Nonrenewable Energy

Chapter 15
Core Case Study: How Long Will Supplies of Conventional Oil Last?

- Oil: energy supplier

- How much is left? When will we run out?

- Three options
  - Look for more
  - Reduce oil use and waste
  - Use other energy sources

- No easy solutions
Thunder Horse Offshore Floating Oil Production Platform in the Gulf of Mexico
15-1 What Major Sources of Energy Do We Use?

- **Concept 15-1A** About three-quarters of the world’s commercial energy comes from nonrenewable fossil fuels and the rest comes from nonrenewable nuclear fuel and renewable sources.

- **Concept 15-1B** Net energy is the amount of high-quality usable energy available from a resource after the amount of energy needed to make it available is subtracted.
Fossil Fuels Supply Most of Our Commercial Energy

- Solar energy
- Indirect solar energy
  - Wind
  - Hydropower
  - Biomass

- Commercial energy
  - Nonrenewable energy resources, e.g. fossil fuels
  - Renewable energy resources
Natural Capital: Important Nonrenewable Energy Resources
Water is heated and brought up as dry steam or wet steam. Water penetrates down through the rock and enters the magma.
Commercial Energy Use by Source for the World and the United States

**World**
- Natural gas: 21%
- Oil: 33%
- Coal: 22%
- Renewable: 18%
- Nuclear power: 6%
- Geothermal, solar, wind: 2.5%
- Hydropower: 4.5%
- Nonrenewable: 82%

**United States**
- Oil: 39%
- Coal: 23%
- Biomass: 3%
- Nuclear power: 8%
- Geothermal, solar, wind: 1%
- Hydropower: 3%
- Nonrenewable: 93%

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World

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- Hydropower: 3%
- Natural gas: 23%
- Biomass: 3%
- Oil: 39%
- Coal: 23%
- Renewable: 7%
- Nonrenewable: 93%

Fig. 15-3, p. 373
Case Study: A Brief History of Human Energy Use

- Muscle power: early humans
- Discovery of fire
- Agriculture
- Use of wind and flowing water
- Machines powered by wood, then coal
- Internal combustion engine
- Nuclear energy
- Energy crisis
How Should We Evaluate Energy Resources?

- Supplies
- Environmental impact
- How much useful energy is provided?
Science Focus: Net Energy Is the Only Energy That Really Counts

- It takes energy to get energy
- Second Law of Thermodynamics
- **Net energy** expressed as **net energy ratio**
- Conventional oil: high net energy ratio
- Electricity produced by the **nuclear power fuel cycle**: low net energy ratio
Net Energy Ratios for Various Energy Systems over Their Estimated Lifetimes

**Space Heating**
- Passive solar: 5.8
- Natural gas: 4.9
- Oil: 4.5
- Active solar: 1.9
- Coal gasification: 1.5
- Electric heating (coal-fired plant): 0.4
- Electric heating (natural-gas-fired plant): 0.4
- Electric heating (nuclear plant): 0.3

**High-Temperature Industrial Heat**
- Surface-mined coal: 28.2
- Underground-mined coal: 25.8
- Natural gas: 4.9
- Oil: 4.7
- Coal gasification: 1.5
- Direct solar (concentrated): 0.9

**Transportation**
- Ethanol from sugarcane residue: 8.0
- Ethanol from switchgrass: 5.4
- Natural gas: 4.9
- Gasoline (refined crude oil): 4.1
- Coal liquefaction: 1.4
- Oil shale: 1.2
- Ethanol from corn: 1.1 (but can reach 1.5)
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Fig. 15-A (1), p. 374
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Animation: Energy use

- Developed Countries: 90% Nonrenewable, 10% Renewable
- Developing Countries: 50% Nonrenewable, 41% Renewable
15-2 What Are the Advantages and Disadvantages of Oil?

- **Concept 15-2A** Conventional oil is currently abundant, has a high net energy yield, and is relatively inexpensive, but using it causes air and water pollution and releases greenhouse gases to the atmosphere.

