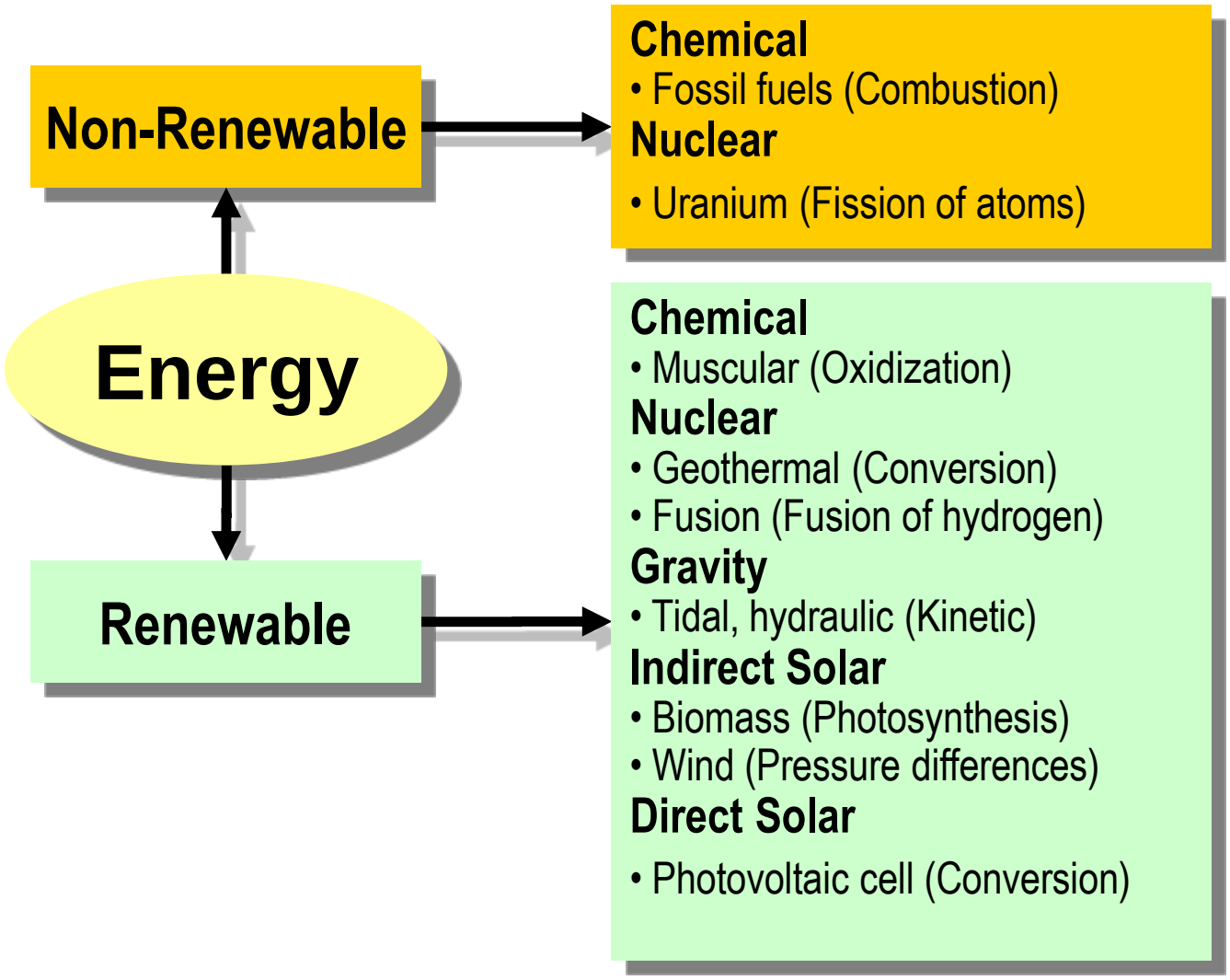
Energy

- 1. Sources of Energy
  - What are the major sources of energy?
  - How our usage of energy has changed in time?
- 2. Energy Use
  - To what purposes energy is used for?
- 3. Challenges
  - What major energy challenges are we facing?

1 Sources of Energy

- Nature
  - Energy is movement or the possibility of creating movement:
    - Exists as potential (stored) and kinetic (used) forms.
  - Conversion of potential to kinetic.
  - Movement states:
    - Ordered (mechanical energy) or disordered (thermal energy).
    - Temperature can be perceived as a level of disordered energy.
    - Major tendency is to move from order to disorder (entropy).
- Importance
  - Human activities are dependant on the usage of several forms and sources of energy.
  - Energy demands:
    - Increased with economic development.
    - The world's power consumption is about 12 trillion watts a year, with 85% of it from fossil fuels.

1 Sources of Energy



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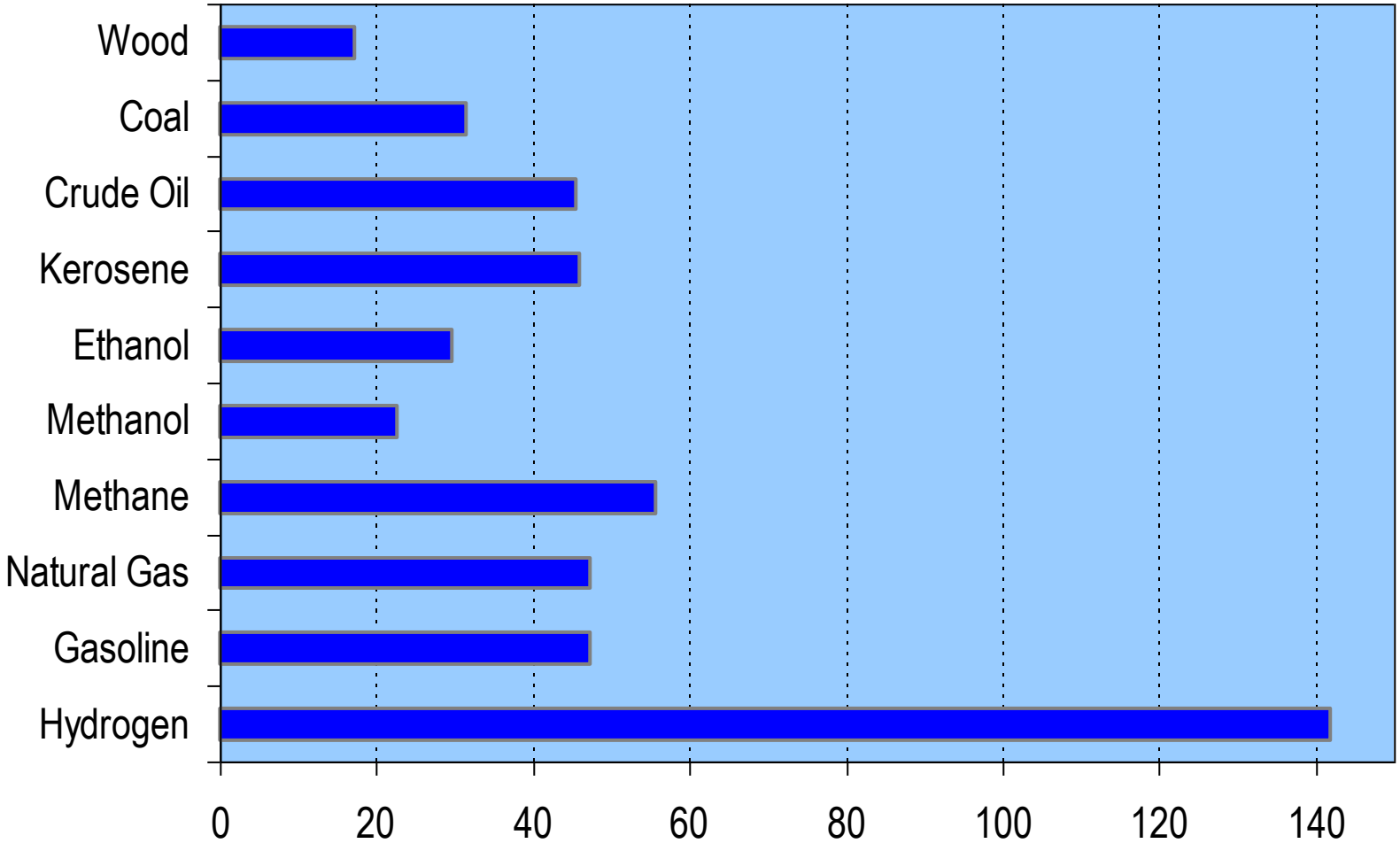
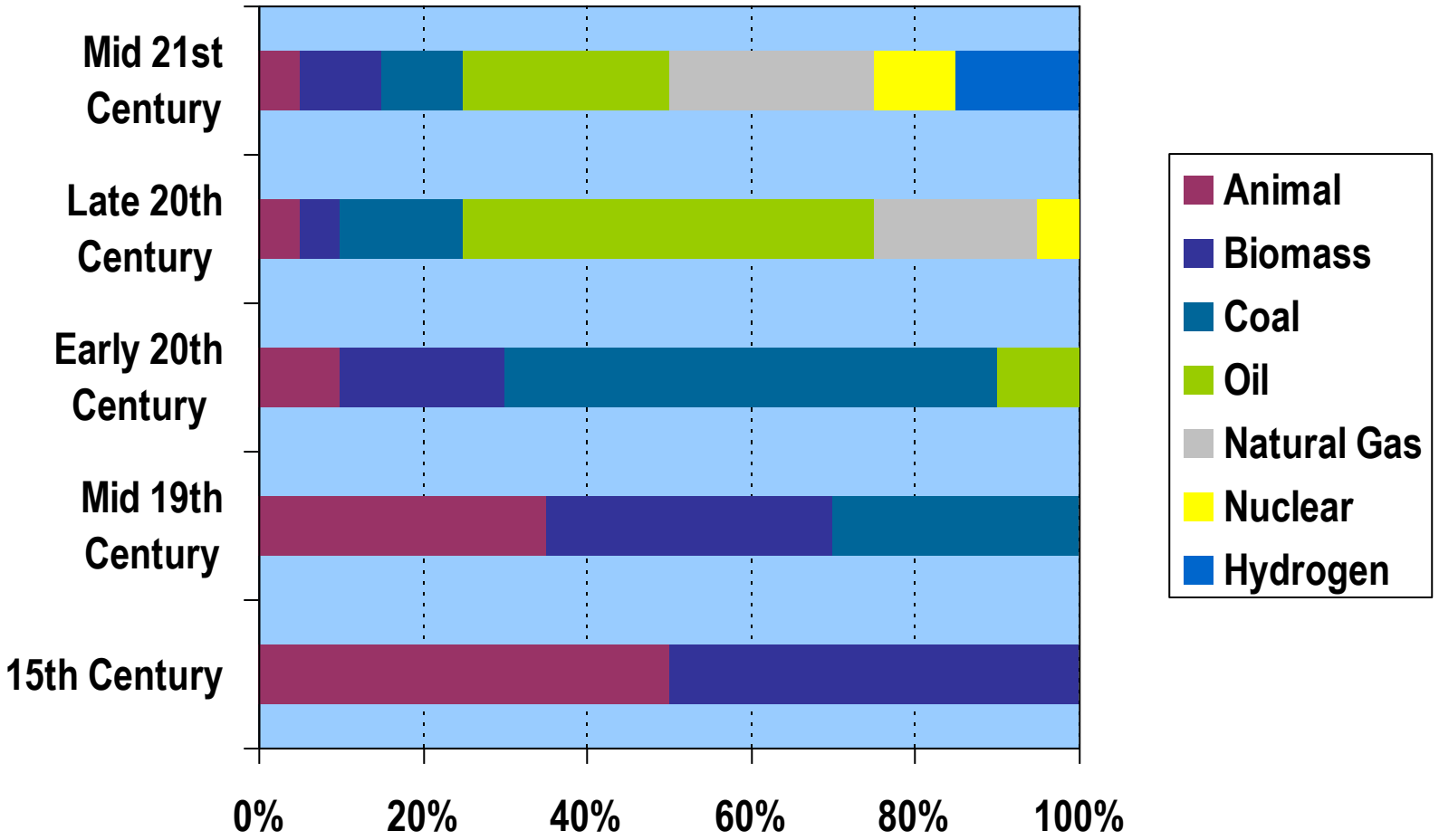
Chemical Energy Content of some Fuels (in MJ/kg)



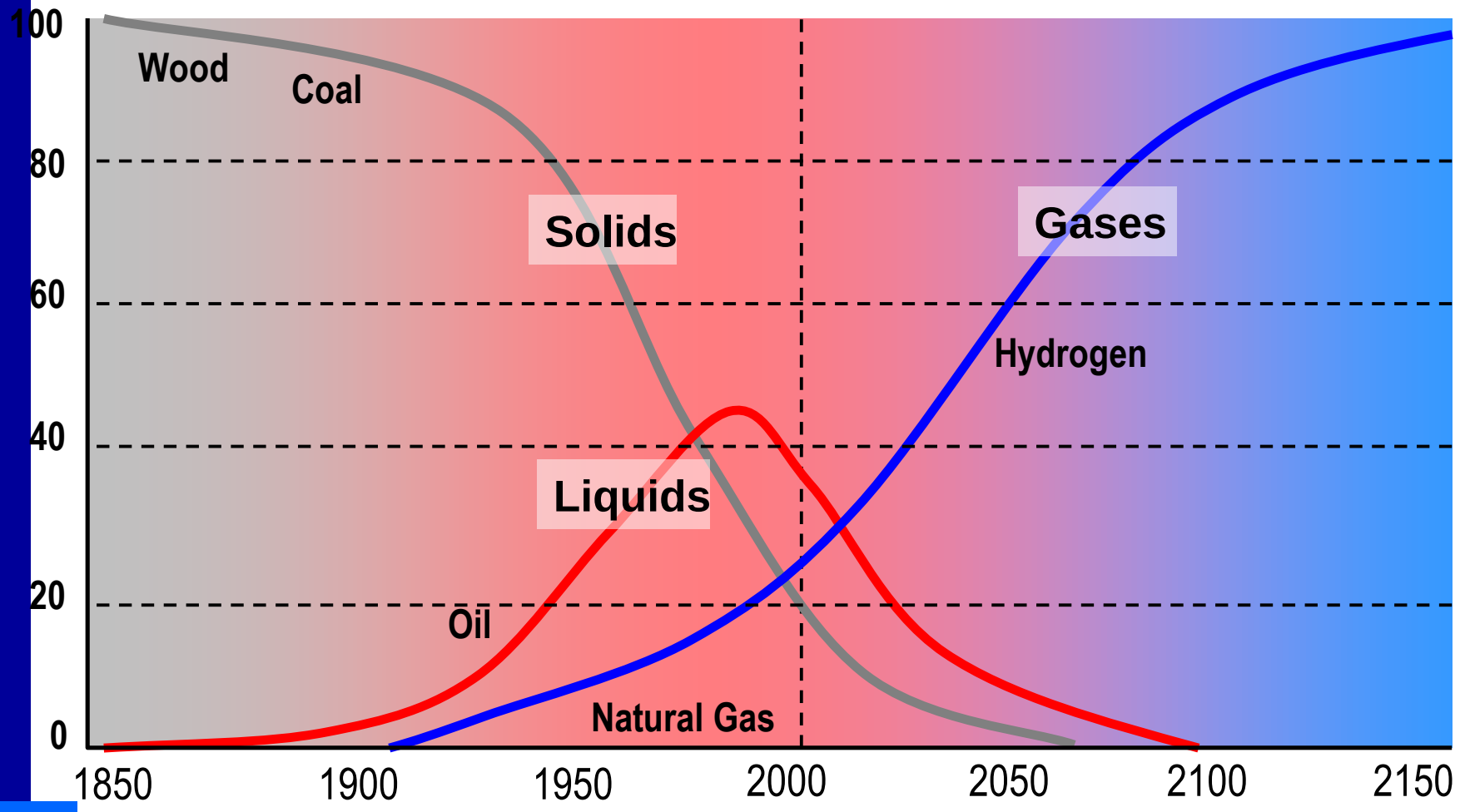
1 Sources of Energy

- Energy transition
  - Shift in the sources of energy that satisfy the needs of an economy / society.
  - Linked with economic and technological development.
  - Linked with availability and/or remaining energy sources.
  - From low efficiency to high efficiency.
  - From solids, to liquids and then gazes:
    - Wood, Coal.
    - Oil.
    - Natural gas and hydrogen.

1 Evolution of Energy Sources



1 Global Energy Systems Transition, (% of market)



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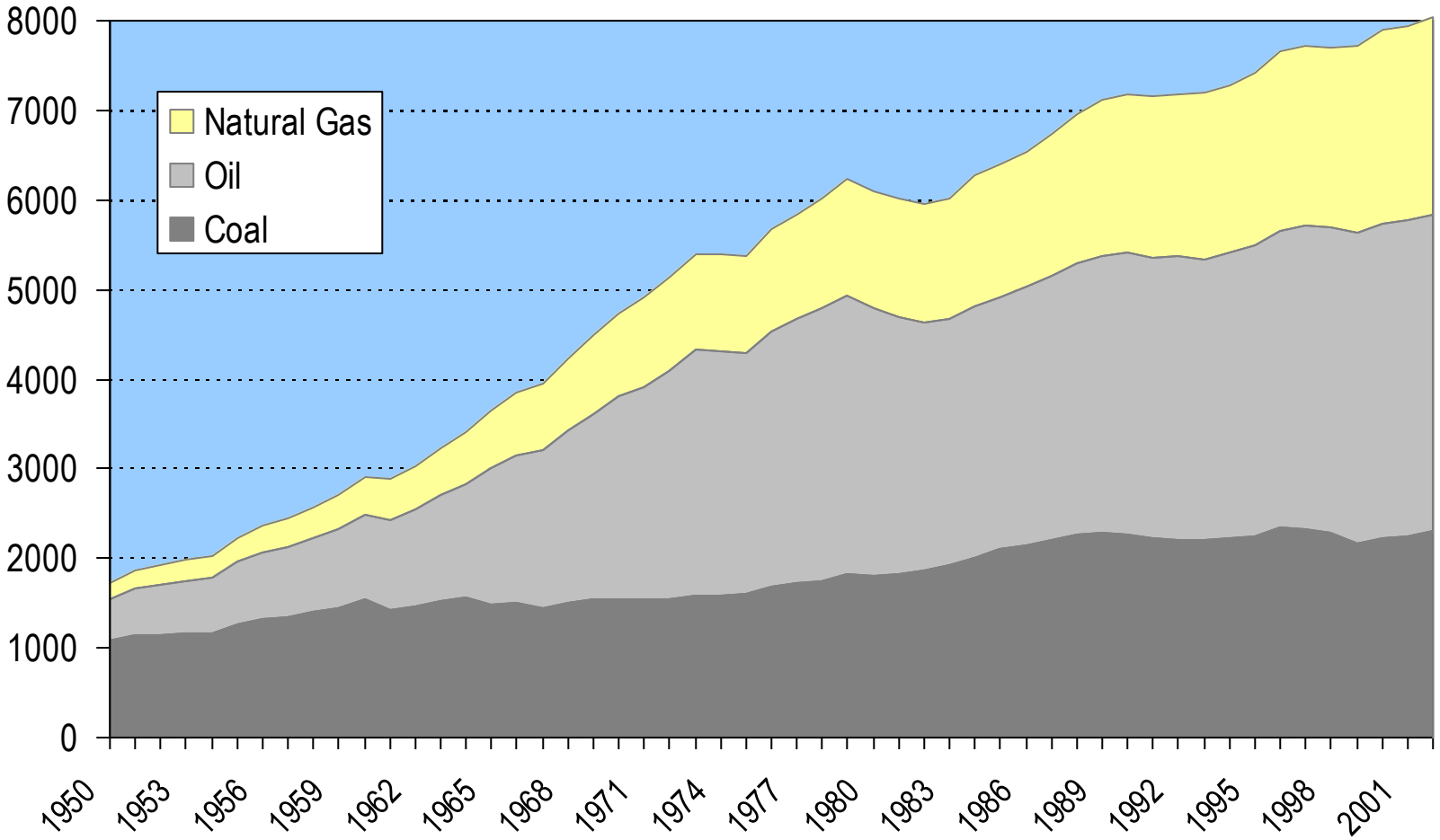
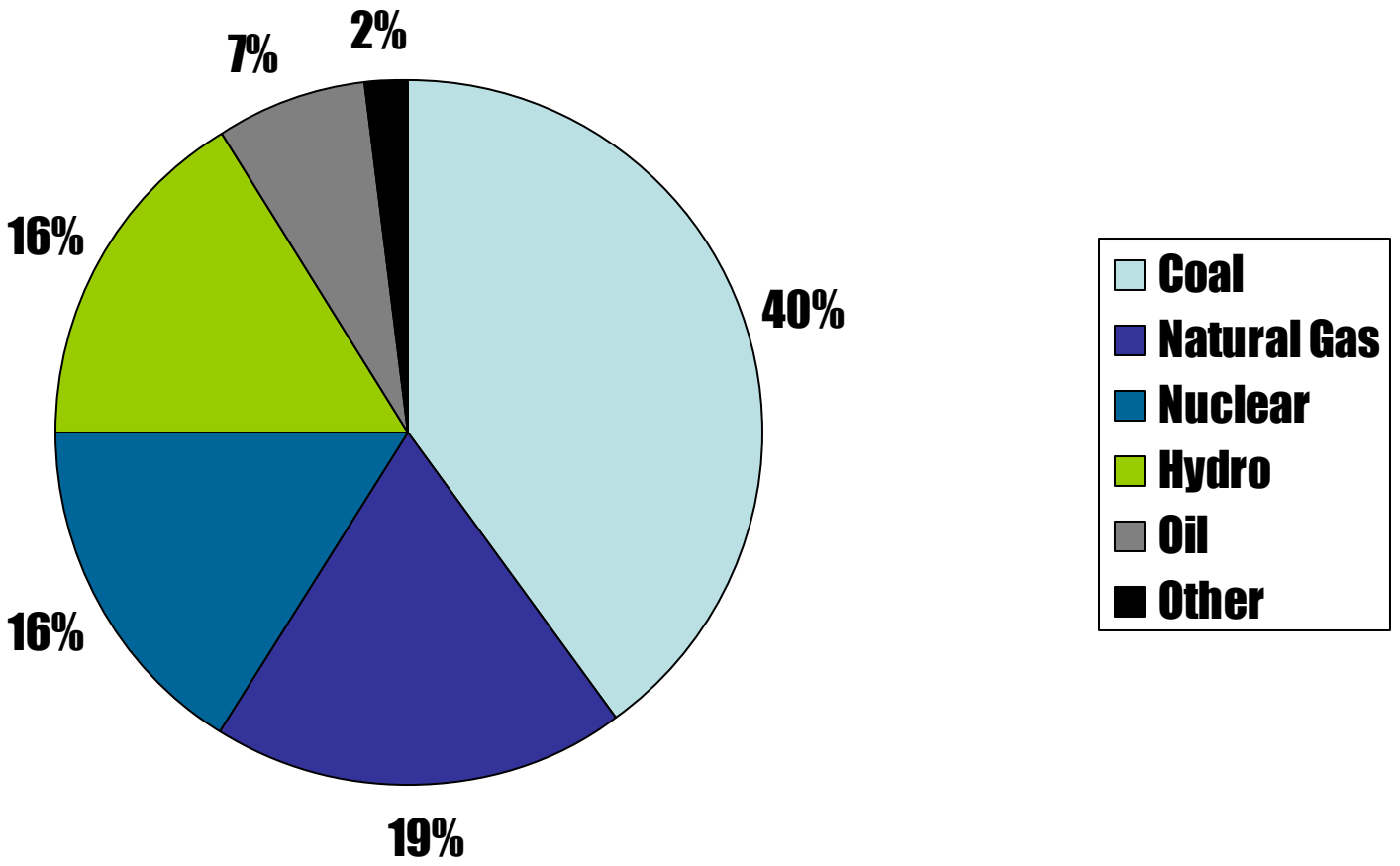
World Fossil Fuel Consumption per Source, 1950-2002 (in million of tons of equivalent oil)



