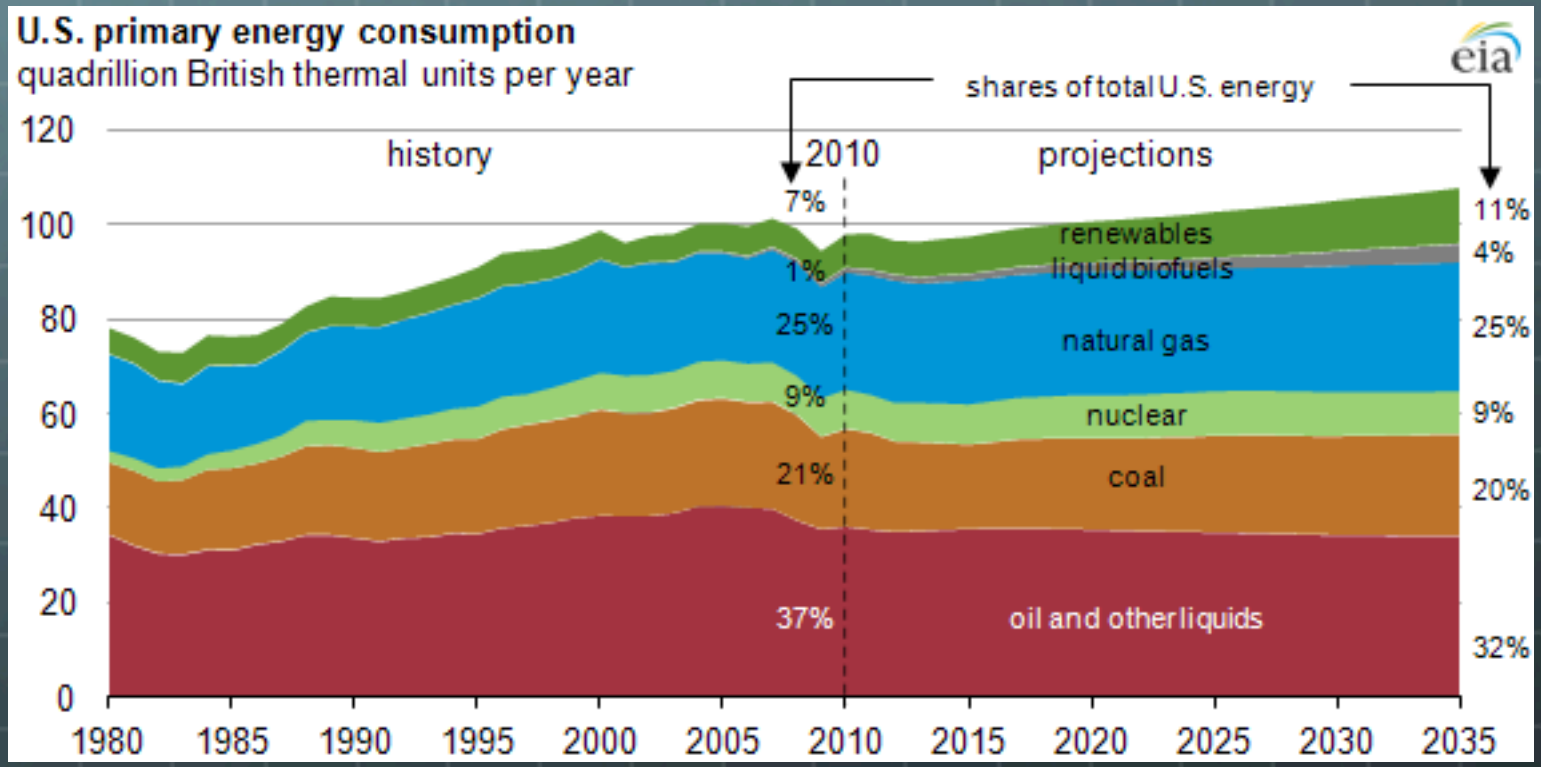
Current- United States

- 103 licensed to operate nuclear power plants
  - 68 pressurized water reactors
  - 35 boiling water reactors
- Generate 9% of the nation's electric

Locations of Nuclear Power Plants in US

http://www.world-nuclear.org/

Where are we headed?



http://
www.eia.gov/

Current- New Zealand

- Nuclear free zone!
- 1968 Plan
  - Need for nuclear plant in next decade
  - Site reserved at Oyster Point
  - Maui gas field was discovered and coal reserves
  - Project abandoned by 1972

Current- Australia

- No current nuclear facilities
- Australia has 31% of the world's uranium deposits
  - Third largest producer of Uranium
- Legislation to ban nuclear power
  - Bill did not pass

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