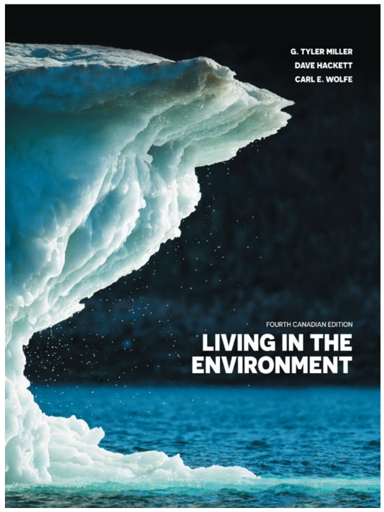
NELSON EDUCATION | Canada's Learning Advantage

# NETA PowerPoint® Slides

to accompany




prepared by
Ian Dawe



# Chapter 17

## Nonrenewable Energy Resources

# Key Concepts

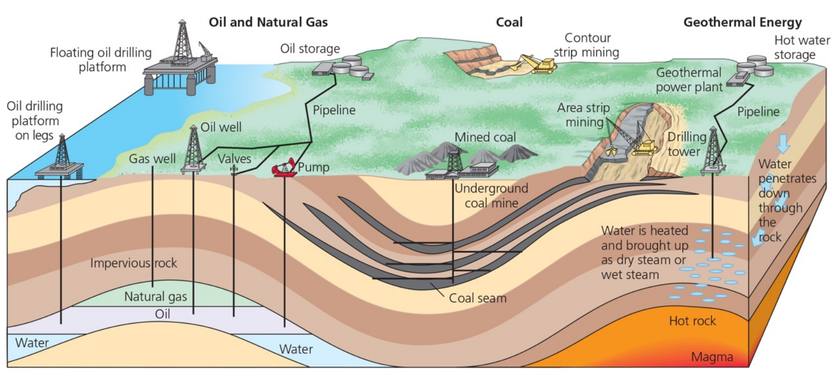
**How should we evaluate energy resources?**

– Conventional oil
– Nonconventional oil
– Natural gas
– Coal and coal conversion
– Nuclear fission and fusion

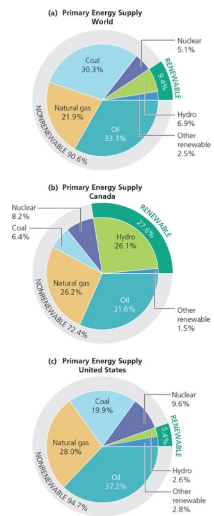




# Types of Nonrenewable Energy Resources



# Commercial Energy Use by Source

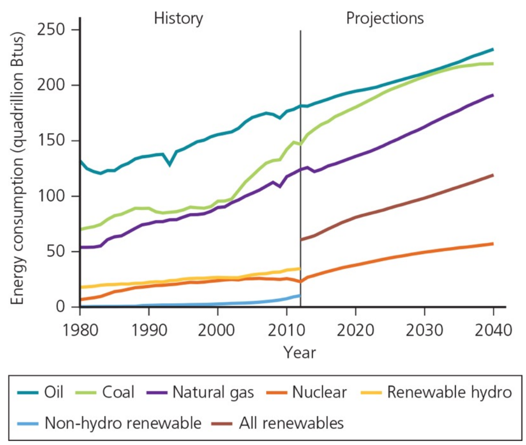



Source: Data from BP Statistical Review of Energy 2015 and the Energy Information Administration. Adjusted for thermal content and conversion efficiency assumptions according to Newell and Quian, 2015.



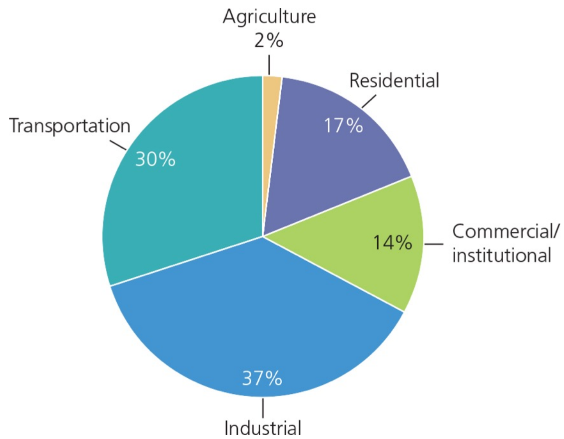


# Global Energy Use by Type




Source: Data from Energy Information Administration (EIA), International Energy Statistics Database (as of July 2015) and Annual Energy Outlook (2013)