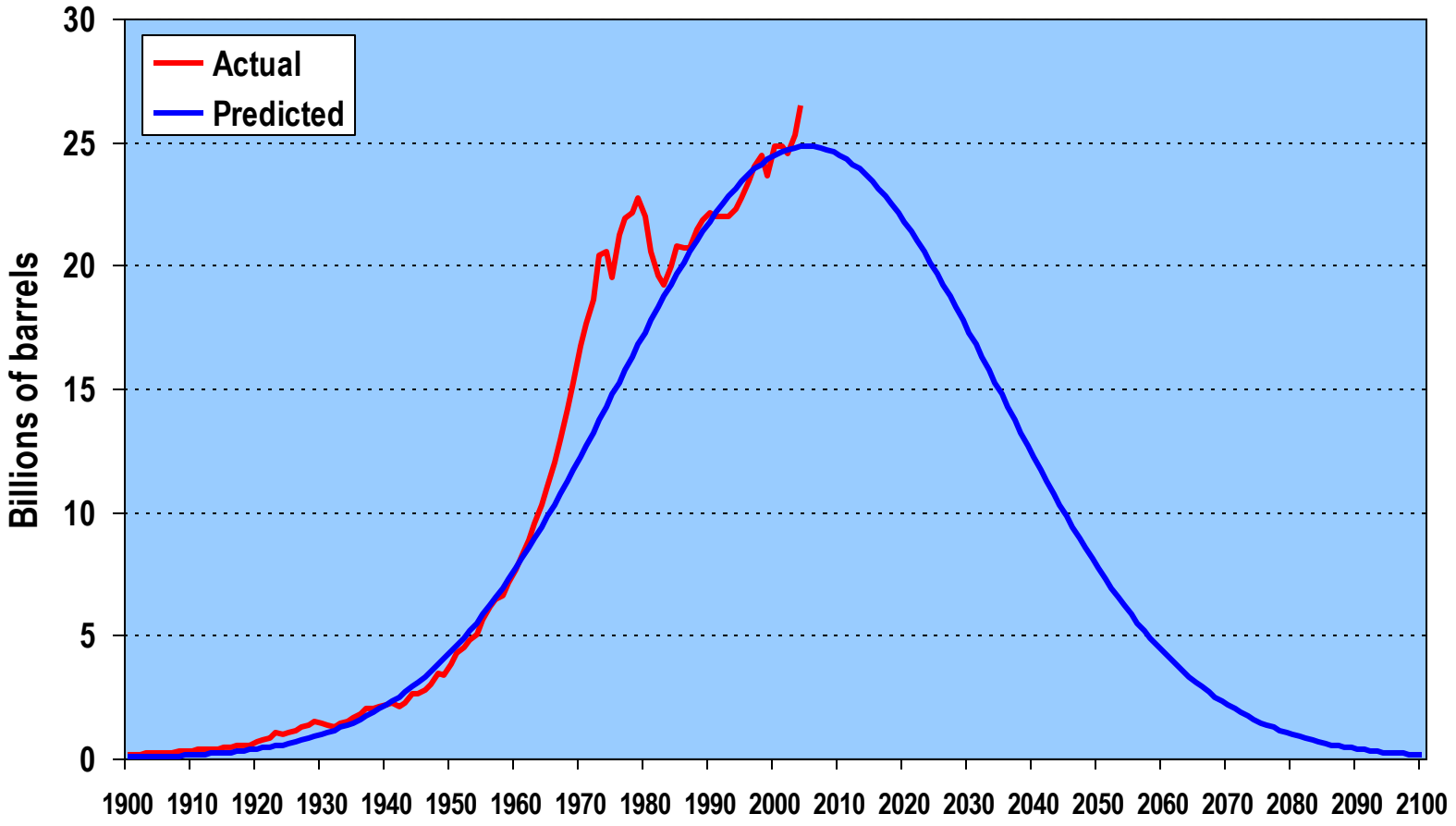
Total World Electricity Generation by Type of Fuel, 2002



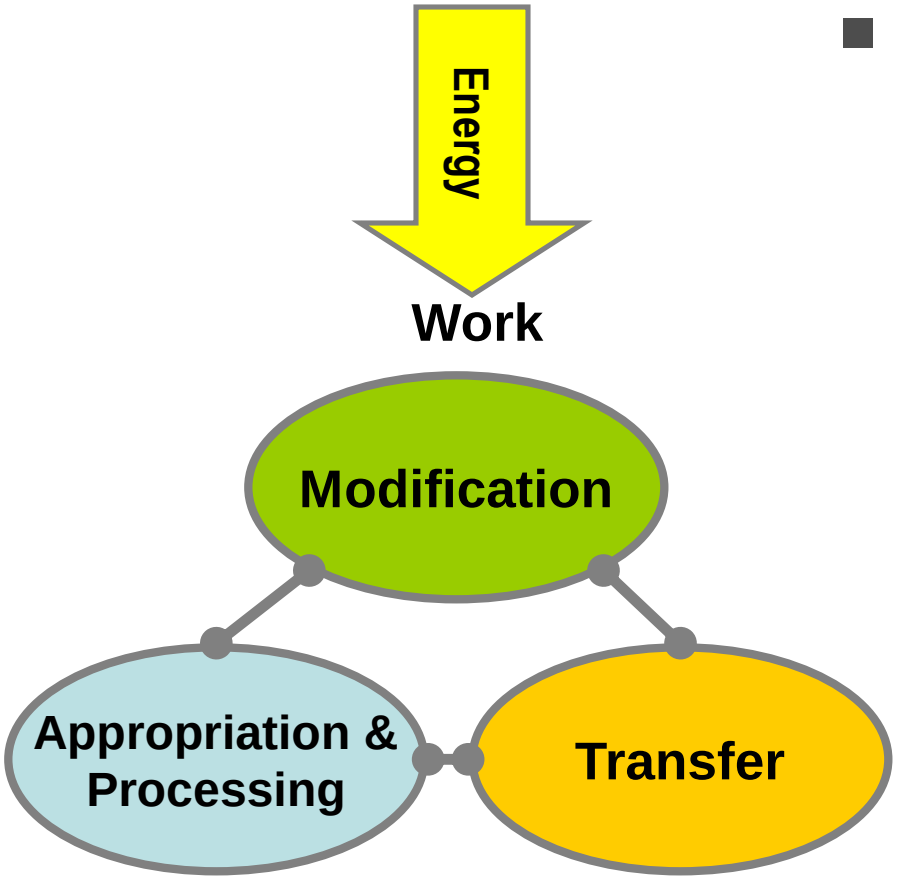
1 Energy Sources

- Hubbert's peak
  - Geologist who predicted in the 1950s that oil production in the United States would peak in the early 1970s:
    - US oil production peaked in 1973.
  - Assumption of finite resource.
  - Production starts at zero.
  - Production then rises to a peak which can never be surpassed.
  - Peak estimated around 2004-2008:
    - One estimate places it symbolically at Thanksgiving 2005.
  - Once the peak has been passed, production declines until the resource is depleted.

World Annual Oil Production (1900-2004) and Estimated Resources (1900-2100)



2 Energy Use



- Energy and work
  - Energy provides work.
  - Technology enables to use energy more efficiently and for more purposes.
  - Traditionally, most of the work was performed by people:
    - Many efforts have been done to alleviate work.
  - Creating more work performed by machines and the usage of even more energy.

2 Energy Use

Modification of the Environment	Appropriation and Processing	Transfer
■ Making space suitable for human activities. ■ Clearing land for agriculture. ■ Modifying the hydrography (irrigation). ■ Establishing distribution infrastructures (roads). ■ Constructing and conditioning (temperature and light) enclosed structures.	■ Extraction of resources (agricultural products and raw materials). ■ Modifying resources (manufacturing). ■ Disposal of wastes (Piling, decontaminating and burning).	■ Movements of freight, people and information. ■ Attenuate the spatial inequities in the location of resources by overcoming distance. ■ Growing share of transportation in the total energy spent

3 Challenges

- Energy Supply
  - Providing supply to sustain growth and requirements.
  - A modern society depends on a stable and continuous flow of energy.
- Energy Demand
  - Generate more efficient devices:
    - Transportation.
    - Industrial processes.
    - Appliances.
- Environment
  - Provide environmentally safe sources of energy.
  - Going through the energy transition (from solid to gazes).

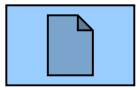
B

Conventional Energy Resources

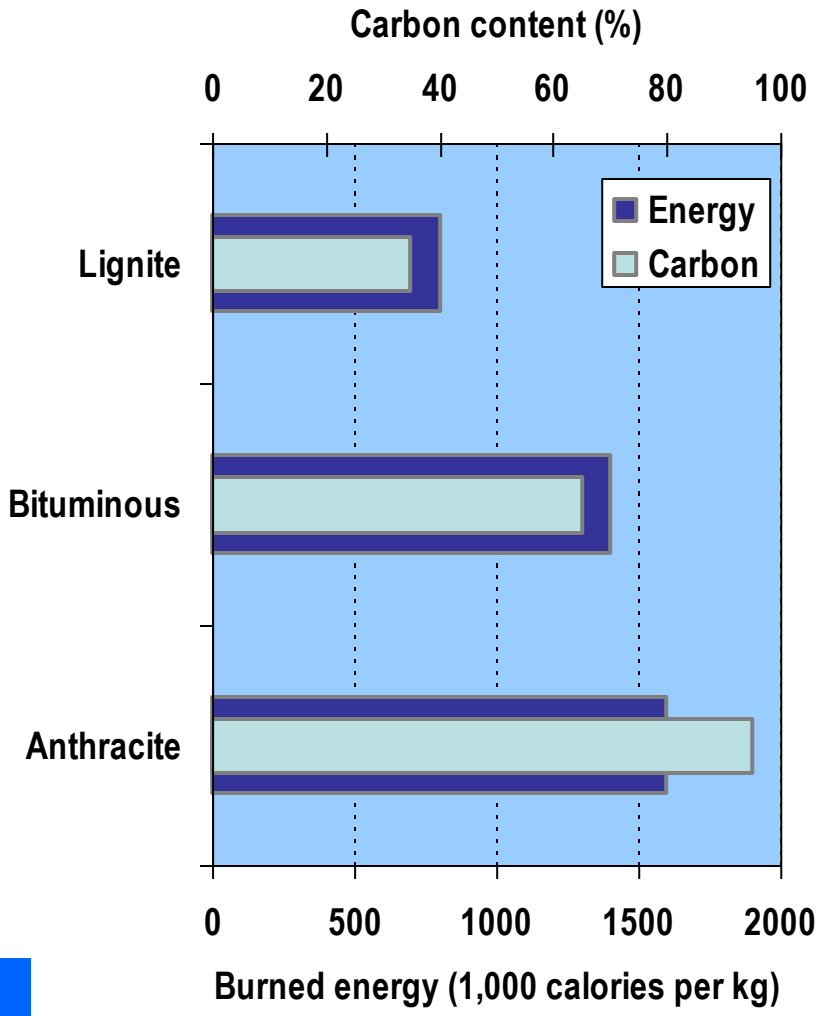
- What sources of energy have filled our requirements so far?
- 1. Coal
- 2. Petroleum
- 3. Natural Gas
- 4. Hydropower
- 5. Nuclear Power

1 Coal

- Nature
  - Formed from decayed swamp plant matter that cannot decompose in the low-oxygen underwater environment.
  - Coal was the major fuel of the early Industrial Revolution.
  - High correlation between the location of coal resources and early industrial centers:
    - The Midlands of Britain.
    - Parts of Wales.
    - Pennsylvania.
    - Silesia (Poland).
    - German Ruhr Valley.
  - Three grades of coal.

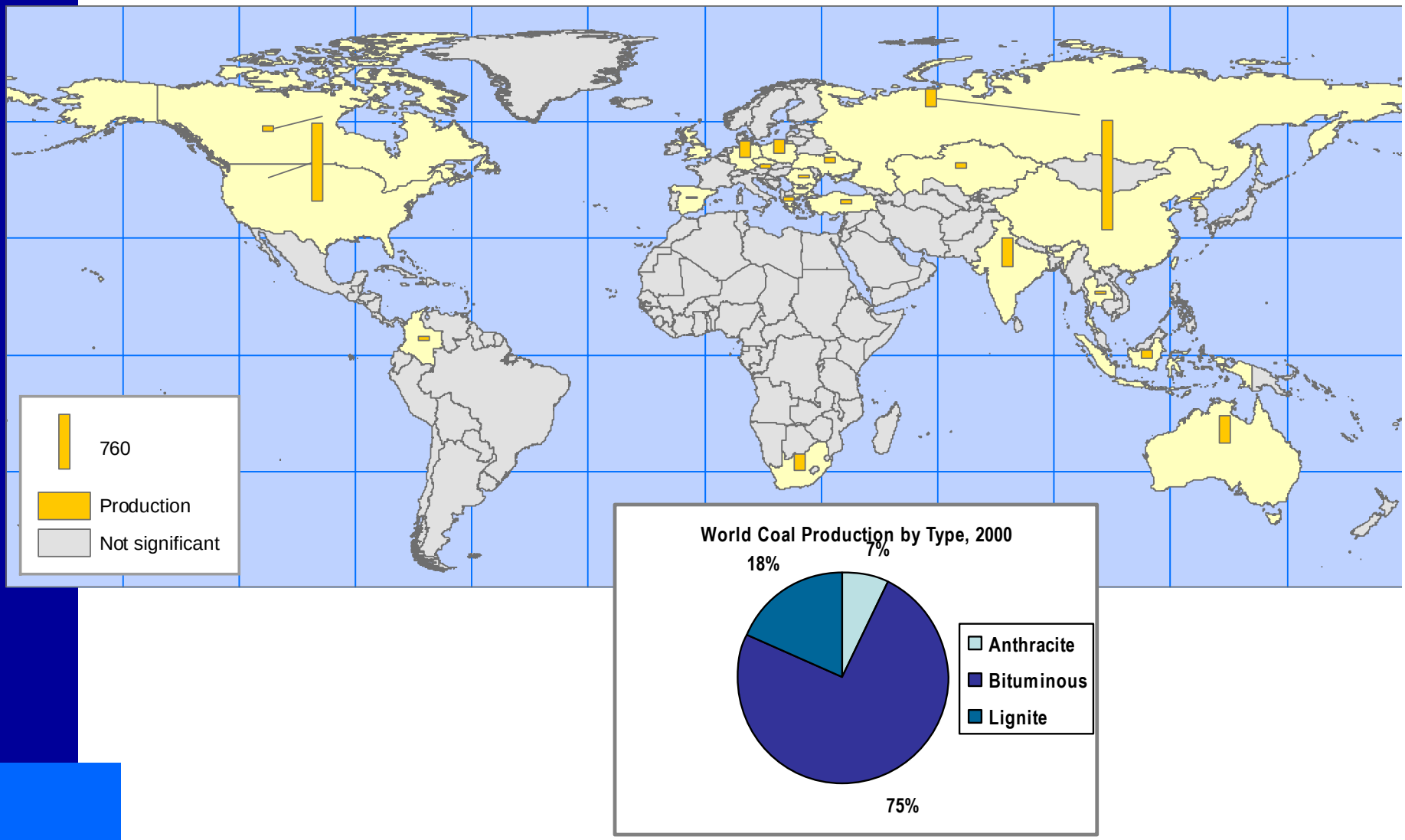


1 Coal



- Anthracite
  - Highest grade; over 85% carbon.
  - Most efficient to burn.
  - Lowest sulfur content; the least polluting.
  - The most exploited and most rapidly depleted.
- Bituminous
  - Medium grade coal, about 50-75% carbon content.
  - Higher sulfur content and is less fuel-efficient.
  - Most abundant coal in the USA.
- Lignite
  - Lowest grade of coal, with about 40% carbon content.
  - Low energy content.
  - Most sulfurous and most polluting.