- **Concept 15-2B** Heavy oils from oil sand and oil shale exist in potentially large supplies but have low net energy yields and higher environmental impacts than conventional oil has.
We Depend Heavily on Oil

- **Petroleum**, or **crude oil** = **conventional**, or **light oil**

- **Fossil fuels**: **crude oil** and **natural gas**

- Oil extraction and refining

- **Petrochemicals**: products of oil distillation

- World oil consumption
Science: Refining Crude Oil

Diagram showing the processes involved in refining crude oil:
- **Lowest Boiling Point**
  - Gases
  - Gasoline
  - Aviation fuel
  - Heating oil
  - Diesel oil
  - Naphtha
- **Highest Boiling Point**
  - Grease and wax
  - Grease and wax solvent
  - Asphalt
  - Furnace
  - Heated crude oil

The diagram illustrates the various products derived from crude oil at different boiling points, with the furnace at the bottom and the products at the top.
**Lowest Boiling Point**
- Gases
  - Gasoline
  - Aviation fuel
  - Heating oil
  - Diesel oil
  - Naphtha

**Heated crude oil**

**Highest Boiling Point**
- Grease and wax
- Asphalt
- Furnace

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Fig. 15-4a, p. 375
OPEC Controls Most of the World’s Oil Supplies (1)

- 13 countries have at least 60% of the world’s crude oil reserves
  - Saudi Arabia: 25%
  - Canada: 15%

- Oil production peaks and flow rates to consumers
OPEC Controls Most of the World’s Oil Supplies (2)

- Possible effects of steeply rising oil prices
  - Reduce energy waste
  - Shift to non-carbon energy sources
  - Higher prices for products made with petrochemicals
  - Higher food prices; buy locally-produced food
  - Airfares higher
  - Smaller more fuel-efficient vehicles
  - Upgrade of public transportation
The United States Uses Much More Oil Than It Produces (1)

- Produces 9% of the world’s oil
- Imports 60% of its oil
- About One-fourth of the world’s conventional oil is controlled by countries that sponsor or condone terrorism
The United States Uses Much More Oil Than It Produces (2)

- Should we look for more oil reserves?
  - Extremely difficult
  - Expensive and financially risky

- A new role for bacteria in the oil industry
Case Study: Oil and the U.S. Arctic National Wildlife Refuge

- The Arctic National Wildlife Refuge (ANWR)
  - Not open to oil and gas development
  - Fragile tundra biome

- Oil companies lobbying since 1980 to begin exploratory drilling
  - Pros
  - Cons
The Amount of Oil That Might Be Found in the ANWR

- Projected U.S. oil consumption
- Arctic refuge oil output over 50 years

Year: 2000 to 2050
Barrels of oil per year (billions)
Projected U.S. oil consumption

Barrels of oil per year (billions)

Year

Arctic refuge oil output over 50 years

Fig. 15-5, p. 378
Conventional Oil Has Advantages and Disadvantages

- Extraction, processing, and burning of nonrenewable oil and other fossil fuels
  - Advantages
  - Disadvantages
Trade-Offs: Conventional Oil, Advantages and Disadvantages

**Advantages**
- Ample supply for 42–93 years
- Low cost
- High net energy yield
- Easily transported within and between countries
- Low land use
- Technology is well developed
- Efficient distribution system

**Disadvantages**
- Need to find substitutes within 50 years
- Large government subsidies
- Environmental costs not included in market price
- Artificially low price encourages waste and discourages search for alternatives
- Pollutes air when produced and burned
- Releases CO₂ when burned
- Can cause water pollution
## Trade-Offs

### Conventional Oil

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<td>Efficient distribution system</td>
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Bird Covered with Oil from an Oil Spill in Brazilian Waters
Will Heavy Oil Spills from Oil Sand Be a Viable Option?

- **Oil sand, tar sand** contains bitumen

- Canada and Venezuela: oil sand have more oil than in Saudi Arabia

- Extraction
  - Serious environmental impact before strip-mining
  - Low net energy yield: Is it cost effective?
Will Oil Shales Be a Useable Resource?