# Canadian Energy Use by Sector




Source: Data from Natural Resources Canada, 2012



7

# Why Is the Energy Future of the United States Important to Canada?

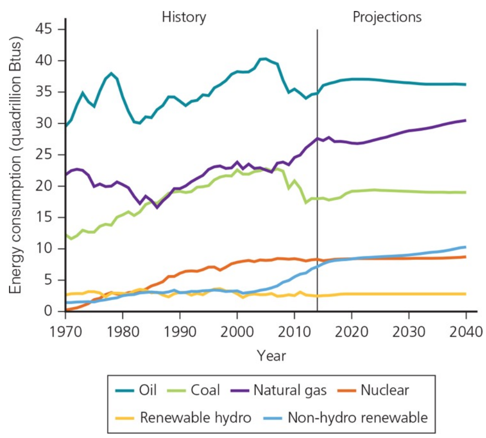
The United States

- Canada's largest trading partner
- World's second-largest energy user
- In 2014, the United States used 18% of the world's commercial energy, with only 4.4% of the population.
- Uses much more nonrenewable energy than other countries, per capita



8

# U.S. Energy Consumption: High Levels of Nonrenewable Use




Source: Data from Energy Information Administration Monthly Energy Review (June 2015) and Annual Energy Outlook 2015.





# Spotlight: Making Energy Choices

**When choosing a resource, consider …**

What is the intended use?

What is the near-future and long-term availability?

What is the net energy yield?

How much will it cost to develop, phase in, and use?

Does it qualify for government development subsidies or tax breaks?

## Spotlight: Making Energy Choices

Will dependence on it affect national and global economic and military security?

How vulnerable is it to disruption through wars, natural disasters, economic problems, or terrorism?

How will the life cycle affect the environment, human health, and the Earth's climate?

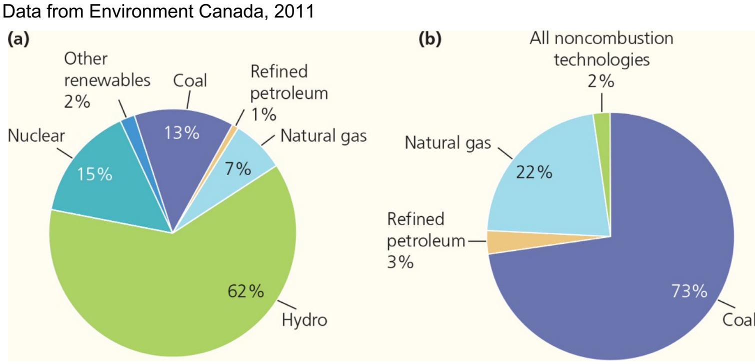




## Spotlight: Making Energy Choices

### Canada's Electricity

Source: Data from Environment Canada, 2011



## What Is Net Energy Yield?

Usable amount of **high-quality energy** available from a given quantity of a resource

- Total energy available minus energy needed to find, extract, process, and get it to consumers = net energy yield

 13

## Energy Return on Investment (EROI)

- Expressed as the ratio of useful energy produced to the useful energy used to produce it
    - The higher the ratio, the greater the net energy
    - When less than 1, there is net energy loss
- Analysts differ on what energy costs should be included.
- There is agreement that EROI on oil and gas is declining.

 14

## Net Energy Yields for Various Systems

| Electricity | Net Energy Yield |
|---|---|
| Energy efficiency | High |
| Hydropower | High |
| Wind | High |
| Coal | High |
| Natural gas | Medium |
| Geothermal energy | Medium |
| Solar cells | Low to medium |
| Nuclear fuel cycle | Low |
| Hydrogen | Negative (Energy loss) |

| High-Temperature Industrial Heat | Net Energy Yield |
|---|---|
| Energy efficiency (cogeneration) | High |
| Coal | High |
| Natural gas | Medium |
| Oil | Medium |
| Heavy shale oil | Low |
| Heavy oil from tar sands | Low |
| Direct solar (concentrated) | Low |
| Hydrogen | Negative (Energy loss) |

| Space Heating | Net Energy Yield |
|---|---|
| Energy efficiency | High |
| Passive solar | Medium |
| Natural gas | Medium |
| Geothermal energy | Medium |
| Oil | Medium |
| Active solar | Low to medium |
| Heavy shale oil | Low |
| Heavy oil from tar sands | Low |
| Electricity | Low |
| Hydrogen | Negative (Energy loss) |

| Transportation | Net Energy Yield |
|---|---|
| Energy efficiency | High |
| Gasoline | High |
| Natural gas | Medium |
| Ethanol (from sugarcane) | Medium |
| Diesel | Medium |
| Gasoline from heavy shale oil | Low |
| Gasoline from heavy tar sand oil | Low |
| Ethanol (from corn) | Low |
| Biodiesel (from soy) | Low |
| Hydrogen | Negative (Energy loss) |