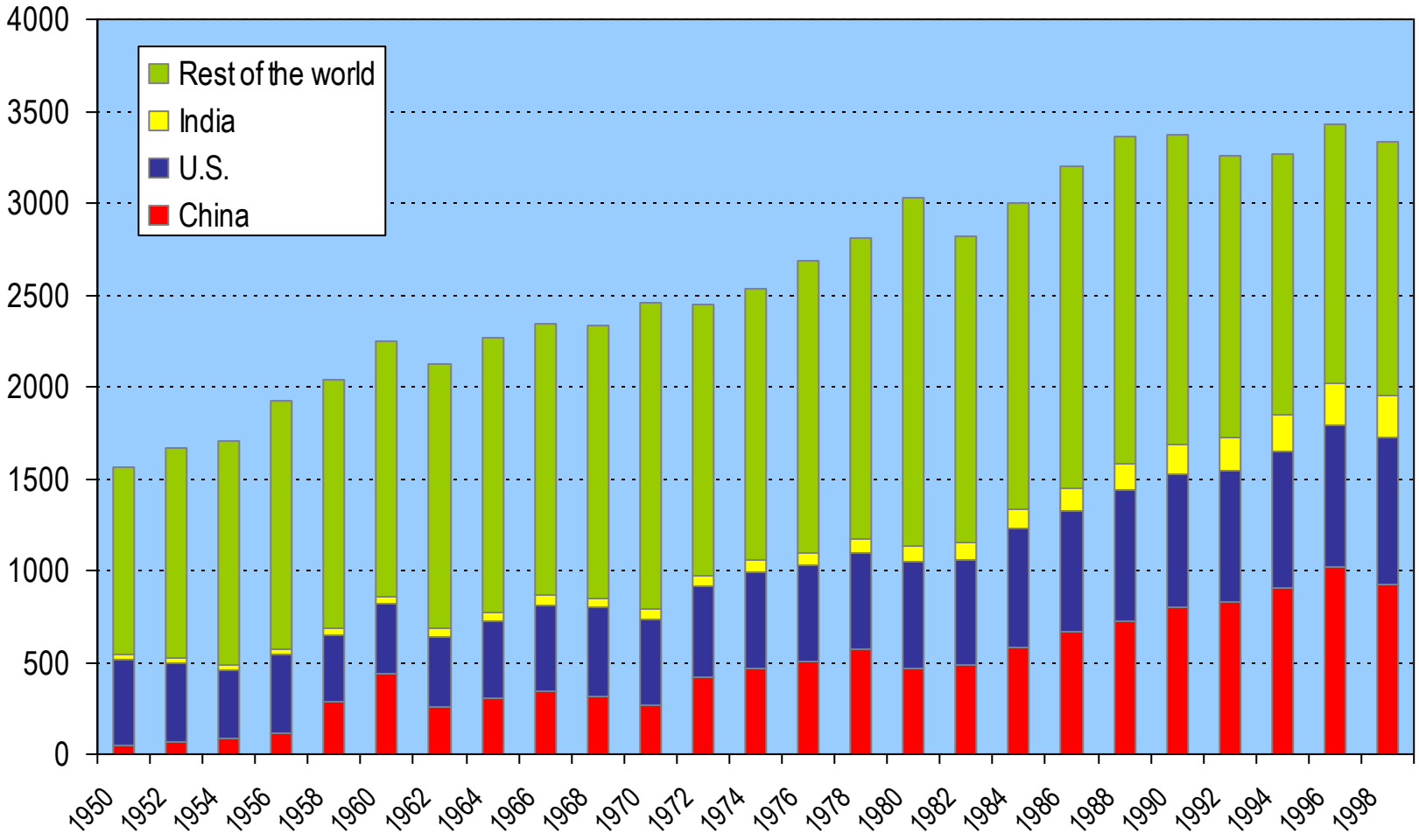
1 Global Coal Production, 2002 (M short tons)



1 Coal

- Coal use
  - Thermal coal (about 90% use):
    - Used mainly in power stations to produce high pressure steam, which then drives turbines to generate electricity.
    - Also used to fire cement and lime kilns.
    - Until the middle of the 20th Century used in steam engines.
  - Metallurgical coal:
    - Used as a source of carbon, for converting a metal ore to metal.
    - Removing the oxygen in the ore by forcing it to combine with the carbon in the coal to form CO2.
  - Coking coal:
    - Specific type of metallurgical coal.
    - Used for making iron in blast furnaces.
  - New redevelopment of the coal industry:
    - In view of rising energy prices.

Coal Consumption, 1950-1998 (in millions of tons)



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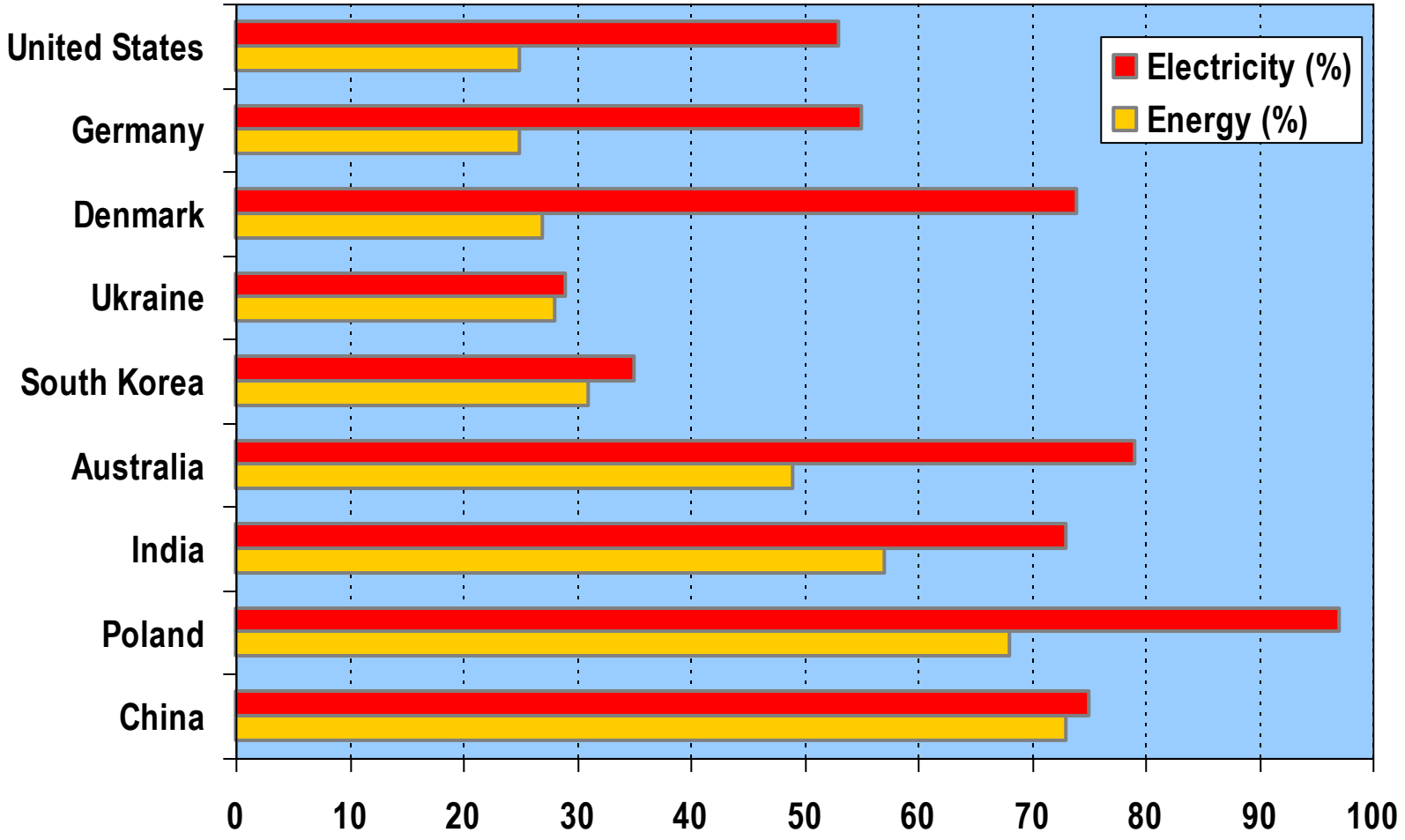
Coal as % of Energy Use and Electricity Generation, 1998



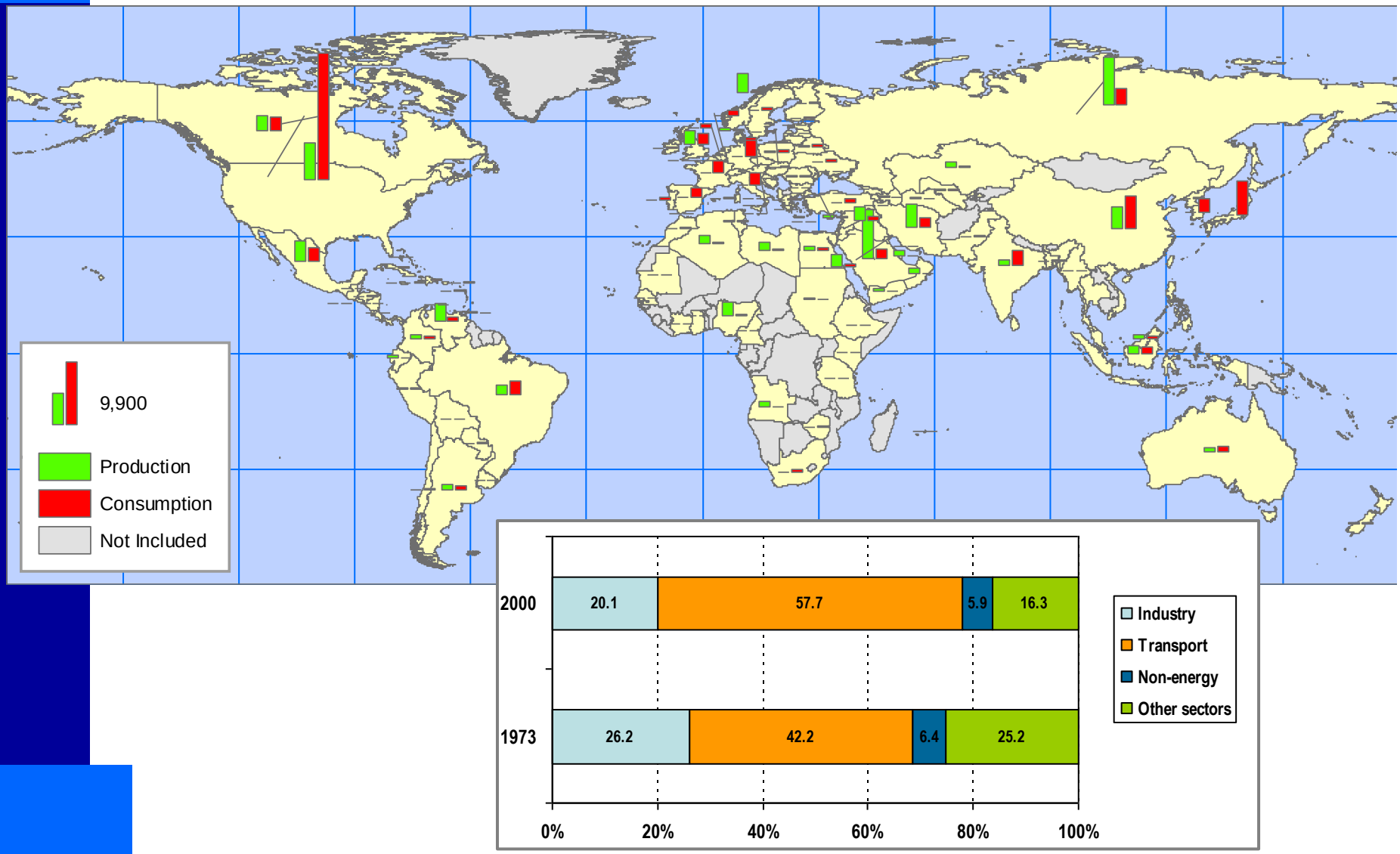
2 Petroleum

- Nature
  - Formation of oil deposits:
    - Decay under pressure of billions of microscopic plants in sedimentary rocks.
    - “Oil window”; 7,000 to 15,000 feet.
    - Created over the last 600 million years.
  - Exploration of new sources of petroleum:
    - Related to the geologic history of an area.
    - Located in sedimentary basins.
    - About 90% of all petroleum resources have been discovered.
  - Production vs. consumption:
    - Geographical differences.
    - Contributed to the political problems linked with oil supply.

2 Petroleum

- Use
  - Transportation:
    - The share of transportation has increased in the total oil consumption.
    - Accounts for more the 55% of the oil used.
    - In the US, this share is 70%.
    - Limited possibility at substitution.
  - Other uses (30%):
    - Lubricant.
    - Plastics.
    - Fertilizers.
  - Choice of an energy source:
    - Depend on a number of utility factors.
    - Favoring the usage of fossil fuels, notably petroleum.

Petroleum Production and Consumption, 2002 (M barrels per day)



2

Petroleum

- Why an oil dependency?
  - Favor the usage of petroleum as the main source of energy for transport activities.
  - The utility factors were so convenient that a dependency on petroleum was created.
- Taxes
  - Should oil be taxed?
  - Should the development of alternative sources of energy be accelerated or enforced?

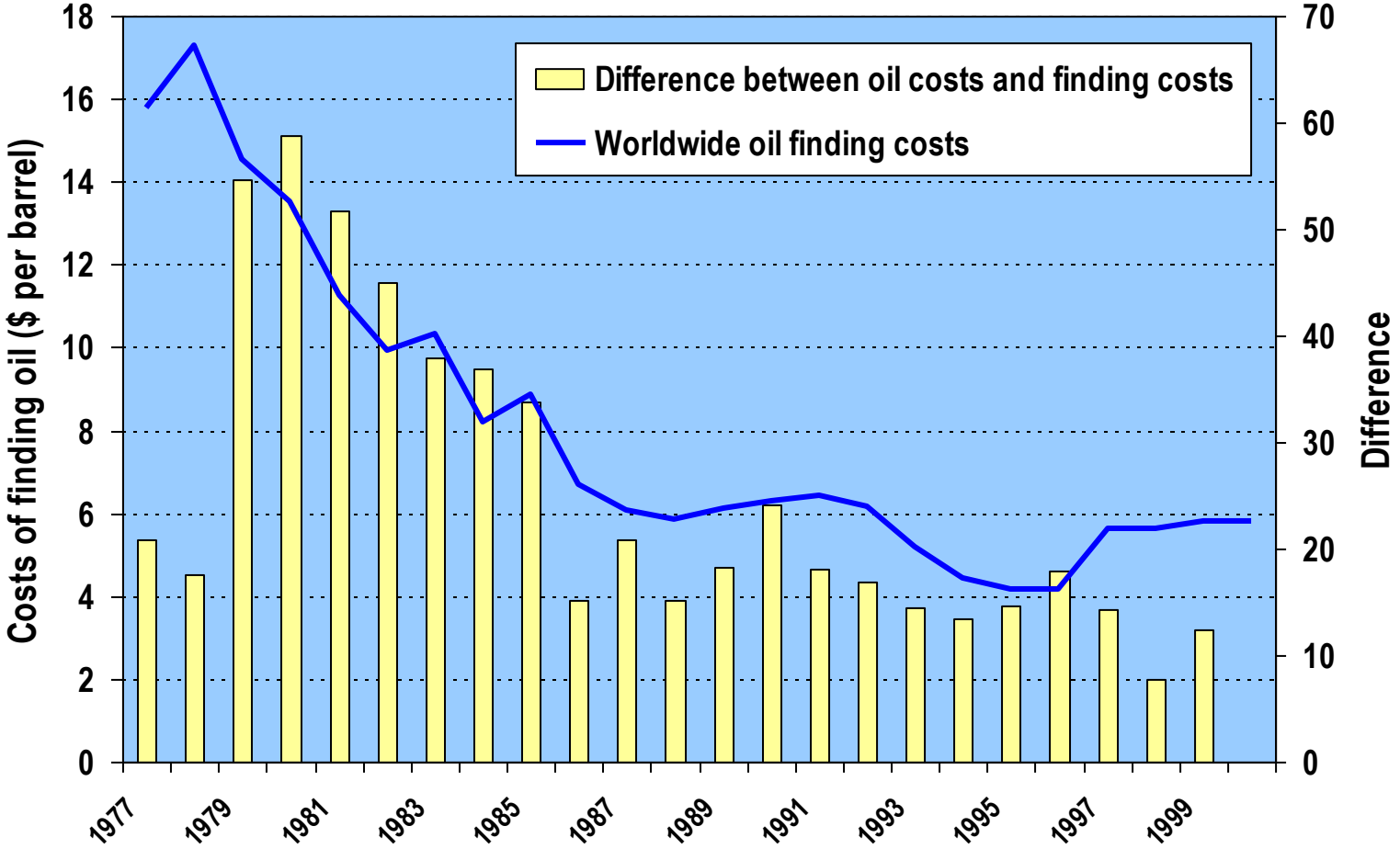
2

Factors of Oil Dependency

Occurrence	Localized large deposits (decades)
Transportability	Liquid that can be easily transported. Economies of scale
Energy content	High mass / energy released ratio
Reliability	Continuous supply; geopolitically unstable
Storability	Easily stored
Flexibility	Many uses (petrochemical industry; plastics)
Safety	Relatively safe; some risks (transport)
Environment	Little wastes, CO_2 emissions
Price	Relatively low costs

2

Costs of Finding Oil, 1977-2000

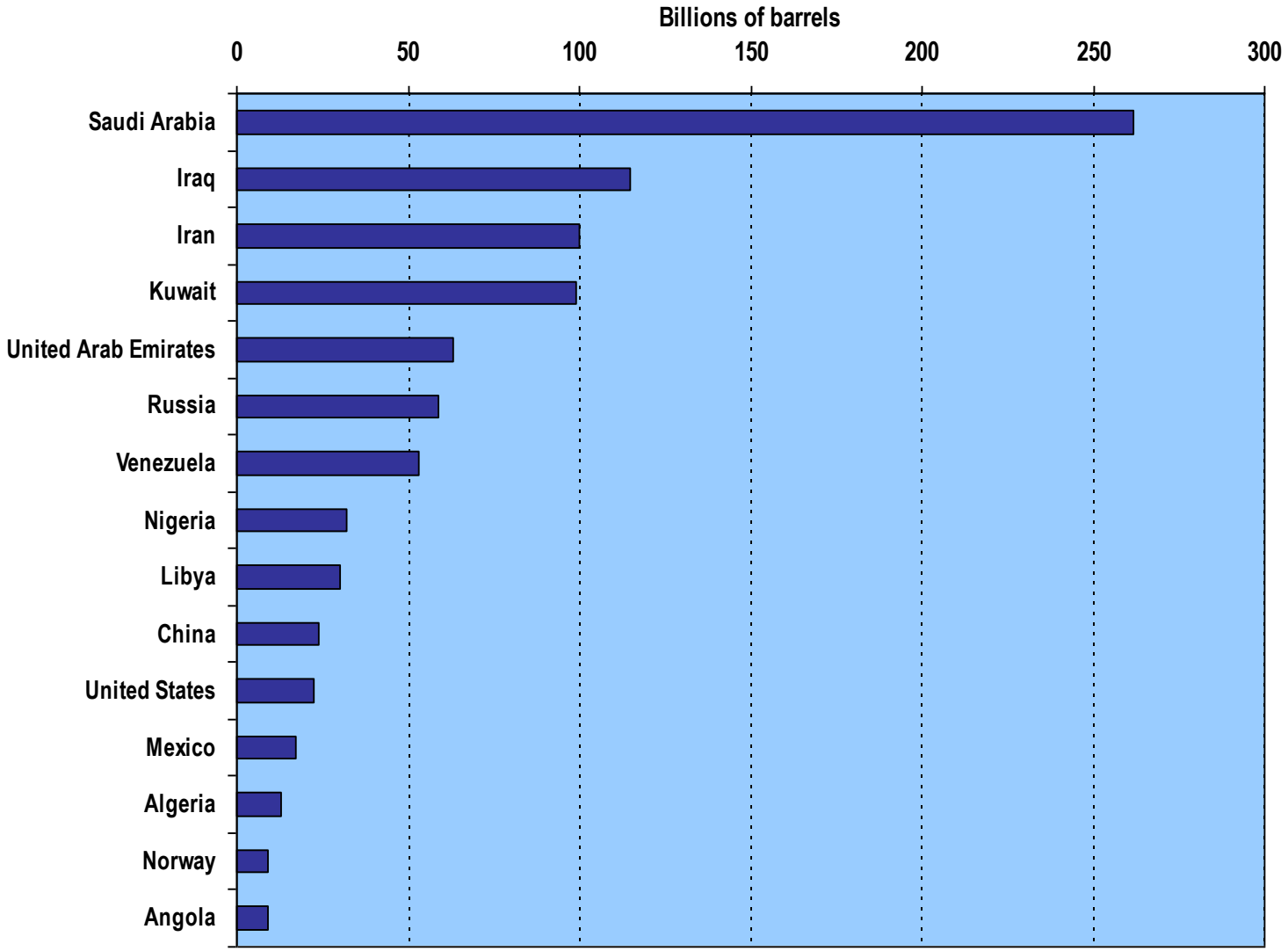


2 Petroleum

- Oil reserves
  - The world oil production is currently running at capacity:
    - Limited opportunities to expand production.
    - 20% of the world's outcome comes from 14 fields.
  - Ghawar:
    - The world's largest oil field; been on production since 1951.
    - Produces approximately 4.5 million barrels of oil per day.
    - 55 to 60% of Saudi Arabia's production.
    - Expected to decline sharply (use of water injection).
    - Could be 90% depleted.
  - OPEC countries may have overstated its reserves:
    - Production quotas are based upon estimated reserves.
    - The larger the reserves, the more an OPEC country can export.
    - In the 1980s, most OPEC reserves doubled "on paper".
    - Extraction continues while reserves remain the same(?).