- **Oil shales** contain kerogen
  - After distillation: **shale oil**

- 72% of the world’s reserve is in arid areas of western United States; there is a catch!
  - Locked up in rock
  - Lack of water needed for extraction and processing
  - Low net energy yield
Oil Shale Rock and the Shale Oil Extracted from It
Trade-Offs: Heavy Oils from Oil Shale and Oil Sand

**Advantages**
- Moderate cost (oil sand)
- Large potential supplies, especially oil sands in Canada
- Easily transported within and between countries
- Efficient distribution system in place
- Technology well-developed (oil sand)

**Disadvantages**
- High cost (oil shale)
- Low net energy yield
- Environmental costs not included in market price
- Large amounts of water needed for processing
- Severe land disruption
- Severe water pollution
- Air pollution and CO₂ emissions when produced and burned
TRADE-OFFS

Heavy Oils from Oil Shale and Oil Sand

**Advantages**
- Moderate cost (oil sand)
- Large potential supplies, especially oil sands in Canada
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- Low net energy yield
- Environmental costs not included in market price
- Large amounts of water needed for processing
- Severe land disruption
- Severe water pollution
- Air pollution and CO₂ emissions when produced and burned
15-3 What Are the Advantages and Disadvantages of Natural Gas?

- **Concept 15-3** Conventional natural gas is more plentiful than oil, has a high net energy yield and a fairly low cost, and has the lowest environmental impact of all fossil fuels.
Natural Gas Is a Useful and Clean-Burning Fossil Fuel (1)

- **Natural gas**: mixture of gases
  - More than half is $\text{CH}_4$

- **Conventional natural gas**
  - Pipelines
  - Liquefied petroleum gas (LPG)
  - Liquefied natural gas (LNG) – low net energy yield
Natural Gas Is a Useful and Clean-Burning Fossil Fuel (2)

- Unconventional natural gas
  - Coal bed methane gas
  - Methane hydrate
Natural Gas Has More Advantages Than Disadvantages

- Will natural gas be the bridge fuel helping us make the transition to a more sustainable energy future?
### Trade-Offs: Conventional Natural Gas

#### Advantages
- Ample supplies
- High net energy yield
- Low cost
- Less air pollution than other fossil fuels
- Lower CO₂ emissions than other fossil fuels
- Easily transported by pipeline
- Low land use
- Good fuel for fuel cells, gas turbines, and motor vehicles

#### Disadvantages
- Nonrenewable resource
- Releases CO₂ when burned
- Government subsidies
- Environmental costs not included in market price
- Methane (a greenhouse gas) can leak from pipelines
- Difficult to transfer from one country to another
- Can be shipped across ocean only as highly explosive LNG
TRADE-OFFS

Conventional Natural Gas

**Advantages**
- Ample supplies
- High net energy yield
- Low cost
- Less air pollution than other fossil fuels
- Lower CO$_2$ emissions than other fossil fuels
- Easily transported by pipeline
- Low land use
- Good fuel for fuel cells, gas turbines, and motor vehicles

**Disadvantages**
- Nonrenewable resource
- Releases CO$_2$ when burned
- Government subsidies
- Environmental costs not included in market price
- Methane (a greenhouse gas) can leak from pipelines
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- Can be shipped across ocean only as highly explosive LNG
15-4 What Are the Advantages and Disadvantages of Coal?

- **Concept 15-4A** Conventional coal is very plentiful and has a high net energy yield and low cost, but it has a very high environmental impact.

- **Concept 15-4B** Gaseous and liquid fuels produced from coal could be plentiful, but they have lower net energy yields and higher environmental impacts than conventional coal has.
Coal Comes in Several Forms and Is Burned Mostly to Produce Electricity

- **Coal**: solid fossil fuel

- Burned in 2100 power plants, generates 40% of the world’s electricity
  - Inefficient

- Three largest coal-burning countries
  - China
  - United States
  - Canada
Stages in Coal Formation over Millions of Years

Peat (not a coal)
- Partially decayed plant matter in swamps and bogs; low heat content

Lignite (brown coal)
- Low heat content; low sulfur content; limited supplies in most areas