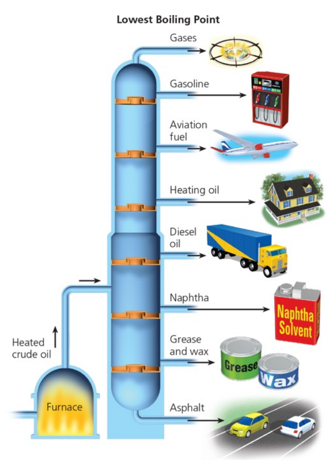
Source: Compiled by the authors using data from the U.S. Department of Energy; U.S. Department of Agriculture; Colorado Energy Research Institute, *Net Energy Analysis,* 1976; Howard T. Odum and Elisabeth C. Odum, *Energy Basis for Man and Nature,* 3rd ed., New York: McGraw-Hill, 1981; *and* Charles A. S. Hall and Kent A. Klitgaard, *Energy and the Wealth of Nations*, New York, Springer*, 2012.*





## Crude Oil

- Mixture of combustible hydrocarbons and some impurities
- Recovery
- Refining
  - Separate different petrochemicals by distillation
- Transport



## Case Study: How Much Oil Do Canada and the United States Have?

Canada is a net exporter, while the United States is the largest user.

Canada exports 70% of production to the United States.

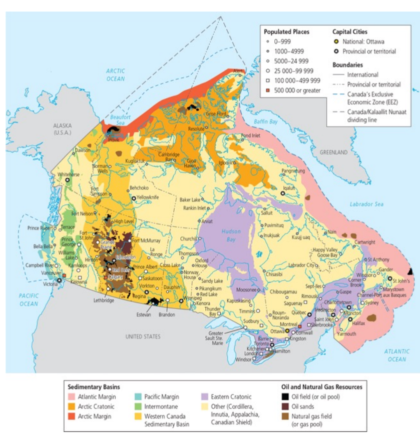
The United States has only about 2.9% of the world's proven oil reserves; uses 20% annual extracted crude.

U.S. oil production started to increase in the 2000s due to fracking.



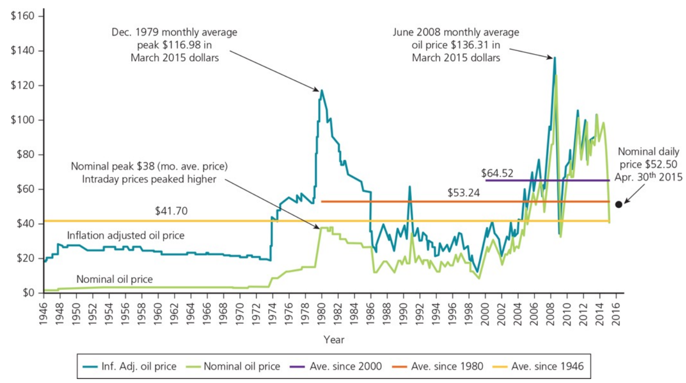


## Case Study:
### How Much Oil Do Canada and the United States Have?




Source: *The Atlas of Canada, http://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada/selected*-thematic-maps/16872. Natural Resources Canada. Reproduced with the permission of the Minister of Public Works and Government Services, 2012

## Nominal and Adjusted Oil Prices




Source: © InflationData.com

 19

## How Long Will Conventional Oil Supplies Last?

Twelve OPEC countries—mostly in the Middle East—have at least 71% of the world's proven oil reserves.

The world's peak production should be reached between 2010 and 2030 (some think it has already happened).

Uncertain when Canada's oil sands will peak

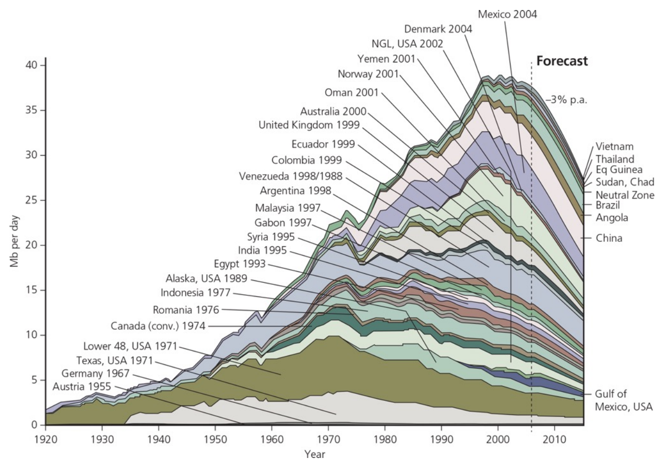
U.S. oil reserves peaked in 1975.