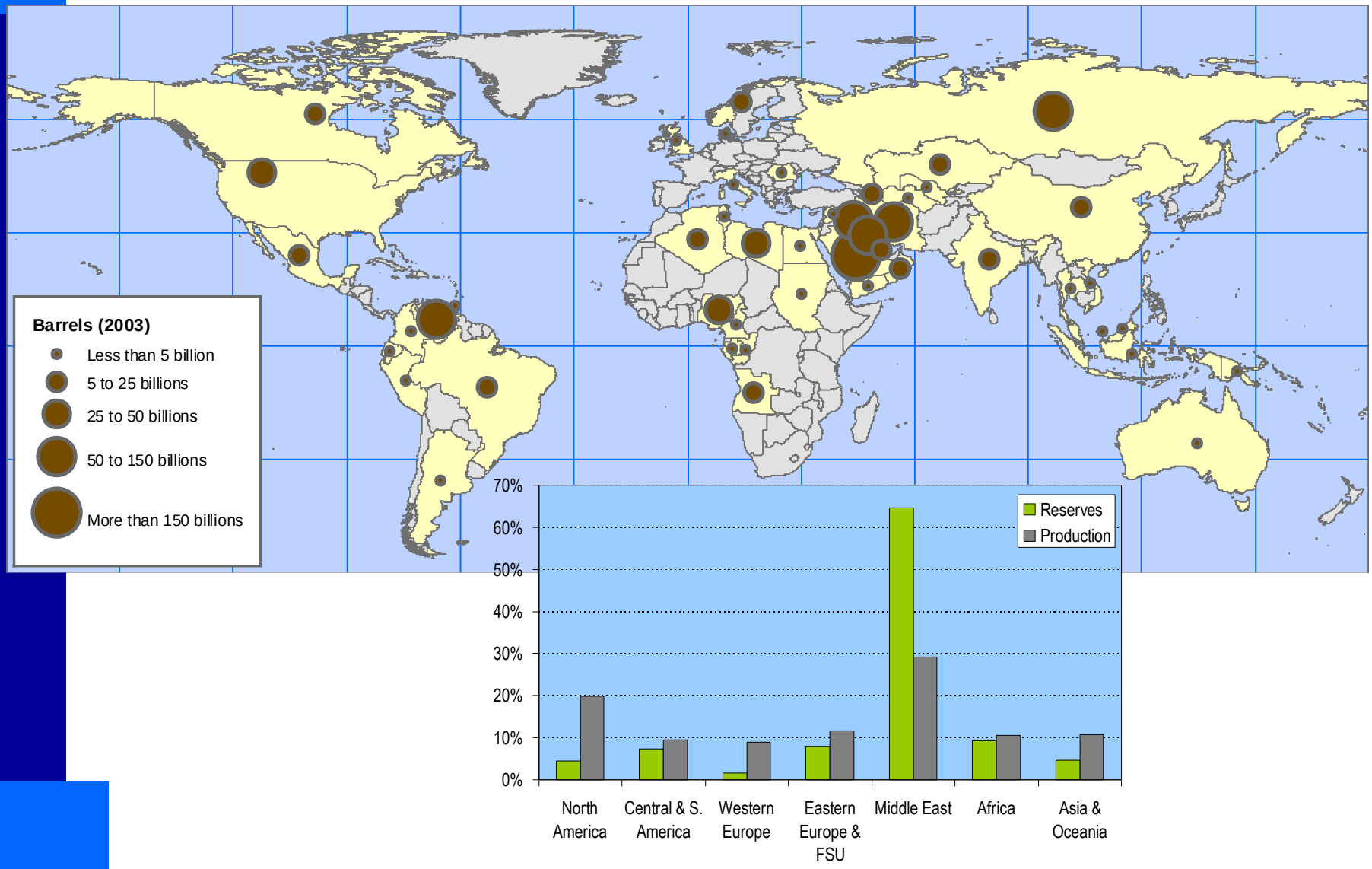
2

Major Crude Oil Reserves, 2003



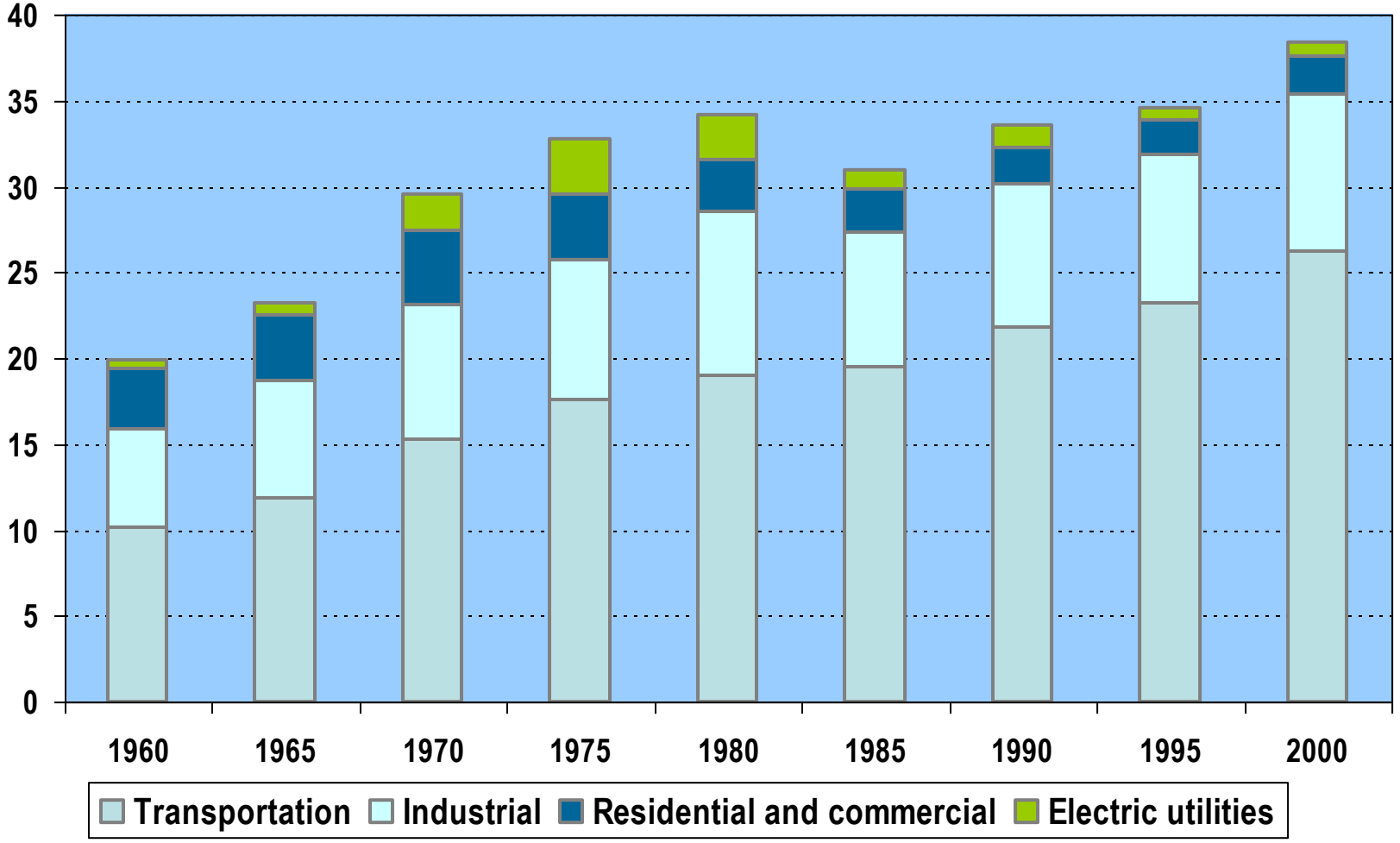
2

Global Oil Reserves, 2003



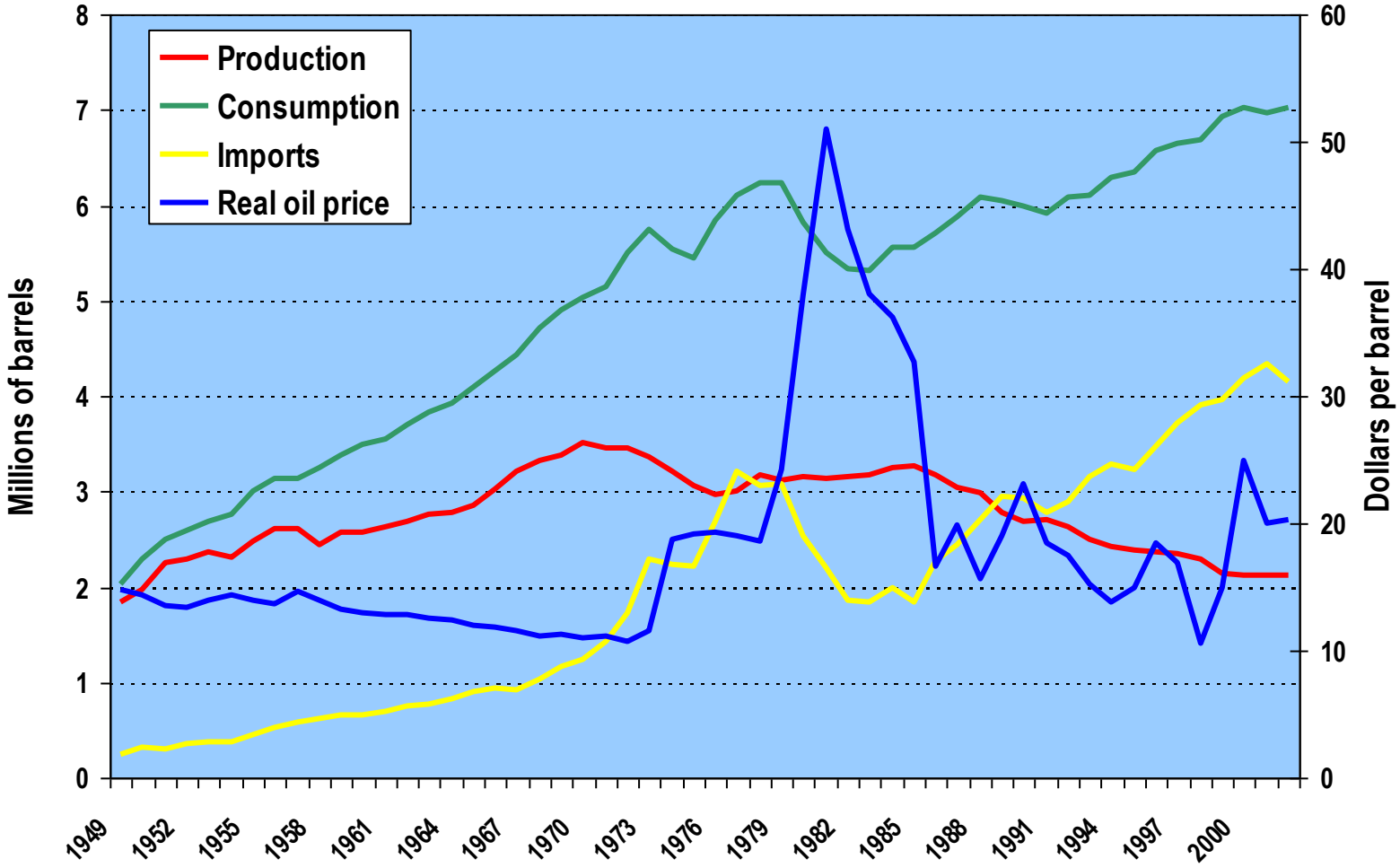
2

Demand for Refined Petroleum Products by Sector in the United States, 1960-2000 (in Quadrillion BTUs)



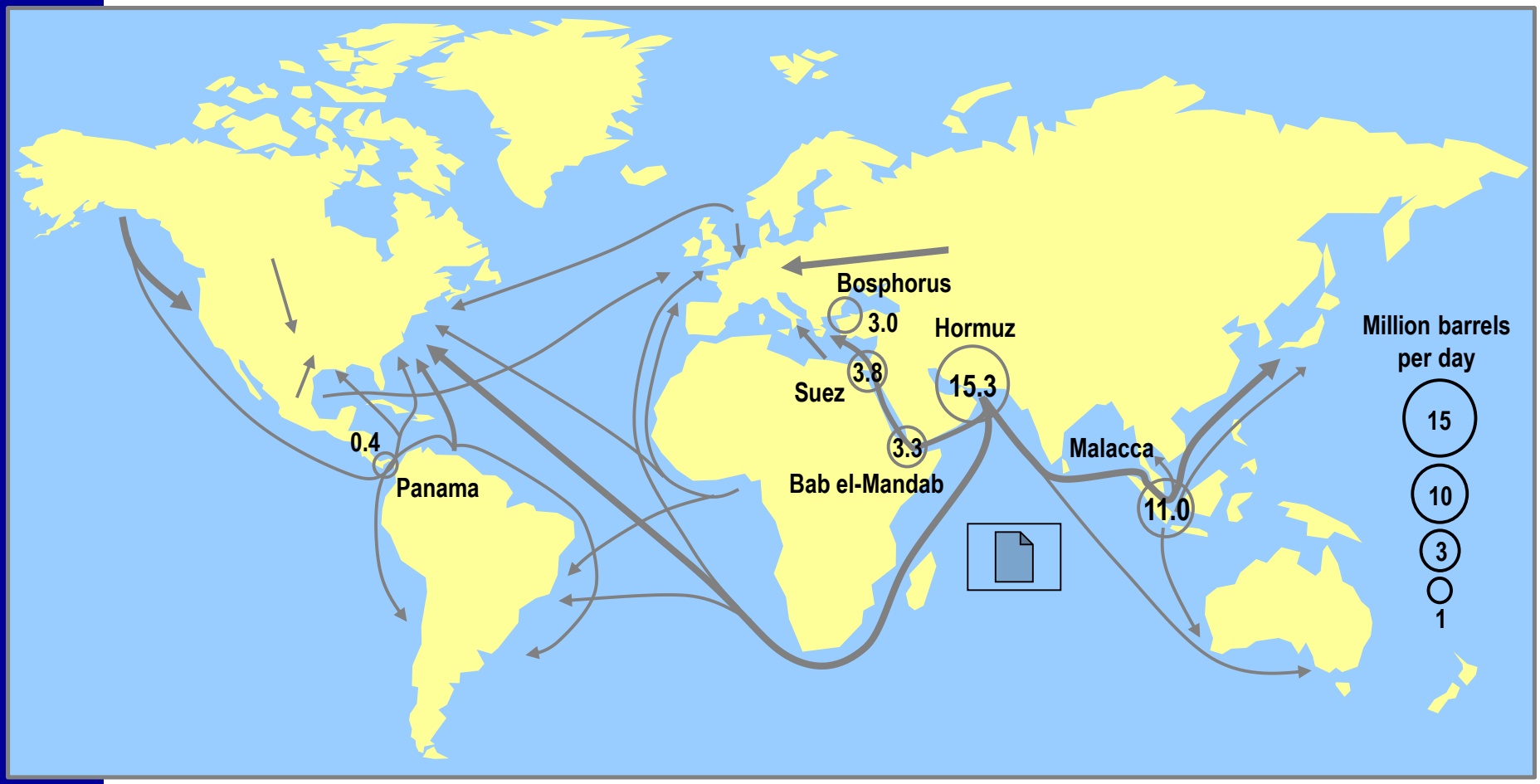
2

Petroleum Production, Consumption and Imports, United States, 1949-2002



2

Major Oil Flows and Chokepoints, 2003



2 Petroleum

- A perfect storm?
  - Booming oil prices after 2004.
  - Prior oil spikes linked with short lived geopolitical events.
  - The situation has changed at the beginning of the 21st century.
  - A production issue:
    - Petroleum extraction appears to be running at capacity.
    - Demand, especially new consumers (China), is going up.
  - A distribution issue:
    - Limited additional tanker and pipeline capacity.
  - A refining issue:
    - Limited additional refining capacity.
    - No refineries were built in the US since 1974.

3 Natural Gas

- Nature
  - Formation:
    - Thermogenic: converted organic material into natural gas due to high pressure.
    - Deeper window than oil.
    - Biogenic: transformation by microorganisms.
  - Composition:
    - Composed primarily of methane and other light hydrocarbons.
    - Mixture of 50 to 90% by volume of methane, propane and butane.
    - “Dry” and “wet” (methane content); “sweet” and “sour” (sulfur content).
  - Usually found in association with oil:
    - Formation of oil is likely to have natural gas as a by-product.
    - Often a layer over the petroleum.

3

Natural Gas

- Reserves
  - Substantial reserves likely to satisfy energy needs for the next 100 years.
  - High level of concentration:
    - 45% of the world's reserves are in Russia and Iran.
  - Regional concentration of gas resources is more diverse:
    - As opposed to oil.
    - Only 36% of the reserves are in the Middle East.

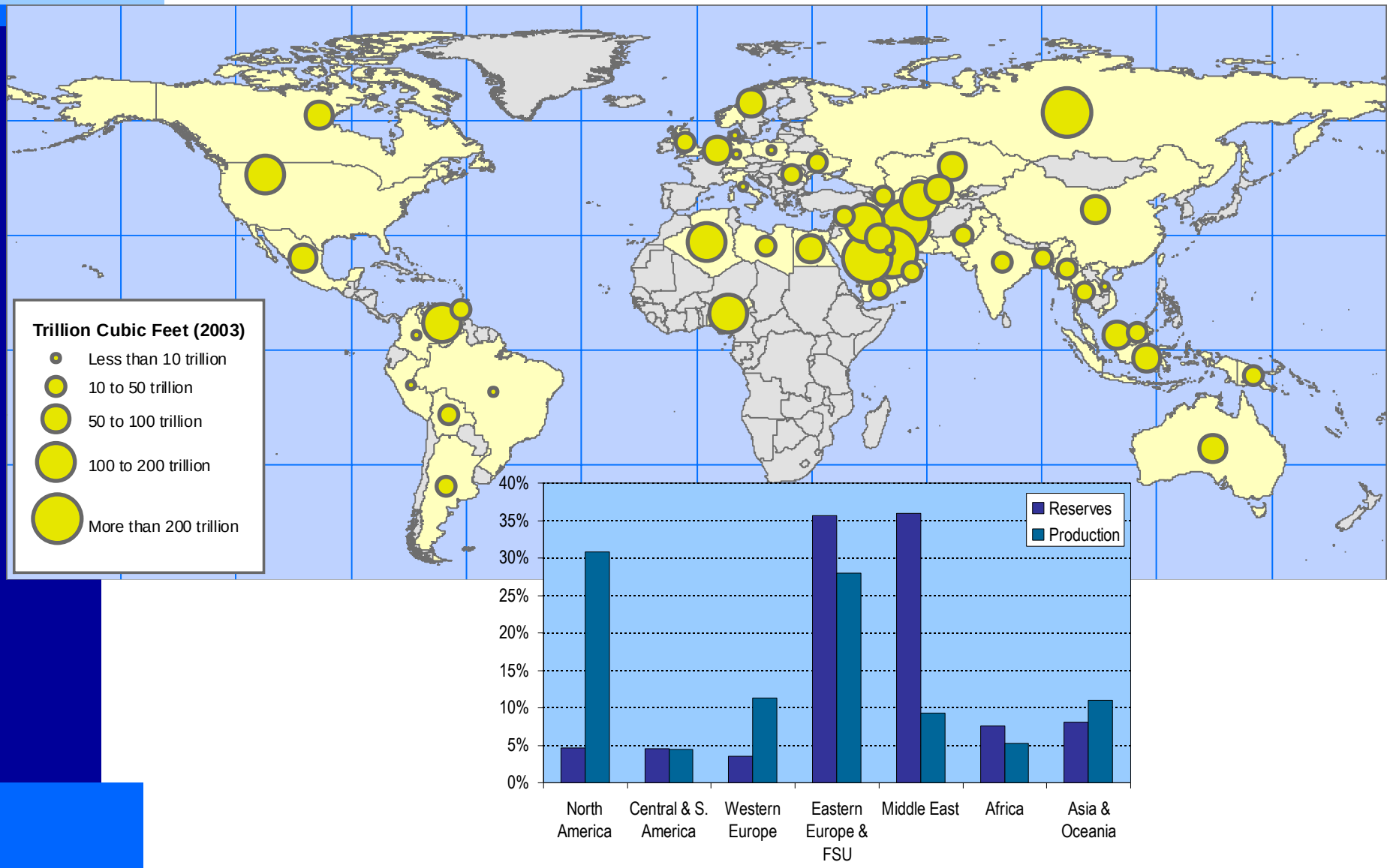
3

Natural Gas

- Use
  - Mostly used for energy generation.
  - Previously, it was often wasted - burned off.
  - It is now more frequently conserved and used.
  - Considered the cleanest fossil fuel to use.
  - The major problem is transporting natural gas, which requires pipelines.
  - Gas turbine technology enables to use natural gas to produce electricity more cheaply than using coal.