Bituminous (soft coal)
- Extensively used as a fuel because of its high heat content and large supplies; normally has a high sulfur content

Anthracite (hard coal)
- Highly desirable fuel because of its high heat content and low sulfur content; supplies are limited in most areas

Increasing moisture content ——> Increasing heat and carbon content
Increasing moisture content

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Increasing heat and carbon content
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Lignite  
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Heat  
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Increasing heat and carbon content
Science: Coal-Burning Power Plant

[Diagram of a coal-burning power plant with labeled components: coal bunker, turbine, generator, condenser, filter, boiler, cooling loop, stack, waste heat, cooling tower, toxic ash disposal.]
Waste heat
Coal bunker
Turbine
Transfers waste heat to atmosphere
Generator
Cooling loop
Stack
Pulverizing mill
Condenser
Filter
Boiler
Toxic ash disposal

Cooling tower transfers waste heat to atmosphere

Fig. 15-12, p. 383
Coal Is a Plentiful but Dirty Fuel (1)

- World's most abundant fossil fuel
  - U.S. has 25%

- Environmental costs of burning coal
  - Severe air pollution
    - Sulfur released as SO$_2$
    - Large amount of soot
    - CO$_2$
    - Trace amounts of Hg and radioactive materials
Coal Is a Plentiful but Dirty Fuel (2)

- Environmentalists call for
  - Taxation on CO$_2$ production by power plants
  - Cleaner coal-burning plants
Air Pollution from a Coal-Burning Industrial Plant in India
CO₂ Emissions Per Unit of Electrical Energy Produced for Energy Sources

- Coal-fired electricity: 286%
- Synthetic oil and gas produced from coal: 150%
- Coal: 100%
- Oil sand: 92%
- Oil: 86%
- Natural gas: 58%
- Nuclear power fuel cycle: 17%
- Geothermal: 10%
Coal-fired electricity: 286%
Synthetic oil and gas produced from coal: 150%
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<td>Coal–burning plants: Inefficient or non-existent pollution controls</td>
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<td>Leading area for SO$_2$ pollution: health hazard</td>
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<tr>
<td>Acid rain due to coal burning</td>
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<td>Hg showing up in salmon off the western coast of the United States</td>
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<td>Air quality of Korea and Japan impacted</td>
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Coal Has Advantages and Disadvantages

- Single biggest air polluter in coal-burning countries
- One-fourth of the annual CO₂ emissions
- Many opposed to new coal-burning power plants

- Advantages
- Disadvantages
### Trade-Offs: Coal, Advantages and Disadvantages as an Energy Resource

#### Advantages
- Ample supplies (225–900 years)
- High net energy yield
- Low cost
- Well-developed technology
- Air pollution can be reduced with improved technology

#### Disadvantages
- Severe land disturbance, air pollution, and water pollution
- Severe threat to human health when burned
- Environmental costs not included in market price
- Large government subsidies
- High CO₂ emissions when produced and burned
- Radioactive particle and toxic mercury emissions
## TRADE-OFFS

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We Can Convert Coal into Gaseous and Liquid Fuels

- Conversion of solid coal to
  - Synthetic natural gas (SNG) by coal gasification
  - Methanol or synthetic gasoline by coal liquefaction

- Are there benefits to using these synthetic fuels?
Trade-Offs: Synthetic Fuels

**Advantages**
- Large potential supply
- Vehicle fuel
- Moderate cost
- Lower air pollution than coal when burned

**Disadvantages**
- Low to moderate net energy yield
- Higher cost than coal
- Requires mining 50% more coal
- Environmental costs not included in market price
- High environmental impact
- Large government subsidies
- High water use
- Higher CO₂ emissions than coal
## TRADE-OFFS

### Synthetic fuels

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Concept 15-5  Nuclear power has a low environmental impact and a very low accident risk, but high costs, a low net energy yield, long-lived radioactive wastes, vulnerability to sabotage, and the potential for spreading nuclear weapons technology have limited its use.
How Does a Nuclear Fission Reactor Work? (1)