Once production peaks, supplies will begin to slow.

Predictions say oil will last between 42–93 years depending on the rate of usage.

 20

# Hubbert's Peak Model




Source: © Energy Watch Group/Ludwig-Boelkow-Foundation

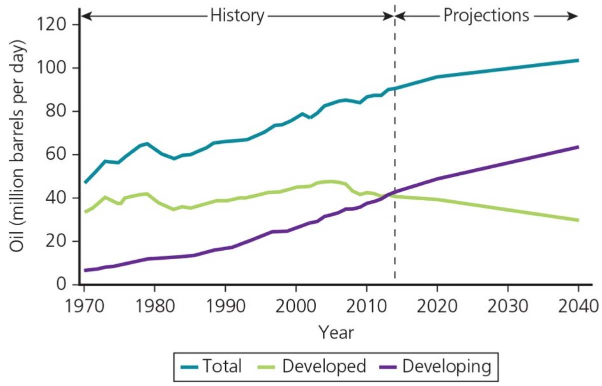




# Can We Meet the World's Growing Demand for Oil?

- To maintain at the current rate, we'd have to discover giant new oil reserves every 10 years (unlikely).
- Venezuela, with the world's largest reserves, could supply the world for 10 years.
- Canada could supply the world for 6 years.
- Reserves in Alaska's Arctic Wildlife National Refuge would only supply the United States for 7–24 months.
- China and India are rapidly consuming oil.
- If everyone consumed as much oil as the average American, oil would be gone in a decade.

# Meeting the World's Growing Demand for Oil




Source: International Energy Agency, World Energy Outlook 2015



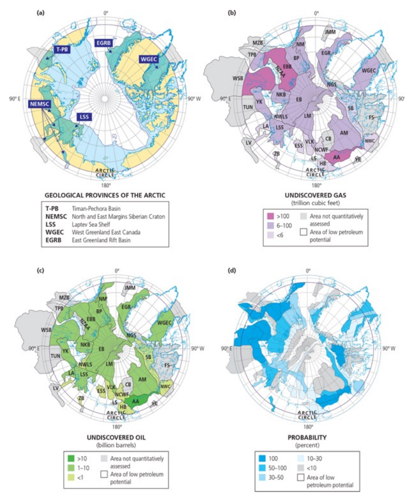


# Case Study: Why Has the Arctic Suddenly Gained World Attention?

- Unprecedented sea ice melting
- Opens large underexplored region to oil and gas discovery
- Uncertain environmental impacts
- Drilling controversies

## Case Study:
## Why Has the Arctic Suddenly Gained World Attention?

Potential undiscovered gas and oil in the Arctic (b) and (c), and the probability of large undiscovered oil/gas deposits (d)



Source: U.S. Geological Survey





## Conventional Oil: Trade-Offs

Trade-Offs, Conventional Oil
Advantages and disadvantages of using conventional crude oil as an energy resource.
Pick the single advantage and disadvantage that you think are the most important.

FIGURE 17-15 **TRADE-OFFS**

**Conventional Oil**

Advantages and disadvantages of using conventional crude oil as an energy resource.
Pick the single advantage and disadvantage that you think are the most important.

**Advantages**
- Ample supply for 42–93 years
- Low cost (with huge subsidies)
- High net energy yield
- Easily transported within and between countries
- Low land use
- Well-developed technology
- Efficient distribution system

**Disadvantages**
- Need to find substitute within 50 years
- Waste encouraged by artificially low price; search for alternatives discouraged
- Air pollution when burned
- Releases $CO_2$ when burned
- Moderate water pollution

(Left): © Alberto Loyo/Shutterstock; (Right): © Philip Lange/Shutterstock

## How Useful Are Heavy Oils from Oil Sand?

**Oil Sands**

– Clay + sand + water + bitumen

**Bitumen**

– High-viscosity, thick heavy oil with high sulfur content

Oil sands supply 50% of Canada's current oil needs.