- Liquefied natural gas (LNG)
  - Liquid form of natural gas; easier to transport.
  - Cryogenic process (-256oF): gas loses 610 times its volume.
  - Value chain:
    - Extraction
    - Liquefaction
    - Shipping
    - Storage and re-gasification

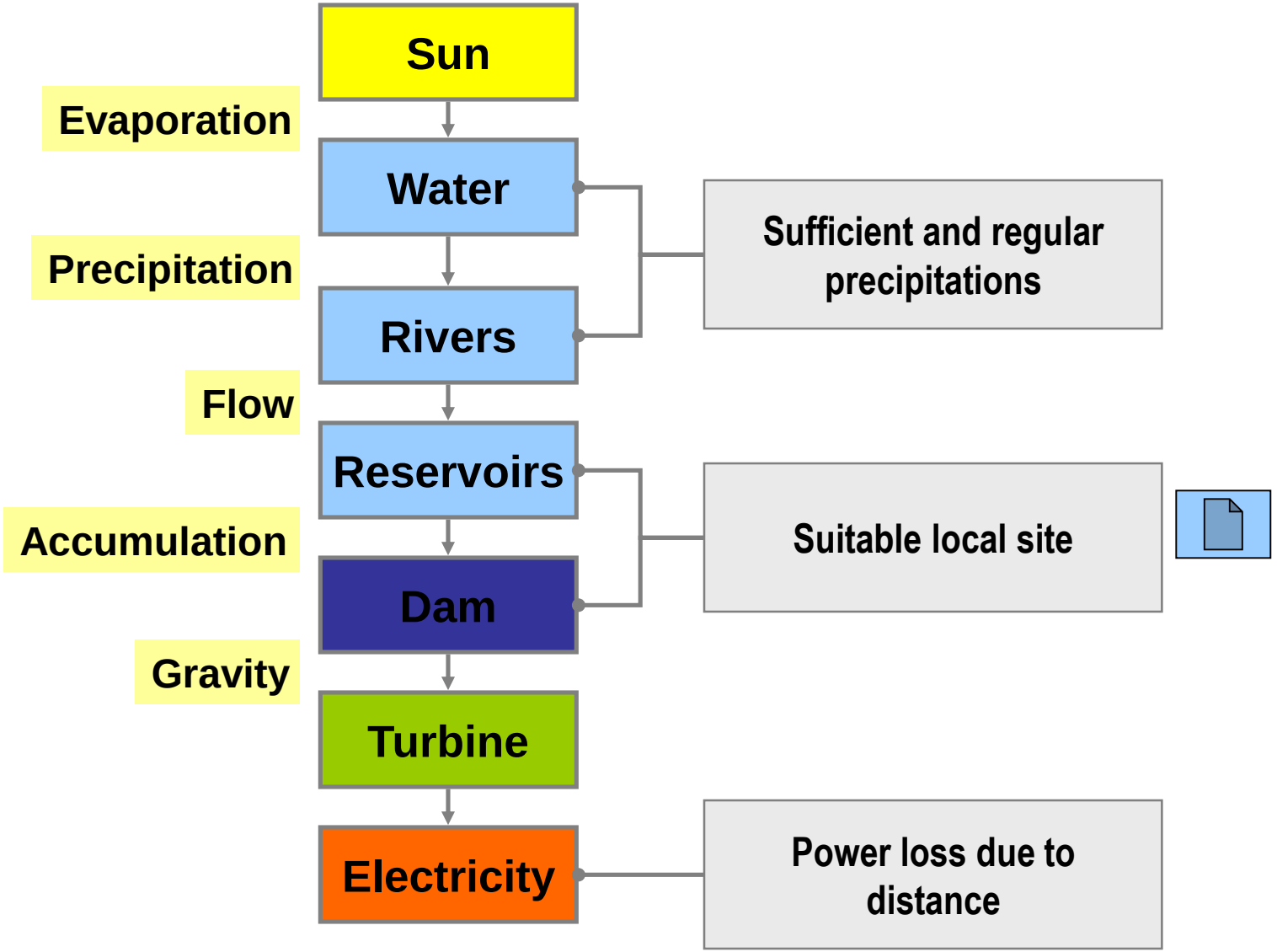
3 Global Natural Gas Reserves, 2003



4 Hydropower

- Nature
  - Generation of electricity using the flow of water as the energy source.
  - Gravity as source.
  - Requires a large reservoir of water.
  - Considered cleaner, less polluting than fossil fuels.
- Tidal power
  - Take advantage of the variations between high and low tides.

4 Hydropower

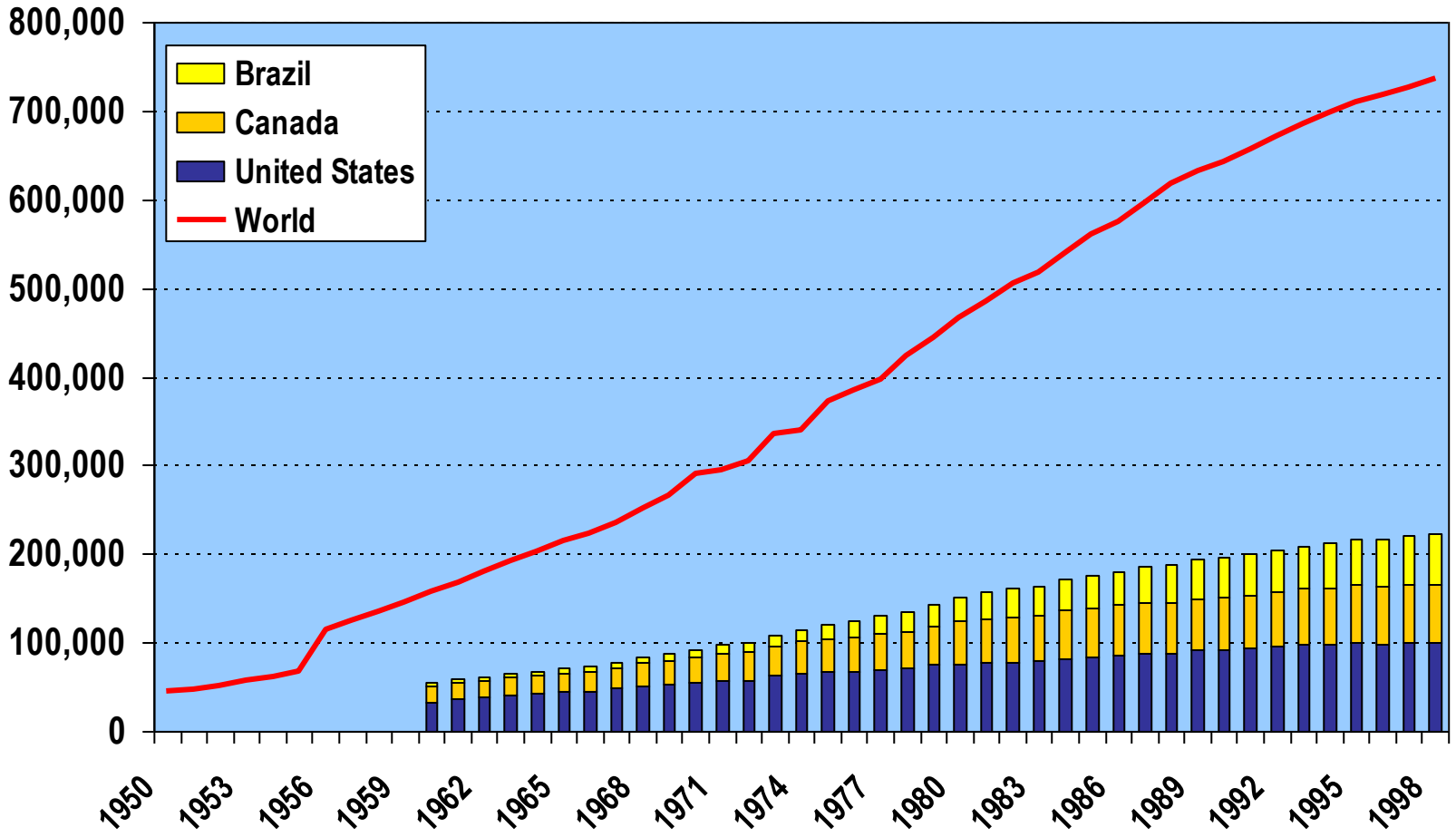


4 Hydropower

- Controversy
  - Require the development of vast amounts of infrastructures:
    - Dams.
    - Reservoirs.
    - Power plants and power lines.
    - Very expensive and consume financial resources or aid resources that could be utilized for other things.
  - Environmental problems:
    - The dams themselves often alter the environment in the areas where they are located.
    - Changing the nature of rivers, creating lakes that fill former valleys and canyons, etc.

4

World Hydroelectric Generating Capacity, 1950-98 (in megawatts)

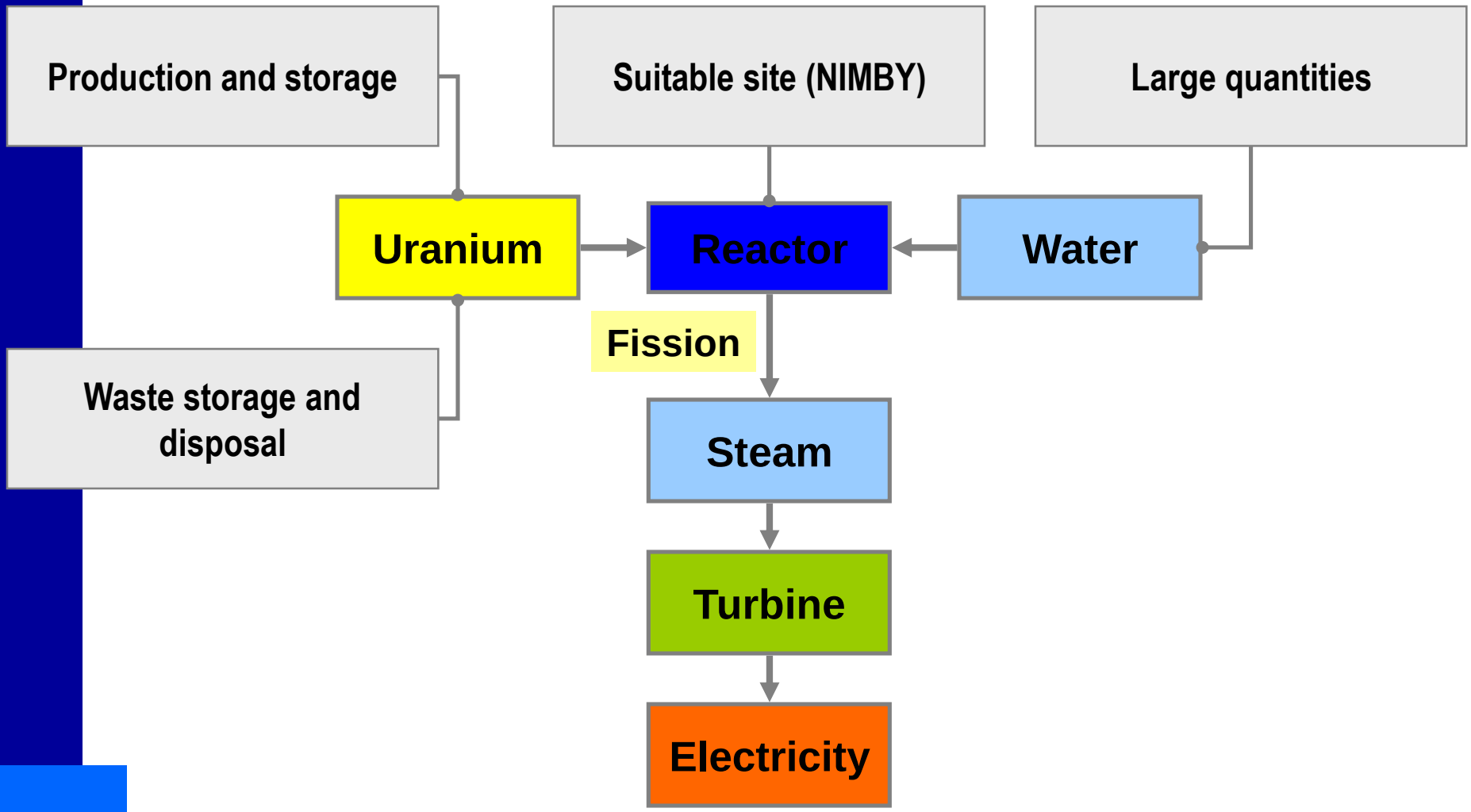


5

Nuclear Power

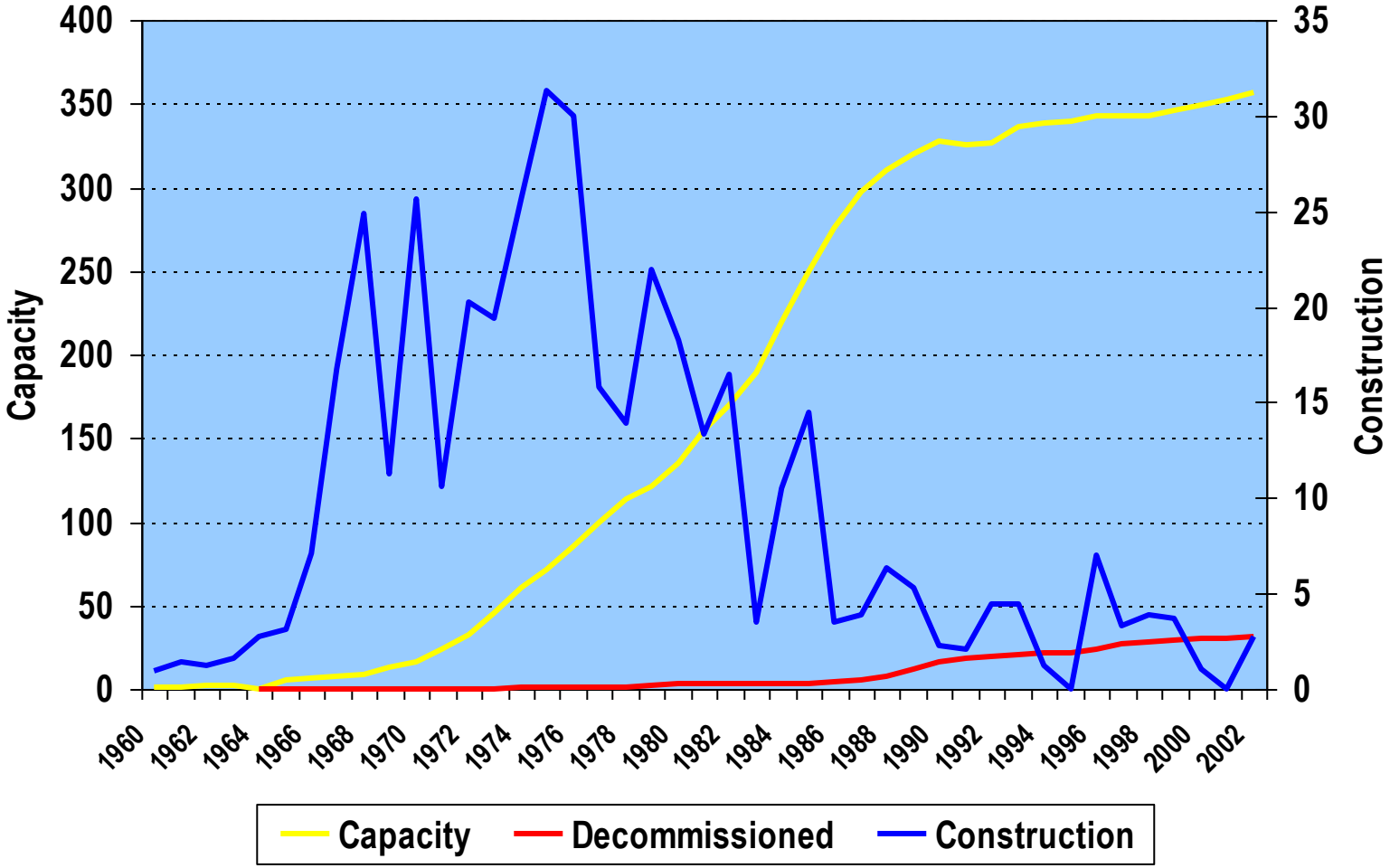
- Nature
  - Fission of uranium to produce energy.
  - The fission of 1 kg (2.2 lb) of uranium-235 releases 18.7 million kilowatt-hours as heat.
  - Heat is used to boil water and activate steam turbines.
  - Uranium is fairly abundant.
  - Requires massive amounts of water for cooling the reactor.

5 Nuclear Power



5

Nuclear Power Plants, 1960-2002 (in gigawatts)



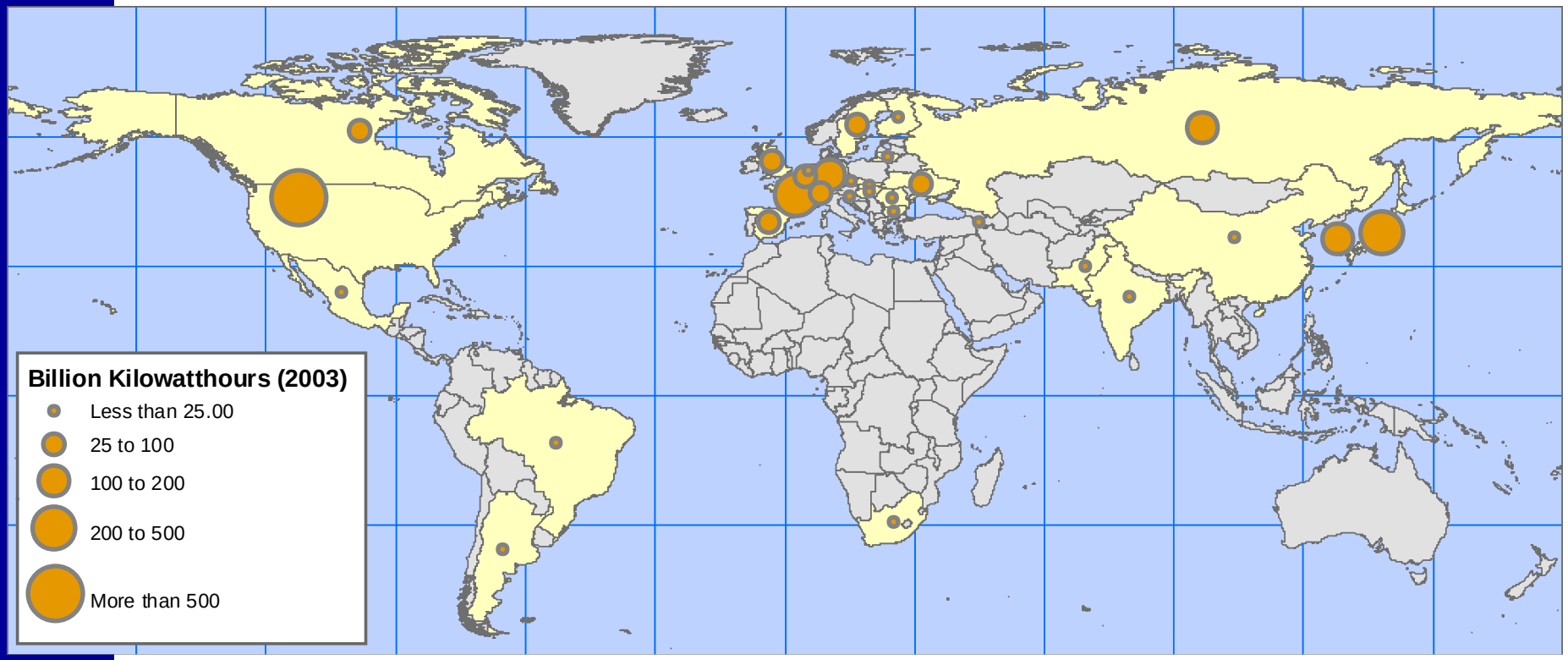
5

Nuclear Power

- Nuclear power plants
  - 430 operating nuclear power plants (civilian) worldwide.
  - Very few new plants coming on line:
    - Public resistance (NIMBY syndrome).
    - High costs.
    - Nuclear waste disposal.
  - 30 countries generate nuclear electricity:
    - About 17% of all electricity generated worldwide.
  - United States:
    - 109 licensed nuclear power plants; about 20% of the electricity.
    - Licenses are usually given for a 40 year period.
    - Many US plants will be coming up for license extensions by 2006.
    - No new nuclear power plant built since 1979 (Three Mile Island incident).
  - China:
    - Plans to had 2 new nuclear reactor per year until 2020.