- Controlled nuclear fission reaction in a reactor
  - Light-water reactors

- Fueled by uranium ore and packed as pellets in fuel rods and fuel assemblies

- Control rods absorb neutrons
How Does a Nuclear Fission Reactor Work? (2)

- Water is the usual coolant
- **Containment shell** around the core for protection
- **Water-filled pools or dry casks** for storage of radioactive spent fuel rod assemblies
Light-Water-Moderated and -Cooled Nuclear Power Plant with Water Reactor
Small amounts of radioactive gases

Control rods
Containment shell

Heat exchanger
Steam
Turbine
Generator

Waste heat

Uranium fuel input (reactor core)

Shielding
Pressure vessel

Coolant passage

Moderator

Coolant

Pump

Waste heat

Useful electrical energy 25%–30%

Periodic removal and storage of radioactive wastes and spent fuel assemblies

Periodic removal and storage of radioactive liquid wastes

Water source (river, lake, ocean)
After 3 or 4 Years in a Reactor, Spent Fuel Rods Are Removed and Stored in Water
What Is the Nuclear Fuel Cycle?

- Mine the uranium
- Process the uranium to make the fuel
- Use it in the reactor
- Safely store the radioactive waste
- Decommission the reactor
Science: The Nuclear Fuel Cycle

- Enrichment of UF₆
- Conversion of U₃O₈ to UF₆
- Fuel fabrication
  - Conversion of enriched UF₆ to UO₂ and fabrication of fuel assemblies
- Reactor
- Fuel assemblies
- Spent fuel reprocessing
  - Uranium-235 as UF₆
  - Plutonium-239 as PuO₂
- Temporary storage of spent fuel assemblies underwater or in dry casks
- Low-level radiation with long half-life
- Decommissioning of reactor
- Geologic disposal of moderate- and high-level radioactive wastes
- Open fuel cycle today
- Recycling of nuclear fuel

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Fuel assemblies

Decommissioning of reactor

Enrichment of UF₆

Fuel fabrication

(conversion of enriched UF₆ to UO to UO₂ and fabrication of fuel assemblies)

Uranium-235 as UF₆

Plutonium-239 as PuO₂

Spent fuel reprocessing

Temporary storage of spent fuel assemblies underwater or in dry casks

Low-level radiation with long half-life

Geologic disposal of moderate- and high-level radioactive wastes

Open fuel cycle today

Recycling of nuclear fuel

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What Happened to Nuclear Power?

- Slowest-growing energy source and expected to decline more

- Why?
  - Economics
  - Poor management
  - Low net yield of energy of the nuclear fuel cycle
  - Safety concerns
  - Need for greater government subsidies
  - Concerns of transporting uranium
Case Study: Worst Commercial Nuclear Power Plant Accident in the U.S.

- Three Mile Island
  - March 29, 1979
  - Near Harrisburg, PA, U.S.
  - Nuclear reactor lost its coolant
  - Led to a partial uncovering and melting of the radioactive core
  - Unknown amounts of radioactivity escaped
  - People fled the area
  - Increased public concerns for safety
    - Led to improved safety regulations in the U.S.
Case Study: Worst Nuclear Power Plant Accident in the World

- Chernobyl
  - April 26, 1986
  - In Chernobyl, Ukraine
  - Series of explosions caused the roof of a reactor building to blow off
  - Partial meltdown and fire for 10 days
  - Huge radioactive cloud spread over many countries and eventually the world
  - 350,000 people left their homes
  - Effects on human health, water supply, and agriculture
Remains of a Nuclear Reactor at the Chernobyl Nuclear Power Plant
Nuclear Power Has Advantages and Disadvantages

- Advantages
- Disadvantages
Trade-Offs: Conventional Nuclear Fuel Cycle, Advantages and Disadvantages

**Advantages**
- Large fuel supply
- Low environmental impact (without accidents)
- Emits 1/6 as much CO₂ as coal
- Moderate land disruption and water pollution (without accidents)
- Moderate land use
- Low risk of accidents because of multiple safety systems (except for Chernobyl-type reactors)