## Oil Sands Extraction

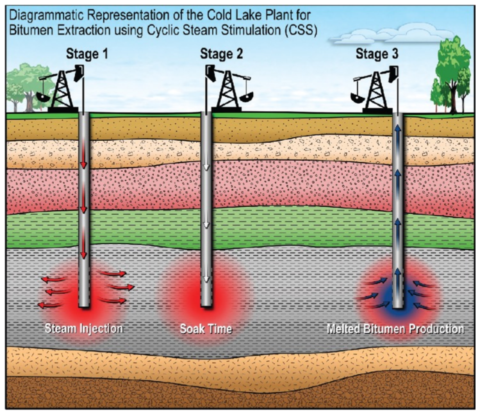
Open-pit mining (only 20% accessible)

Cyclic steam stimulation (CSS)

Steam-assisted gravity drainage (SAGD)

Vapour extraction

# Oil Sands Extraction: CSS

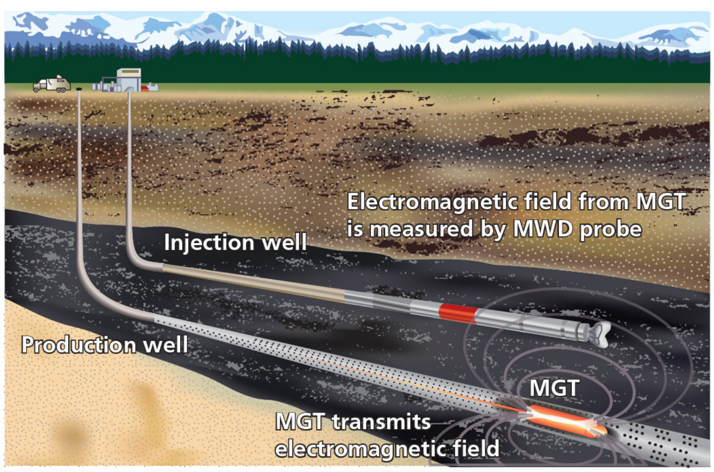



Energy Resources Conservation Board / Alberta Geological Survey





# Oil Sands Extraction: SAGD




Courtesy of Halliburton Energy Services

# Heavy Oils from Oil Shale: Trade-Offs

FIGURE 17-20 **TRADE-OFFS**

**Heavy Oils from Oil Sand**

Advantages and disadvantages of using heavy oils from oil sand and oil shale as energy resources. Pick the single advantage and disadvantage that you think are the most important.

**Advantages**

- Moderate cost (oil sand)
- Large potential supplies, especially oil sands in Canada
- Yields a convenient liquid fuel
- Easily transported within and between countries
- Efficient distribution system in place
- Well-developed technology

**Disadvantages**

- Low net energy yield
- Large amount of water needed for processing
- Severe land disruption from surface mining
- Water pollution from mining residues
- Air pollution when burned
- $CO_2$ emissions when burned

(Left): © Peter Gudella/Shutterstock; (Right): © Jupiterimages/Thinkstoc





# Natural Gas

- Comprised of 50–90% methane
- **Conventional**
  - Lies above most crude oil reservoirs
- **Unconventional**
  - Underground sources
  - Methane hydrates
- Removed as liquified petroleum gas (**LPG**)
- Shipped as liquified natural gas (**LNG**)

# Conventional Natural Gas: Trade-Offs

FIGURE 17-22 **TRADE-OFFS**

**Conventional Natural Gas**

Advantages and disadvantages of using conventional natural gas as an energy resource. Pick the single advantage and disadvantage that you think are the most important.

**Advantages**

- Ample supplies (125 years)
- High net energy yield
- Low cost (with huge subsidies)
- Less air pollution than other fossil fuels
- Lower $CO_2$ emissions than other fossil fuels
- Moderate environmental impact
- Easily transported by pipeline
- Low land use
- Good fuel for fuel cells and gas turbines

**Disadvantages**

- Nonrenewable resource
- Releases $CO_2$ when burned
- Possible leakage of methane (a greenhouse gas) from pipelines
- Difficult to transfer from one country to another
- Shipped across ocean as highly explosive LNG
- Sometimes burned off and wasted at wells because of low price
- Requires pipelines

(Left): © Glovatskiy/Shutterstock; (Right): © imantsu/Shutterstock





# Shale Gas

Natural gas trapped in sedimentary rocks

**Hydraulic fracturing (fracking)**

1. Drill well and inject pressurized fluid or gas to fracture rock
2. Fluid pumped into cracks
   - Usually water mixed with sand and additives
3. Sand keeps cracks open after pumping
4. Natural gas collected