5

Global Nuclear Energy Generation, 2003



5

Nuclear Power

- Nuclear waste disposal
  - Problem of nuclear waste disposal; radioactivity.
  - Low level wastes:
    - Material used to handle the highly radioactive parts of nuclear reactors .
    - Water pipes and radiation suits.
    - Lose their radioactivity after 10 to 50 years.
  - High level wastes:
    - Includes uranium, plutonium, and other highly radioactive elements made during fission.
    - Nuclear wastes have a half-life about of 10,000 to 20,000 years.
    - Requirements of long-term storage in a geologically stable area.
    - Long Term Geological Storage site at Yucca Mountain.

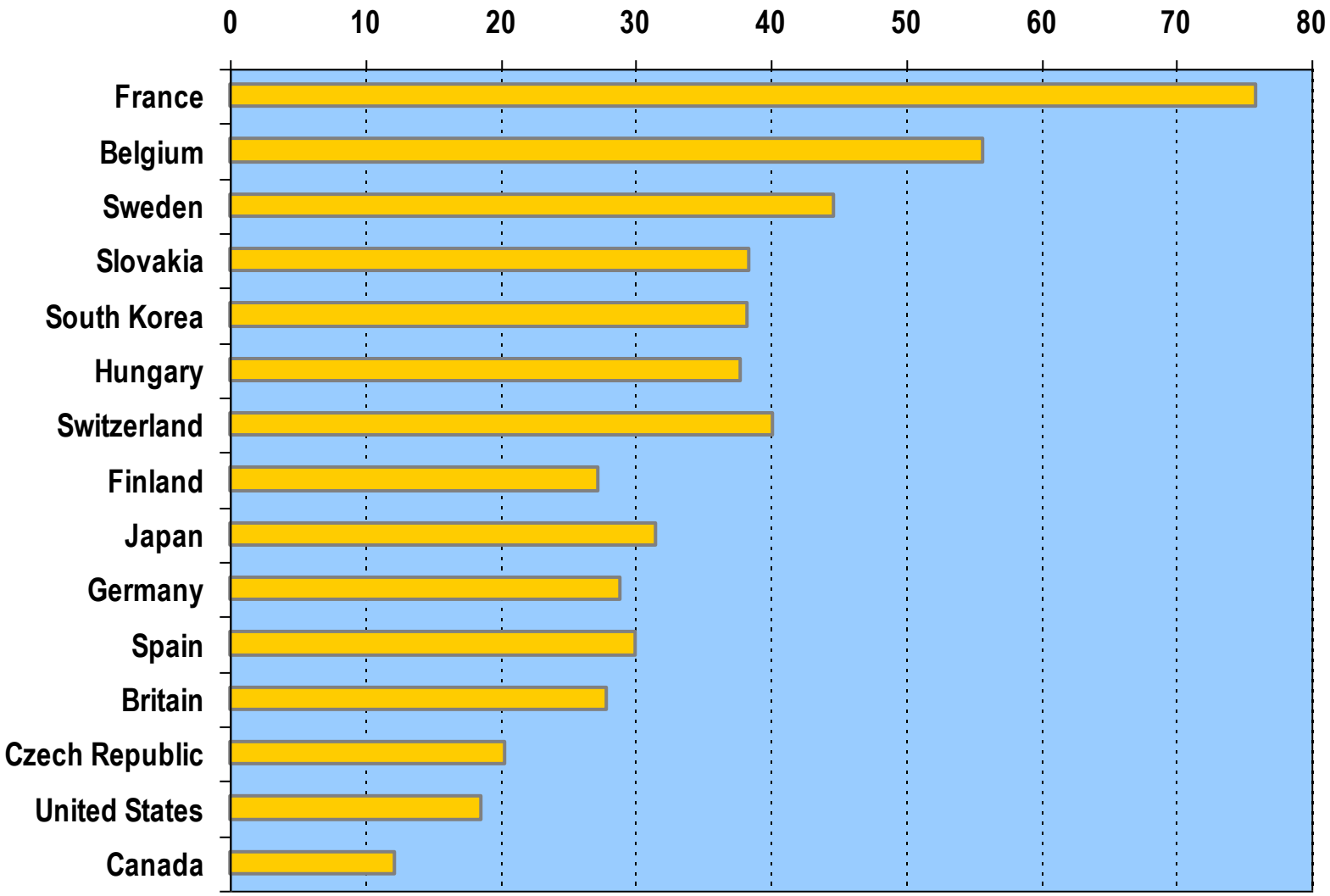
5

Nuclear Power

- Reliance
  - Some countries have progressed much further in their use of nuclear power than the US.
  - High reliance:
    - France, Sweden, Belgium, and Russia have a high reliance on nuclear energy.
    - France has done this so as not to rely on foreign oil sources.
    - It generates 75% of its electricity using nuclear energy.
    - The need to import most fossil fuels provides an extra impetus to turn to nuclear energy.
  - Phasing out:
    - Nuclear energy perceived as financially unsound and risky.
    - No new nuclear power plant built in Europe since Chernobyl (1986).
    - The German parliament decided in 2001 to phase out nuclear energy altogether.

5

Nuclear Power as % of Electricity Generation, 1998



5 Nuclear Power

Pro Nuclear Side	Con Nuclear Side
■ Reduced fossil fuels dependence ■ Enhanced energy security ■ Environmental benefits	■ Fear of accidents and sabotage (terrorism) ■ Waste disposal ■ High construction and decommission costs

C

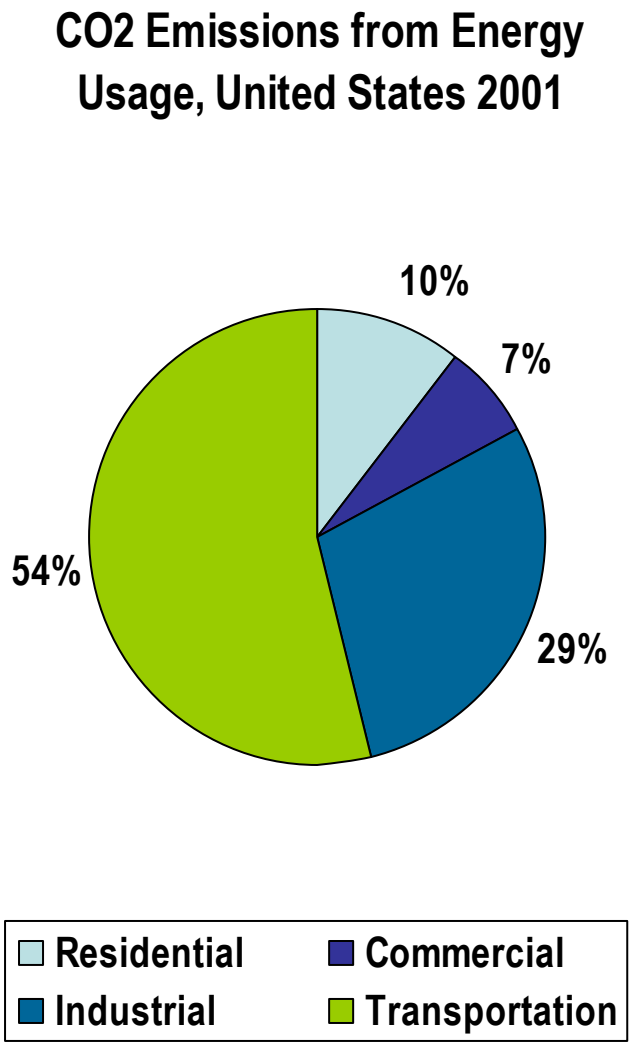
Alternative Energy Resources

- What new sources of energy are likely to satisfy future demands?
- 1. Context
- 2. Hydrogen and Fuel Cells
- 3. Solar Energy
- 4. Wind Energy
- 5. Geothermal Energy
- 6. Biomass Fuels

1 Context

- Emergence
  - Received increasing attention since the first oil crisis in 1973:
    - Attention varies with fluctuations in the price of oil.
  - Several alternate sources need further research before they can become truly viable alternatives.
  - Moving from carbon-based sources to non-carbon based:
    - Europe: 22% of its energy to come from renewable sources by 2010.
- Unsustainability of fossil fuels
  - The resource itself is finite.
  - Use contributes to the global warming problem.
  - Some 35% of the carbon emissions in the USA is attributable to electric power generation.
  - Employing substitutes for fossil fuels in that area alone would help alleviate our greenhouse gas problem.

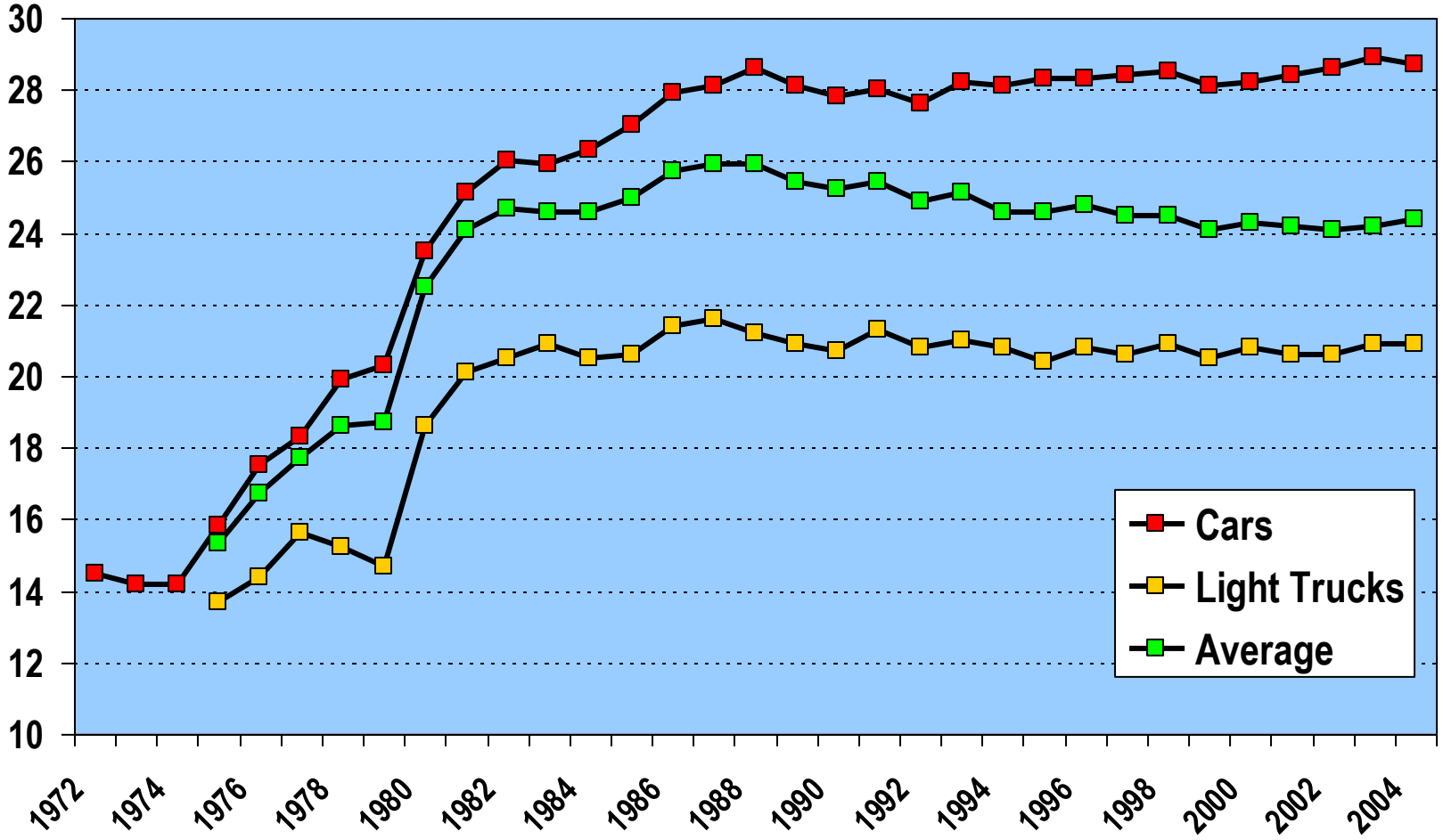
1 Context



- Fuel use efficiency
  - Not an alternate energy source.
  - Can have a great impact on conservation.
  - After 1973, many industries were motivated to achieve greater efficiency of energy use.
  - Many appliances (including home air conditioners) were made more energy efficient.
  - The USA continually ranks behind Europe and Japan in energy efficiency.

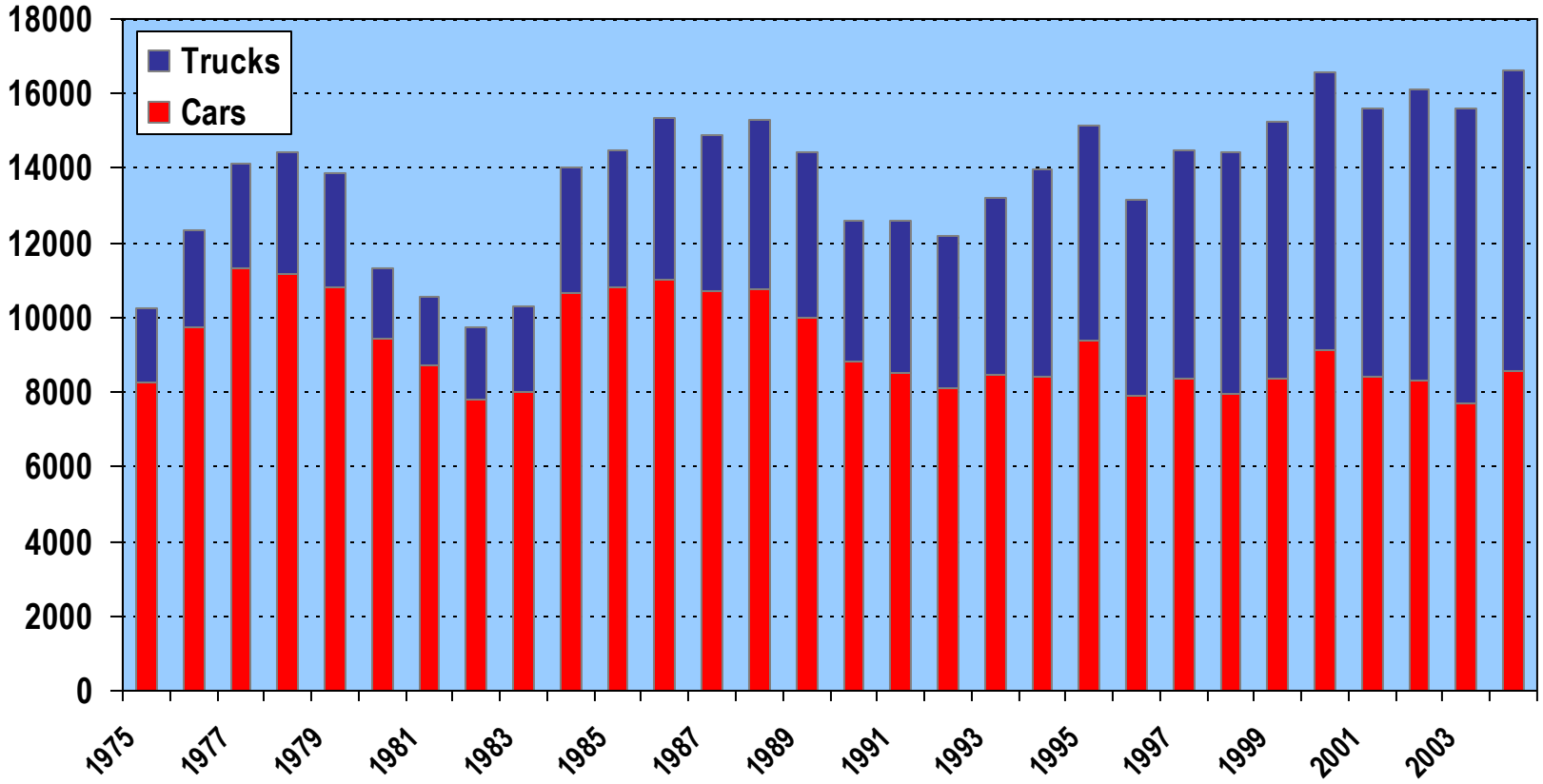
1

Average Gasoline Consumption for New Vehicles, United States, 1972-2004 (in miles per gallon)



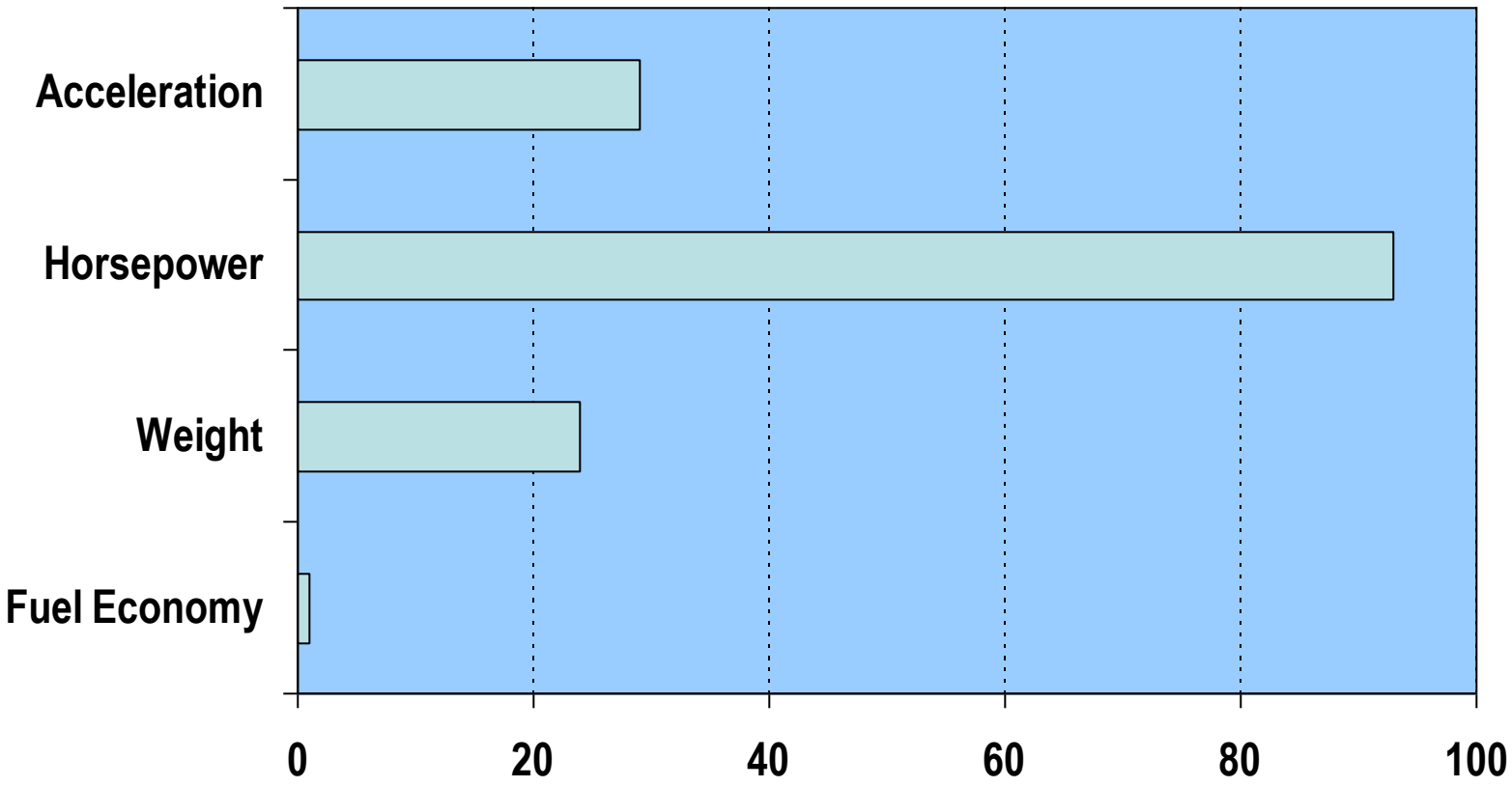
1

Light-Duty Vehicles Sales in the United States, 1975-2004 (in 1,000s)