**Disadvantages**
- Cannot compete economically without huge government subsidies
- Low net energy yield
- High environmental impact (with major accidents)
- Environmental costs not included in market price
- Risk of catastrophic accidents
- No widely acceptable solution for long-term storage of radioactive wastes
- Subject to terrorist attacks
- Spreads knowledge and technology for building nuclear weapons
## TRADE-OFFS

### Conventional Nuclear Fuel Cycle

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- Spreads knowledge and technology for building nuclear weapons
Trade-Offs: Coal versus Nuclear to Produce Electricity

Coal
- Ample supply
- High net energy yield
- Very high air pollution
- High CO₂ emissions
- High land disruption from surface mining
- High land use
- Low cost (with huge subsidies)

Nuclear
- Ample supply of uranium
- Low net energy yield
- Low air pollution
- Low CO₂ emissions
- Much lower land disruption from surface mining
- Moderate land use
- High cost (even with huge subsidies)
TRADE-OFFS

Coal vs. Nuclear

Coal
Ample supply
High net energy yield
Very high air pollution
High CO₂ emissions
High land disruption from surface mining
High land use
Low cost (with huge subsidies)

Nuclear
Ample supply of uranium
Low net energy yield
Low air pollution
Low CO₂ emissions
Much lower land disruption from surface mining
Moderate land use
High cost (even with huge subsidies)
Explosions or meltdowns possible at the power plants

Storage pools and casks are more vulnerable to attack

60 countries have or have the ability to build nuclear weapons
Dealing with Radioactive Wastes Produced by Nuclear Power Is a Difficult Problem

- **High-level radioactive wastes**
  - Must be stored safely for 10,000–240,000 years

- **Where to store it**
  - Deep burial: safest and cheapest option
  - Would any method of burial last long enough?
  - There is still no facility

- Can the harmful isotopes be changed into harmless isotopes?
1985: plans in the U.S. to build a repository for high-level radioactive wastes in the Yucca Mountain desert region (Nevada)

Problems
- Cost: $58–100 billion
- Large number of shipments to the site: protection from attack?
- Rock fractures
- Earthquake zone
- Decrease national security
What Do We Do with Worn-Out Nuclear Power Plants?

- Decommission or retire the power plant

- Some options
  - Dismantle the plant and safely store the radioactive materials
  - Enclose the plant behind a physical barrier with full-time security until a storage facility has been built
  - Enclose the plant in a tomb
    - Monitor this for thousands of years
Can Nuclear Power Lessen Dependence on Imported Oil, Reduce Global Warming?

- Nuclear power plants: no CO\textsubscript{2} emission

- Nuclear fuel cycle: emits CO\textsubscript{2}

- Opposing views on nuclear power and global warming
  - Nuclear power advocates
  - 2003 study by MIT researchers
  - 2007: Oxford Research Group
Will Nuclear Fusion Save Us?

- “Nuclear fusion is the power of the future and always will be”

- Still in the laboratory phase after 50 years of research and $34 billion dollars

- 2006: U.S., China, Russia, Japan, South Korea, and European Union
  - Will build a large-scale experimental nuclear fusion reactor by 2040
Experts Disagree about the Future of Nuclear Power

- Proponents of nuclear power
  - Fund more research and development
  - Pilot-plant testing of potentially cheaper and safer reactors
  - Test breeder fission and nuclear fusion

- Opponents of nuclear power
  - Fund rapid development of energy efficient and renewable energy resources
Science Focus: Are New and Safer Nuclear Reactors the Answer? (1)

- **Advanced light-water reactors (ALWR)**
  - Built-in passive safety features

- **High-temperature-gas-cooled reactors (HTGC)**

- **Pebble bed modular reactor (PBMR)**
  - Pros: no need to shut down for refueling
  - Cons

- **Breeder nuclear fission reactors**
New Generation nuclear reactors must satisfy these five criteria

• Safe-runaway chain reaction is impossible
• Fuel can not be used for nuclear weapons
• Easily disposed of fuel
• Nuclear fuel cycle must generate a higher net energy yield than other alternative fuels, without huge government subsidies
• Emit fewer greenhouse gases than other fuels
Animation: Chernobyl fallout
Video: Nuclear energy