# Shale Gas: Trade-Offs

## Advantages

- May double natural gas supplies
- Natural gas has relatively low environmental impact

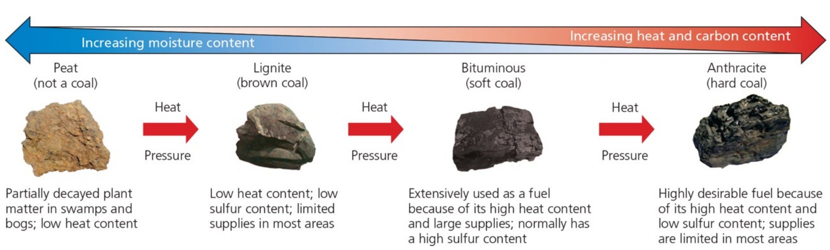
## Disadvantages

- Actual resource amount not well known
- Contains more $CH_4$ than conventional natural gas
- Serious water pollution
  - Only 50–70% of fracking fluid recovered





# What Is Coal?



## How Is Coal Used, and How Long Will Supplies Last?

- Generates 40% of world electricity
- Most abundant fossil fuel
  - 10x more energy than oil/gas combined
  - Canada has 1% of reserve
  - Canada exports 14% of coal to United States
- Reserves expected to last 260 years
  - But if coal use increases by just 4%, it will only last 64 years.



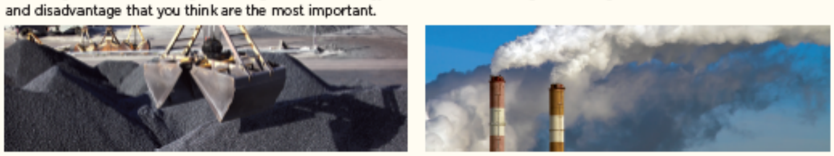


## Coal: Trade-Offs

FIGURE 17-24 **TRADE-OFFS**

**Coal**

Advantages and disadvantages of using coal as an energy resource. Pick the single advantage and disadvantage that you think are the most important.



**Advantages**
- Ample supplies (225–900 years)
- High net energy yield
- Low cost (with huge subsidies)
- Well-developed mining and combustion technology
- Reduced air pollution possible with improved technology (but more cost)

**Disadvantages**
- Very high environmental impact
- Severe land disturbance, air pollution, and water pollution
- High land use (including mining)
- Severe threat to human health
- High $CO_2$ emissions when burned
- Releases radioactive particles and toxic mercury into air

(Left): © ArturNyk/Shutterstock; (Right): © Djinn/Shutterstock

## Converting Coal into Gas or Liquid Fuels

Synthetic fuels burn cleaner than coal..

Synthetic natural gas (SNG)

– Coal gasification

Synthetic gasoline

– Coal liquefaction





## Synthetic Fuels: Trade-Offs

FIGURE 17-25 **TRADE-OFFS**

**Synthetic Fuels**

Advantages and disadvantages of using synthetic natural gas (SNG) and liquid synfuels produced from coal. Pick the single advantage and disadvantage that you think are the most important.

**Advantages**

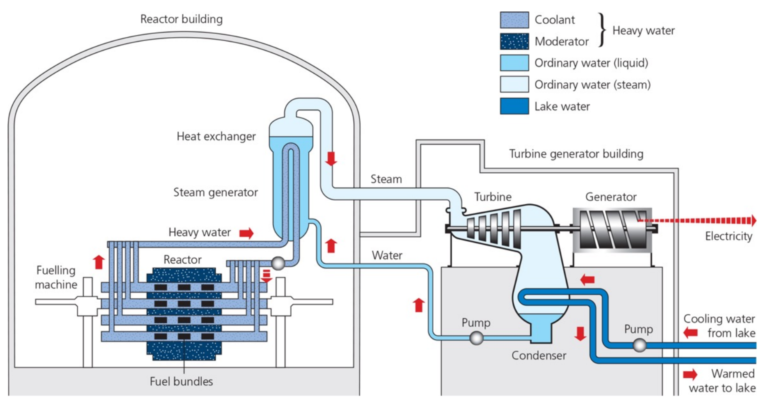
- Large potential supply
- Vehicle fuel
- Moderate cost (with large government subsidies)
- Lower air pollution when burned than coal

**Disadvantages**

- Low-to-moderate net energy yield
- Higher cost than coal
- Requires mining 50% more coal when processing included
- High environmental impact
- Increased surface mining of coal
- High water use
- Higher $CO_2$ emissions than coal when processing is included