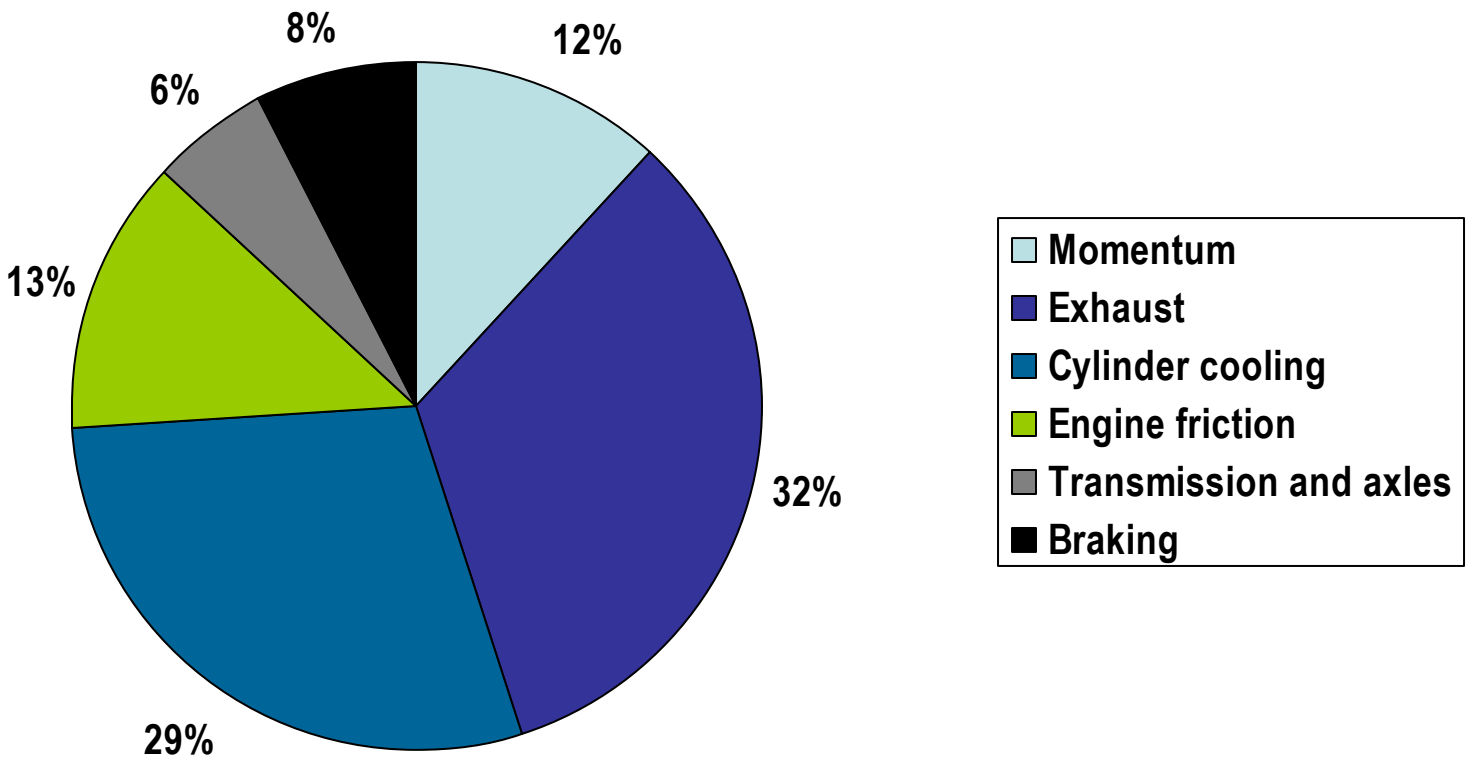
1

Change in Average Vehicle Characteristics, 1981-2003 (in %)



1

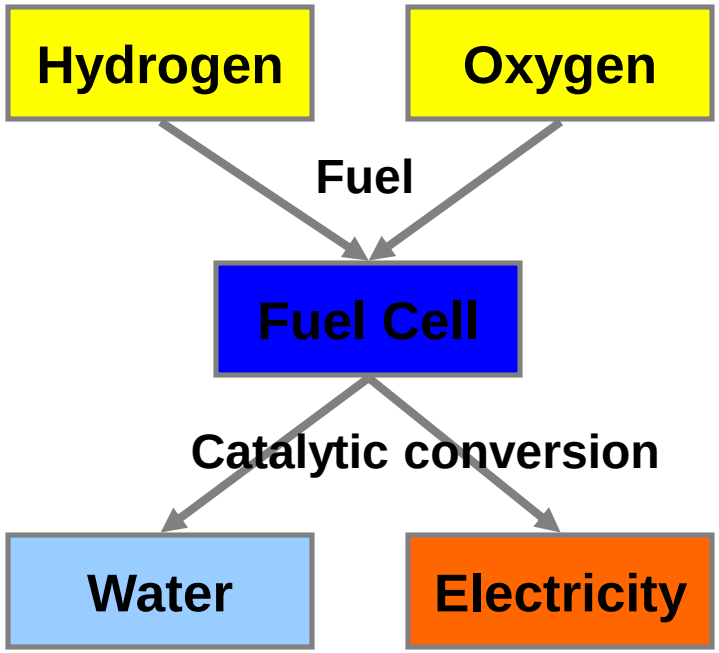
Typical Energy Use for a Car



1 Context

- Nuclear fusion
  - Currently researched but without much success.
  - It offers unlimited potential.
  - Not realistically going to be a viable source of energy in the foreseeable future.

2 Hydrogen and Fuel Cells



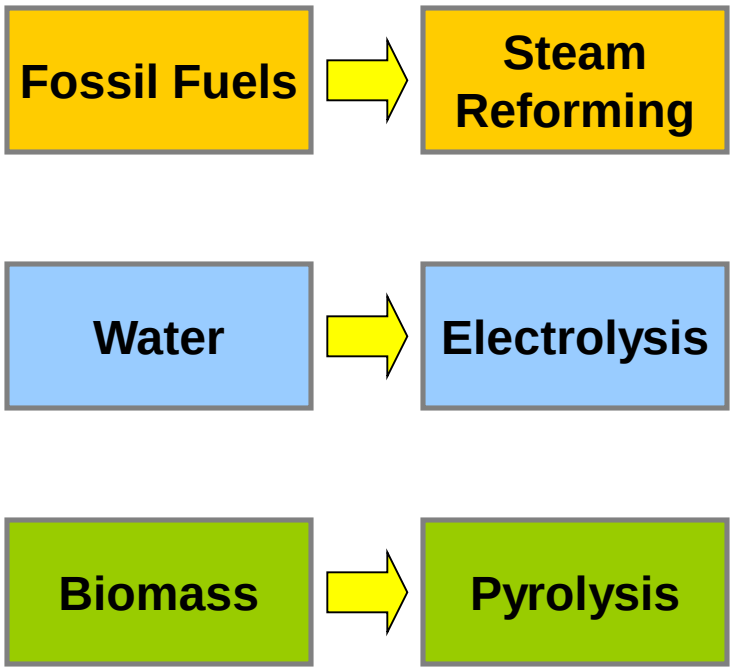
- Hydrogen
  - Considered to be the cleanest fuel.
  - Compose 90% of the matter of the universe.
  - Non polluting (emits only water and heat).
  - Highest level of energy content.
- Fuel cells
  - Convert fuel energy (such as hydrogen) to electric energy.
  - No combustion is involved.
  - Composed of an anode and a cathode.
    - Fuel is supplied to the anode.
    - Oxygen is supplied to the cathode.
    - Electrons are stripped from a reaction at the anode and attracted to form another reaction at the cathode.

2

Hydrogen and Fuel Cells

- Fuel cell cars
  - Most likely replacement for the internal combustion engine.
  - Efficiency levels are between 55% and 65%.
  - May be introduced by 2004 (working prototypes).
  - Mass produced by 2010.
- Storage issues
  - Hydrogen is a highly combustive gas.
  - Find a way to safely store it, especially in a vehicle.
- Delivery issues
  - Distribution from producers to consumers.
  - Production and storage facilities.
  - Structures and methods for transporting hydrogen.
  - Fueling stations for hydrogen-powered applications.

2 Hydrogen and Fuel Cells



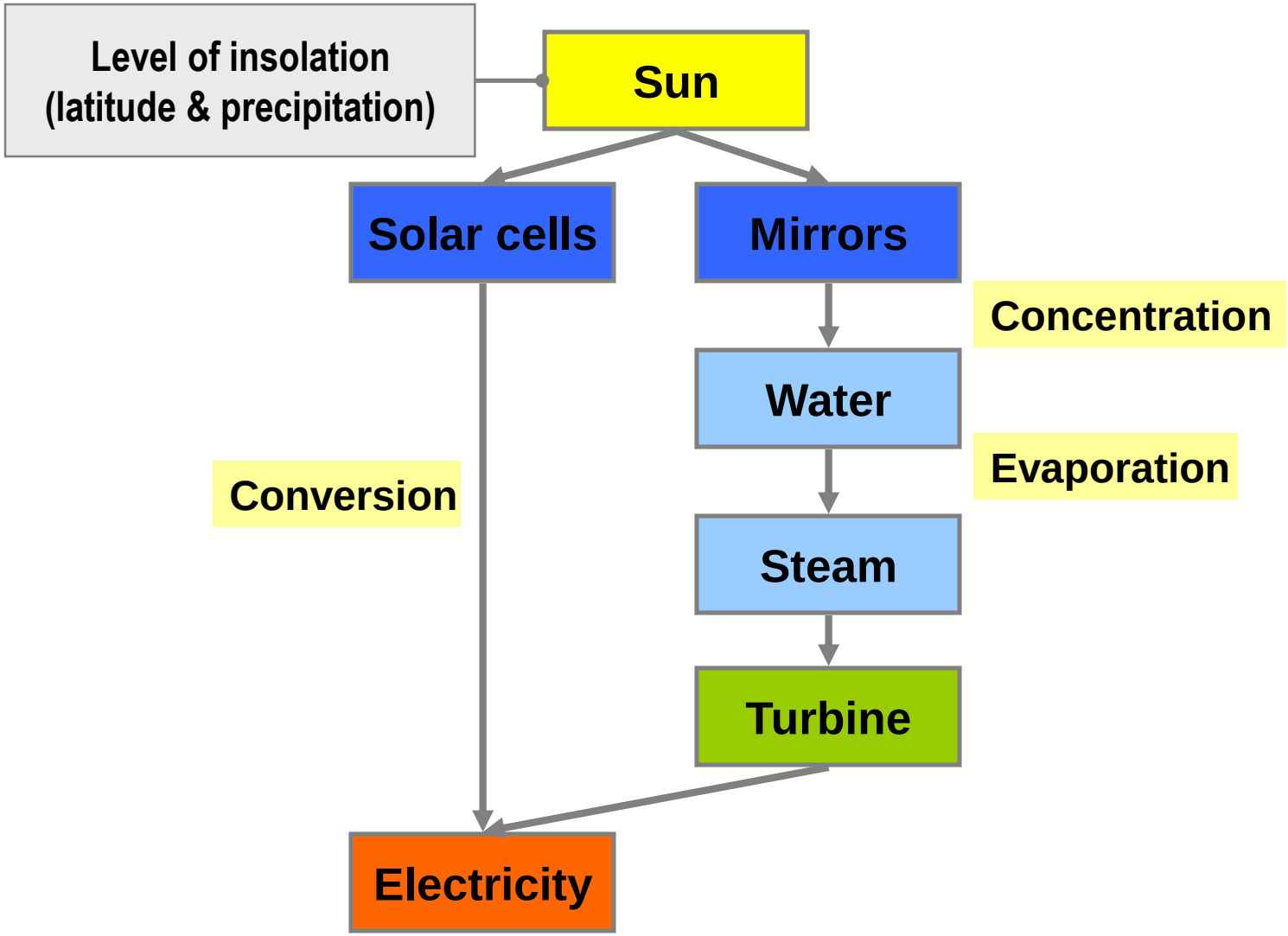
- Hydrogen production
  - Not naturally occurring.
  - Producing sufficient quantities to satisfy the demand.
  - Extraction from fossil fuels:
    - From natural gas.
    - Steam reforming.
  - Electrolysis of water:
    - Electricity from fossil fuels not a environmentally sound alternative.
    - Electricity from solar or wind energy is a better alternative.
  - Pyrolysis of the biomass:
    - Decomposing by heat in an oxygen-reduced atmosphere.

3

Solar Energy

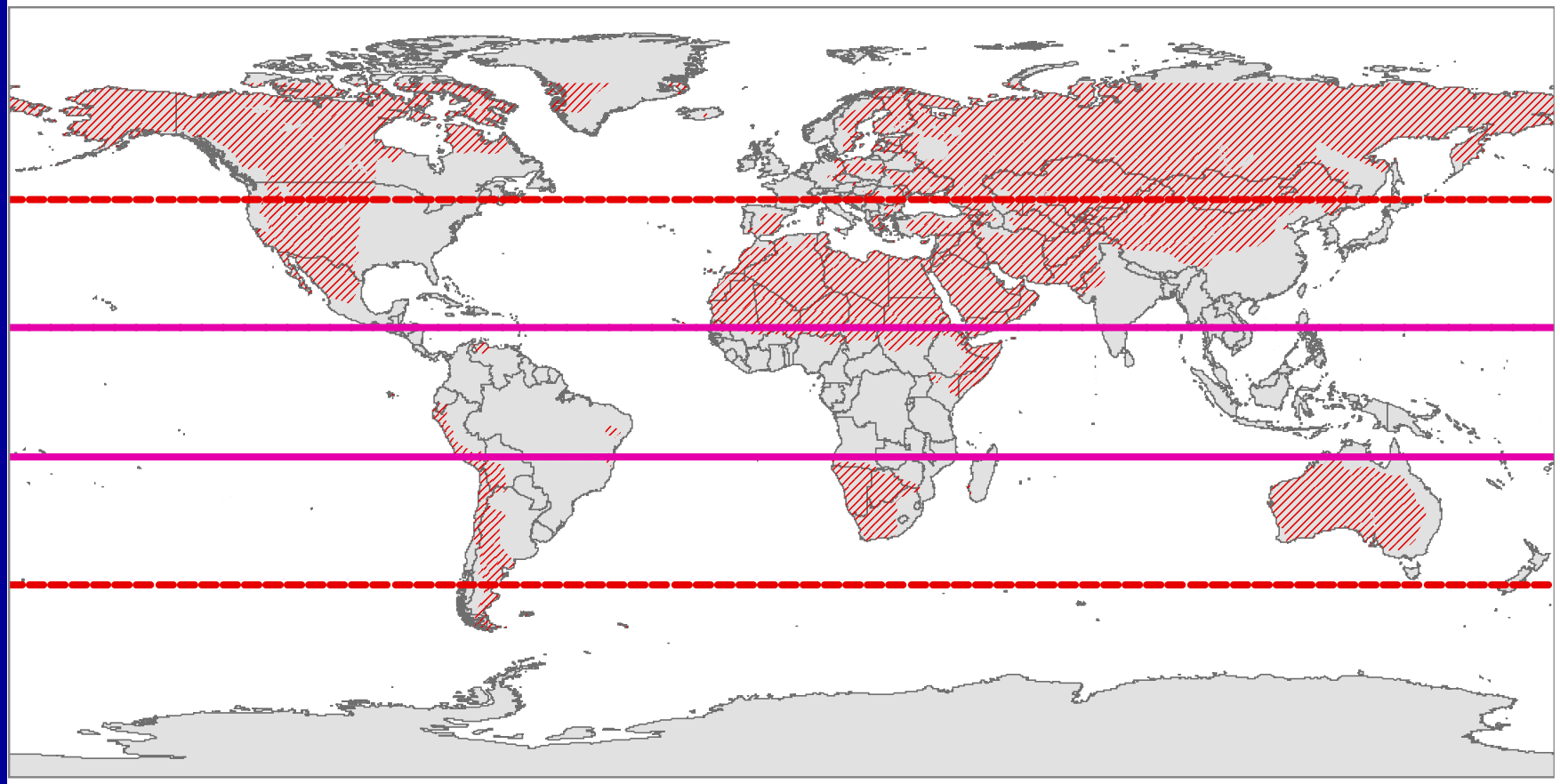
- Definition
  - Radiant energy emitted by the sun (photons emitted by nuclear fusion).
  - Conversion of solar energy into electricity.
- Photovoltaic systems
- Solar thermal systems

3 Solar Energy



3

Global Solar Energy Potential



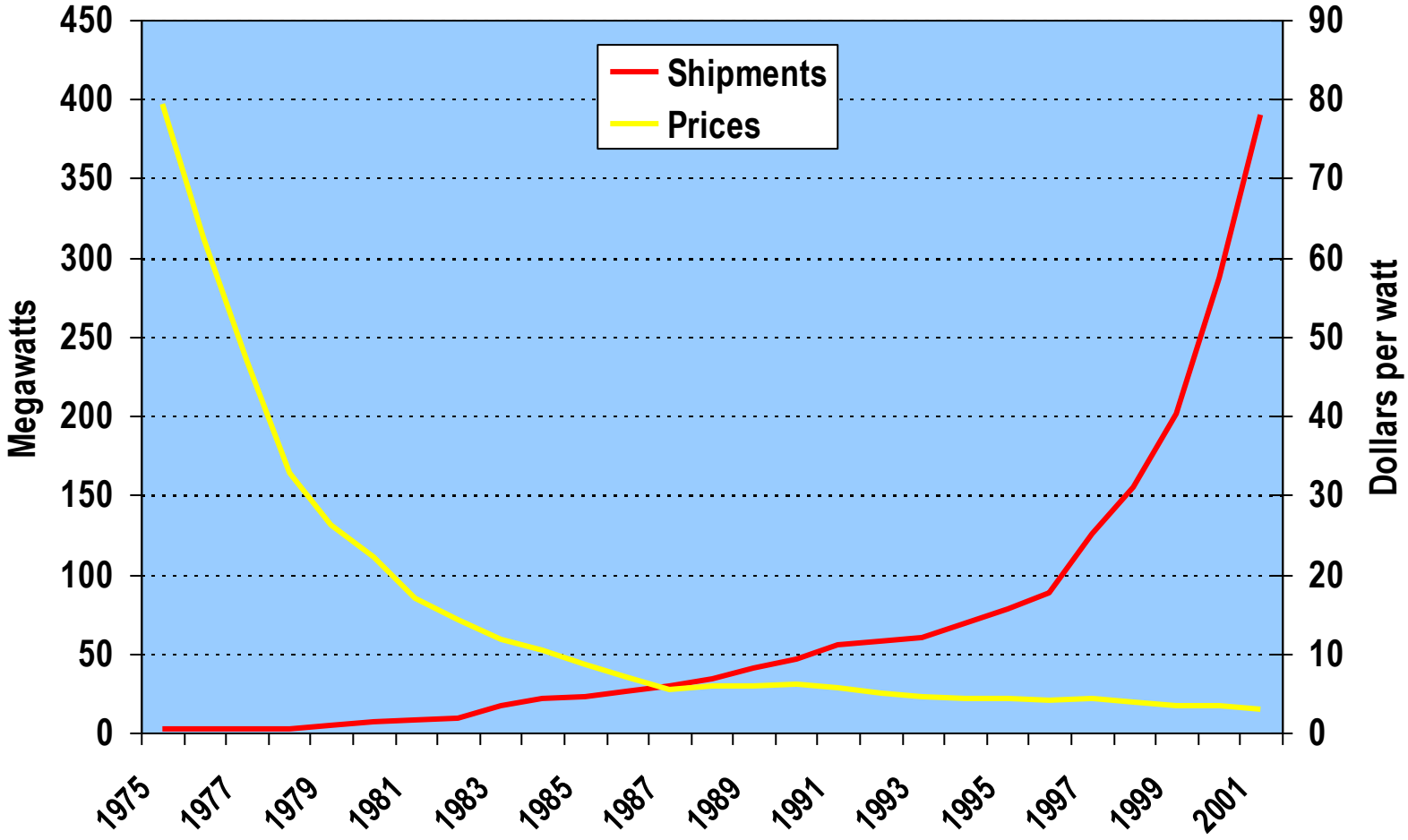
3

Solar Energy

- Photovoltaic systems
  - Semiconductors to convert solar radiation into electricity.
  - Better suited for limited uses such as pumping water that do not require large amounts of electricity.
  - Costs have declined substantially:
    - 5 cents per kilowatt-hour.
    - Compared to about 3 cents for coal fired electrical power.
  - Economies of scale could then be realized in production of the necessary equipment.
  - Japan generates about 50% of the world's solar energy.