(Left): © Minerva Studio/Shutterstock; (Right): © Jim Parkin/Shutterstock

# Nuclear Energy: How Does a Nuclear Fission Reactor Work?




© 2007 Jeremy Whitlock





# Nuclear Reactors in Canada


Source: Natural Resources Canada

# What Is the Nuclear Fuel Cycle?

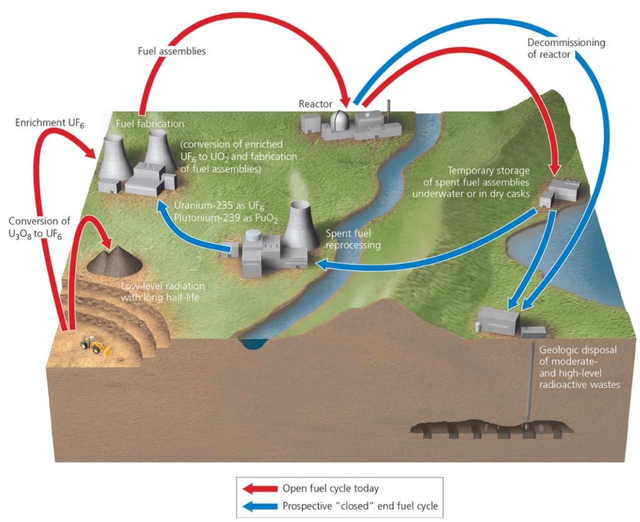
Life cycle of uranium, including …

- Mining
- Processing into fuel
- Use in a reactor (15–60 years)
- Safe storage of high-level radioactive waste
  - **Closed cycle (10 000 years)**
    - Removal of fissionable nuclei for further use
  - **Open cycle (240 000 years)**





# Nuclear Fuel Cycle



# Conventional Nuclear Fuel Cycle

FIGURE 17-29 **TRADE-OFFS**

**Conventional Nuclear Fuel Cycle**

Advantages and disadvantages of using the conventional nuclear fuel cycle (Figure 17-28) to produce electricity. Pick the single advantage and disadvantage that you think are the most important.


**Advantages**

- Large fuel supply
- Low environmental impact (without accidents)
- Emits 1/6 as much $CO_2$ as coal
- Moderate land disruption and water pollution (without accidents)
- Moderate land use
- Low risk of accidents because of multiple safety systems (except in 35 poorly designed and run reactors in former Soviet Union and Eastern Europe)

**Disadvantages**

- High cost even with large subsidies
- Low net energy yield (depending on enrichment process used)
- High environmental impact (with major accidents)
- Catastrophic accidents can happen (Chernobyl)
- No widely acceptable solution for long-term storage of radioactive wastes and decommissioning worn-out plants
- Subject to terrorist attacks
- Spreads knowledge and technology for building nuclear weapons

(Left): © TTstudio/Shutterstock; (Right): © Tanya/Thinkstock





# Coal *vs.* Nuclear

FIGURE 17-30 **TRADE-OFFS**

**Coal vs. Nuclear**

Comparison of the risks of using nuclear power (based on the nuclear fuel cycle) and coal-burning plants to produce electricity. If you had to choose, would you rather live next door to a coal-fired power plant or a nuclear power plant?

**Coal**

- Ample supply
- High net energy yield
- Very high air pollution
- High $CO_2$ emissions
- High land disruption from surface mining
- High land use
- Low cost (with huge subsidies)

**Nuclear**

- Ample supply of uranium
- Low net energy yield (depending on enrichment process used)
- Low air pollution (mostly from fuel reprocessing)
- Low $CO_2$ emissions (mostly from fuel reprocessing)
- Much lower land disruption from surface mining
- Moderate land use
- High cost (with huge subsidies)

(Left): © topten22photo/Shutterstock; (Right): © Meryll/Shutterstock

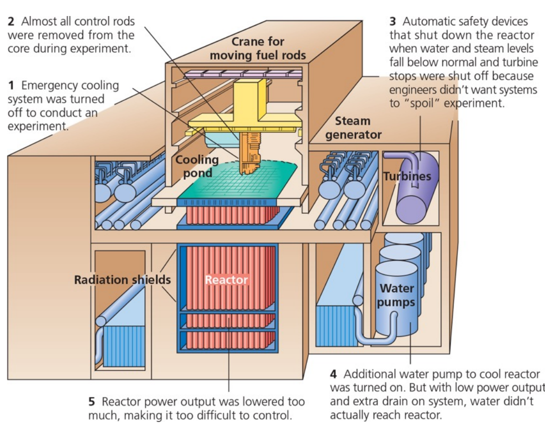
## How Vulnerable Are Nuclear Power Plants to Disasters of Various Kinds?

**Spent fuel rods** are the highest risk.
- Kept underwater in pools or in dry casks
- Typically holds 5–10x more long-lived radioactivity than the radioactive core
  inside the reactor

Risk factors
- Terrorist attack
- Natural disasters
- Airplane crash




## What Went Wrong at Chernobyl?



# Spotlight: Fukushima, Japan (2011)

Most serious nuclear accident since Chernobyl

Magnitude 9.0 earthquake and 15 m tsunami

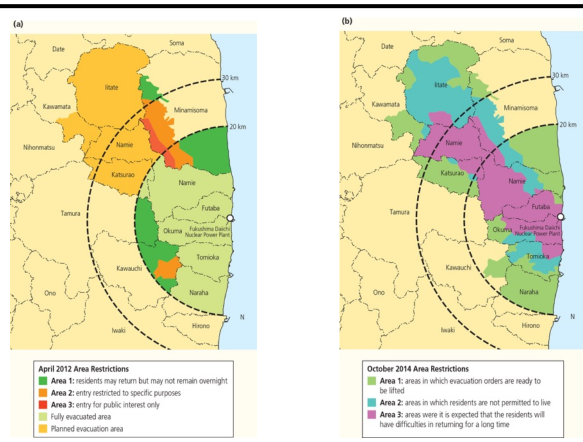
Four reactors at Fukushima severely damaged

- Destroyed seawater pumps and backup generators
- Flooded power rooms
- Compromised core cooling for two weeks
- Pressure relief measures released radioactive material.
- Hydrogen gas explosions damaged other buildings.





# Fukushima, 2012-2014




Source: a) Based on www.cnn.com/2011/WORLD/asiapcf/03/16/japan.nuclear.reactors/index.html, world-nuclear.orgfocus/fukushima/fukushima-accident.aspx, and www.ndreport.com/wp-content/uploads/2011/07/table3.gif. b) Japanese Ministry of Economy, Trade and Industry (As of Oct 1, 2014) http://www.meti.go.jp/english/earthquake/nuclear/roadmap/pdf/141001MapOfAreas.pdf

## Disposing of Low-Level Radioactive Waste

- Only gives off minimal ionizing radiation
- Stored for 100–500 years to decay to safe levels
- Includes contaminated tools, building materials, clothing, etc.
- Managed on-site or stored in above-ground buildings





## Disposing of High-Level Radioactive Waste

- No agreement about the best strategy
- Proposed methods include
  - Disposal in space
  - Burial in ice sheets
  - Dumping into subduction zones
  - Burial in ocean mud
  - Conversion into harmless materials (no known way)
  - Deep underground burial

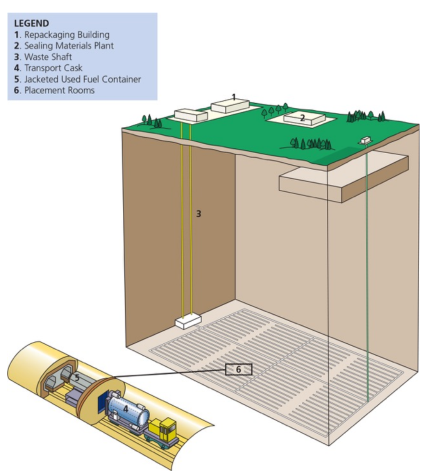
## Case Study:
## Deep Disposal of High-Level Nuclear Wastes

- Wastes stored and guarded in one place: deep, stable, controlled access
- Possible long-term groundwater contamination
- Security and safety concerns during waste transport to the site



53

## Case Study:
## Deep Disposal of High-Level Nuclear Wastes




Source: Nuclear Waste Management Organization



54

## What Can We Do With Worn-Out Nuclear Plants?

**Decommissioning** options

- Dismantling
  - *Is immediate dismantling safe?*
- Mothball
  - *Erect a barrier for 30–100 years first*
- Entombment
  - *1000-year concrete encasement*





## Future Nuclear Alternatives

New reactor designs

Breeder reactors

Nuclear fusion

Important to keep nuclear on "the table" for now and keep all options open

## Conclusion

- Nonrenewable resources are finite.
- Find new ways to extract, but these are energy-intensive
- Trade-offs for oil, coal, and natural gas use
- Reserves of fossil fuels are running out.
- Nuclear power attractive option with many drawbacks