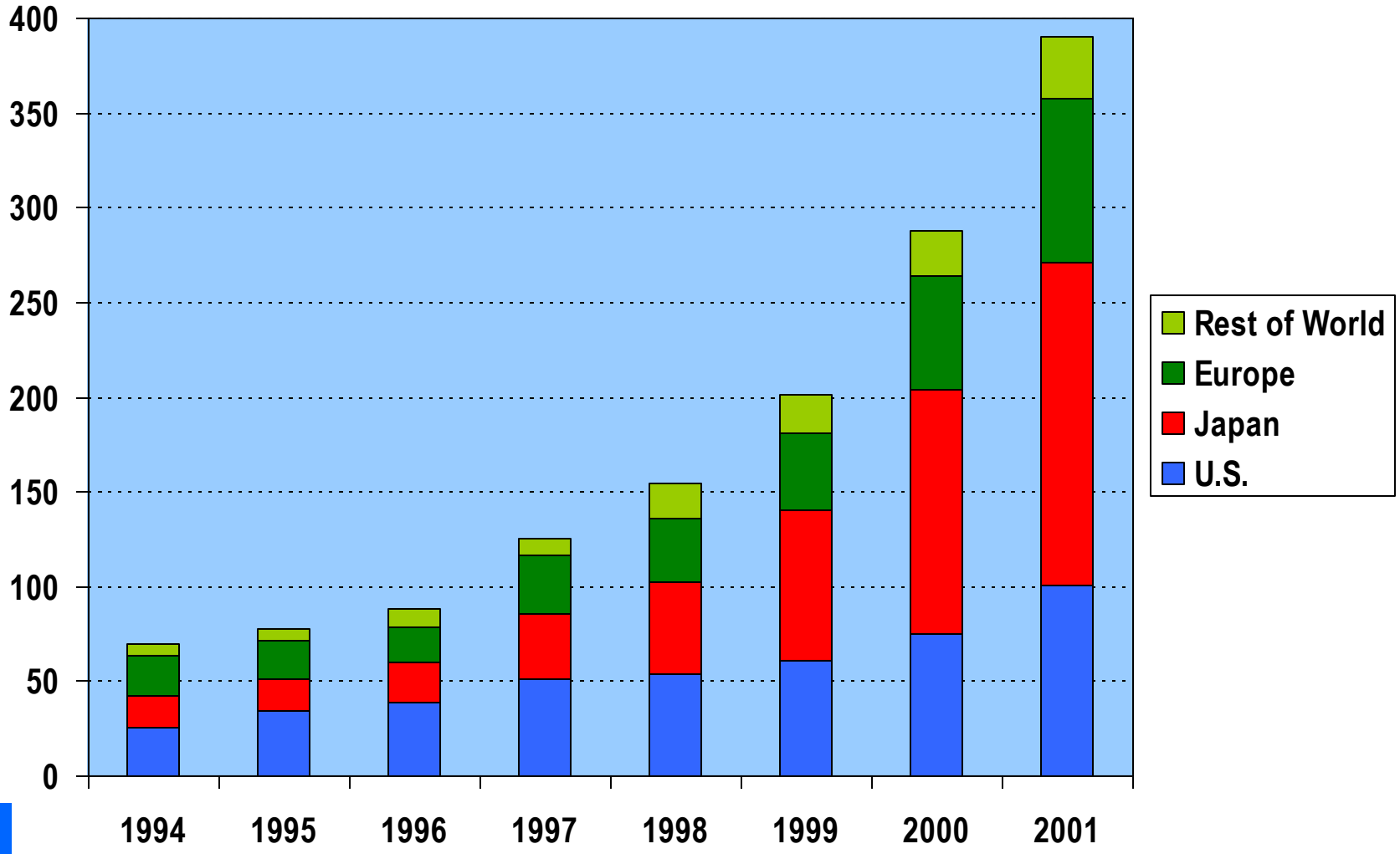
3

World Photovoltaic Annual Shipments and Price 1975-2001



3

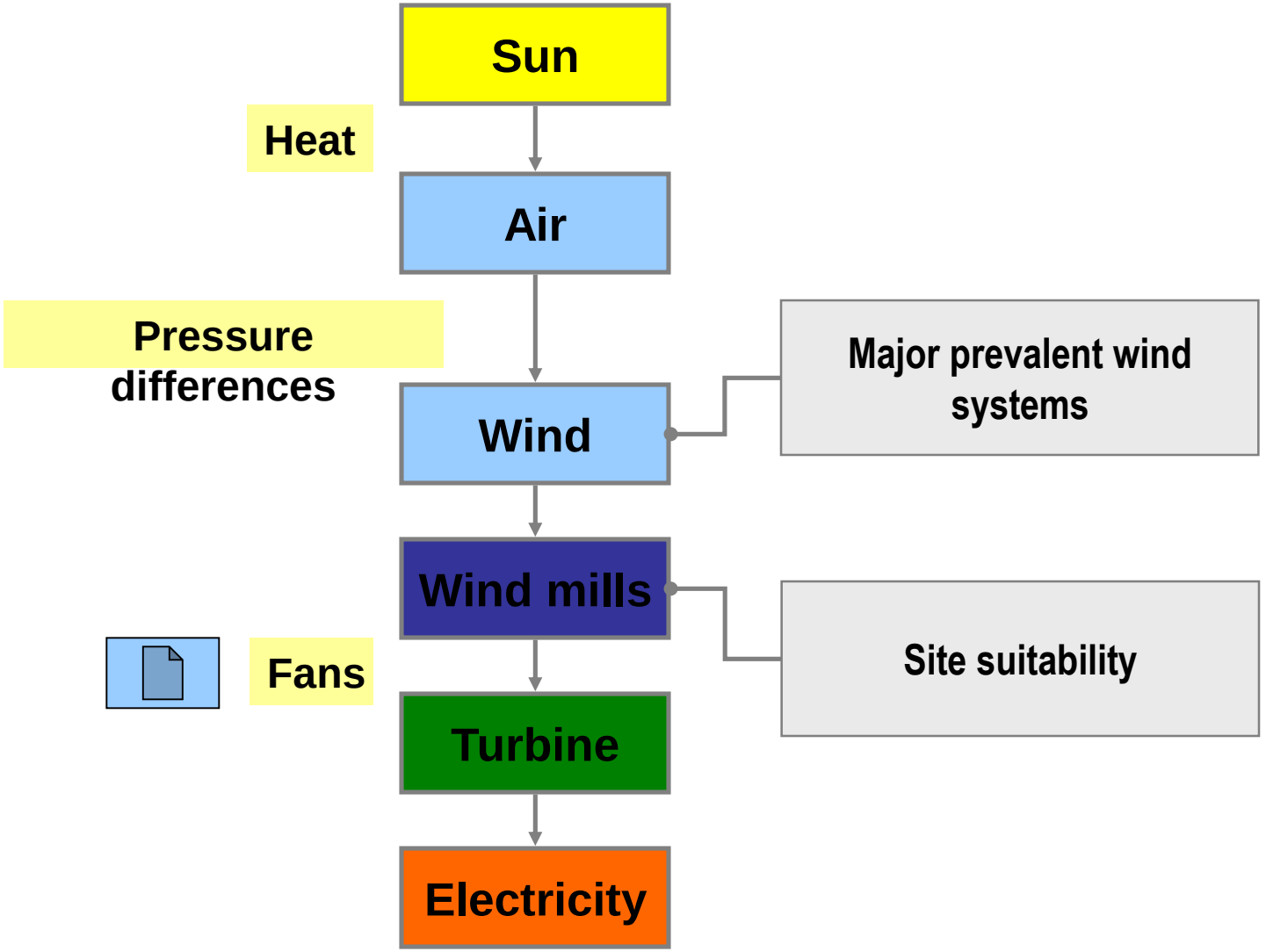
Photovoltaic Production by Country or Region, 1994-2001



3 Solar Energy

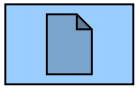
- Solar thermal systems
  - Employ parabolic reflectors to focus solar radiation onto water pipes, generating steam that then power turbines.
  - Costing about 5-10 cents per Kwh.
  - Require ample, direct, bright sunlight.
  - Drawback of the solar thermal systems is their dependence on direct sunshine, unlike the photovoltaic cells.
- Limitations
  - Inability to utilize solar energy effectively.
  - There is currently only about a 15% conversion rate of solar energy into electricity.
  - Low concentration of the resource.
  - Need a very decentralized infrastructure to capture the resource.

4 Wind Power


Sun
Heat
Air
Pressure differences
Wind
Major prevalent wind systems
Wind mills
Fans
Site suitability
Turbine
Electricity

4 Wind Power

- Potential use
  - Growing efficiency of wind turbines.
  - 75% of the world's usage is in Western Europe:
    - Provided electricity to some 28 million Europeans in 2002.
    - Germany, Denmark (18%) and the Netherlands.
  - New windfarms are located at sea along the coast:
    - The wind blows harder and more steadily.
    - Does not consume valuable land.
    - No protests against wind parks marring the landscape.
  - United States:
    - The USA could generate 25% of its energy needs from wind power by installing wind farms on just 1.5% of the land.
    - North Dakota, Kansas, and Texas have enough harnessable wind energy to meet electricity needs for the whole country.

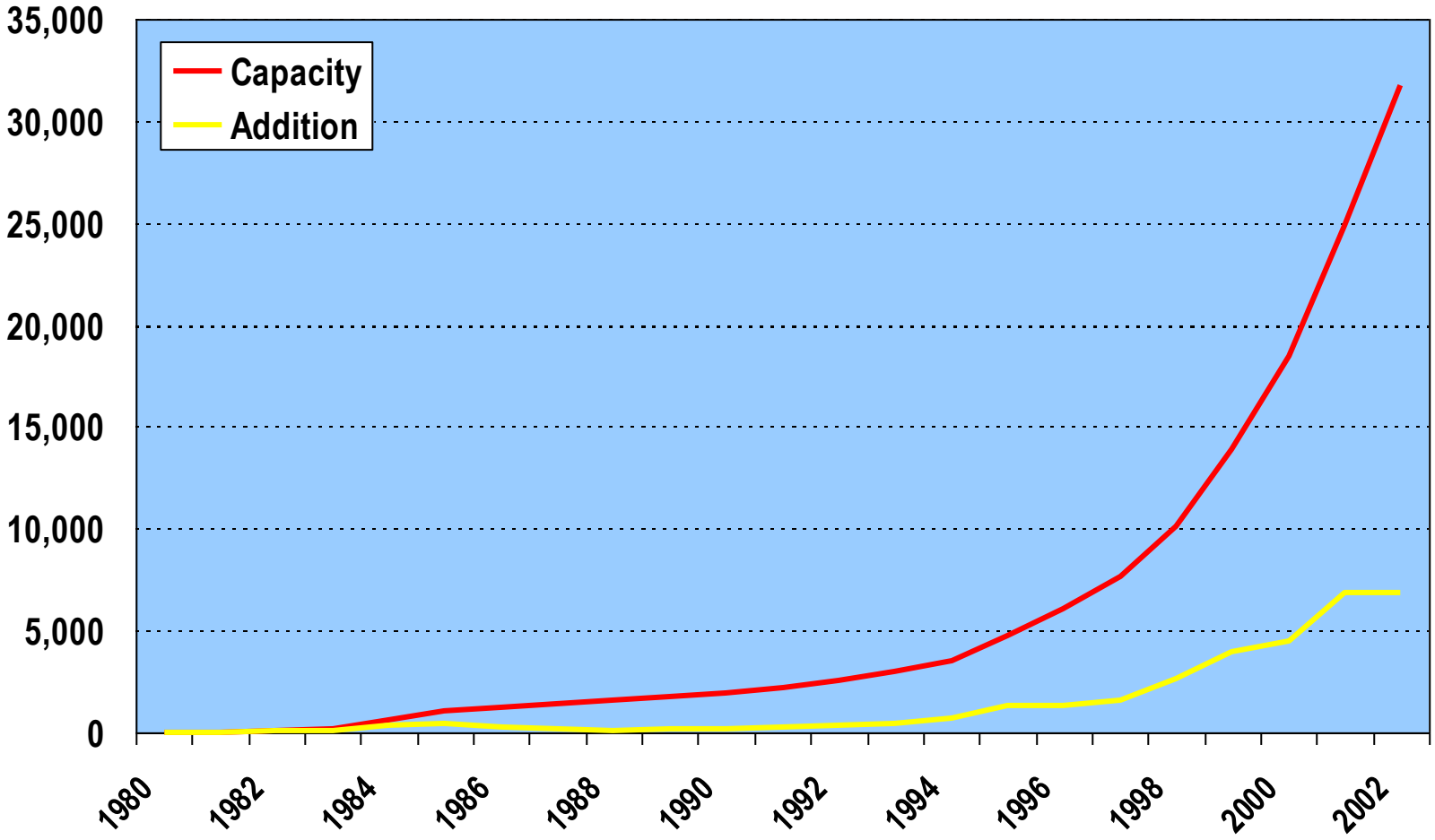


4 Wind Power

- Farms are a good place to implement wind mills:
  - A quarter of a acre can earn about $2,000 a year in royalties from wind electricity generation.
  - That same quarter of an acre can only generate $100 worth or corn.
  - Farmland could simultaneously be used for agriculture and energy generation.
  - Wind energy could be used to produce hydrogen.
- Limitations
  - Extensive infrastructure and land requirements.
    - 1980: 40 cents per kwh.
    - 2001: 3-4 cents per kwh.
  - Less reliable than other sources of energy.
  - Inexhaustible energy source that can supply both electricity and fuel.

4

World Wind Energy Generating Capacity, 1980-2002 (in megawatts)

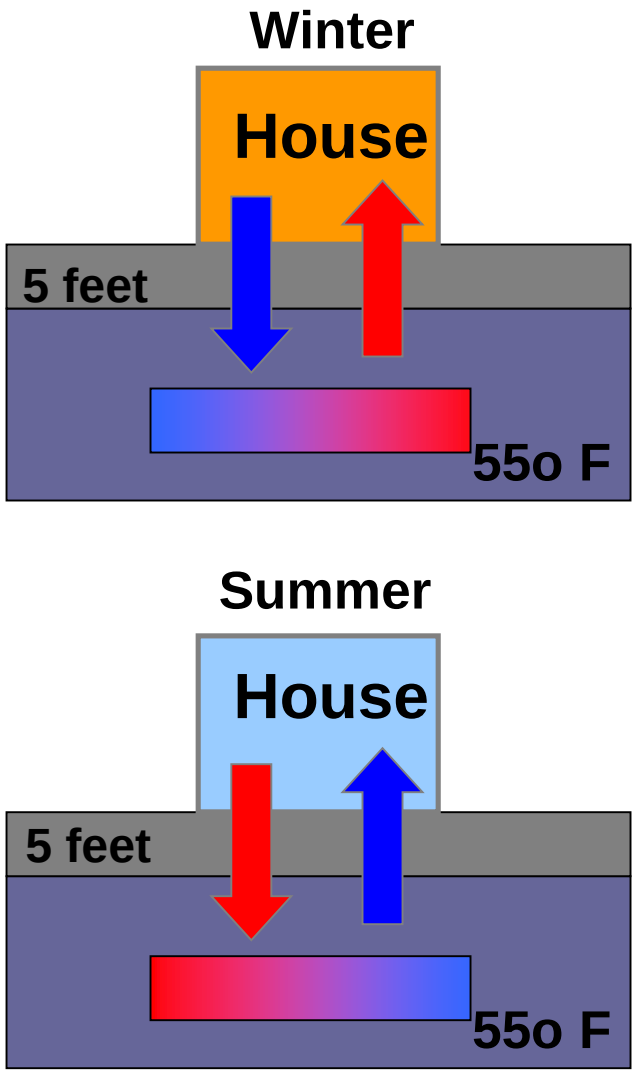


5

Geothermal Energy

- Hydrogeothermal
  - 2-4 miles below the earth's surface, rock temperature well above boiling point.
  - Closely associated with tectonic activity.
  - Fracturing the rocks, introducing cold water, and recovering the resulting hot water or steam which could power turbines and produce electricity.
  - Areas where the natural heat of the earth’s interior is much closer to the surface and can be more readily tapped.

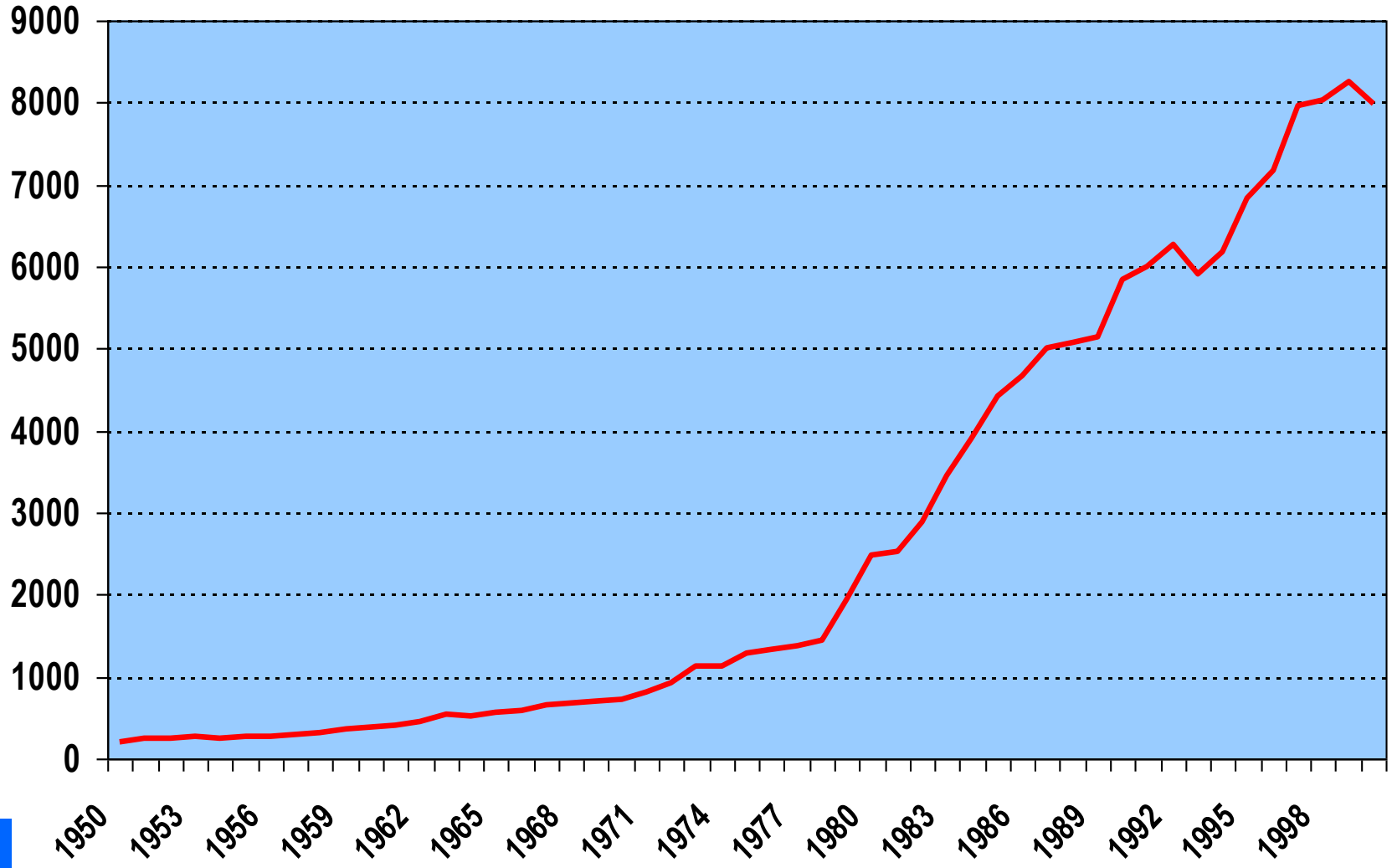
5 Geothermal Energy



- Geothermal heat pumps
  - Promising alternative to heating/cooling systems.
  - Ground below the frost line (about 5 feet) is kept around 55oF year-round.
  - During winter:
    - The ground is warmer than the outside.
    - Heat can be pumped from the ground to the house.
  - During summer:
    - The ground is cooler than the outside.
    - Heat can be pumped from the house to the ground.

5

World Geothermal Power, 1950-2000 (in megawatts)

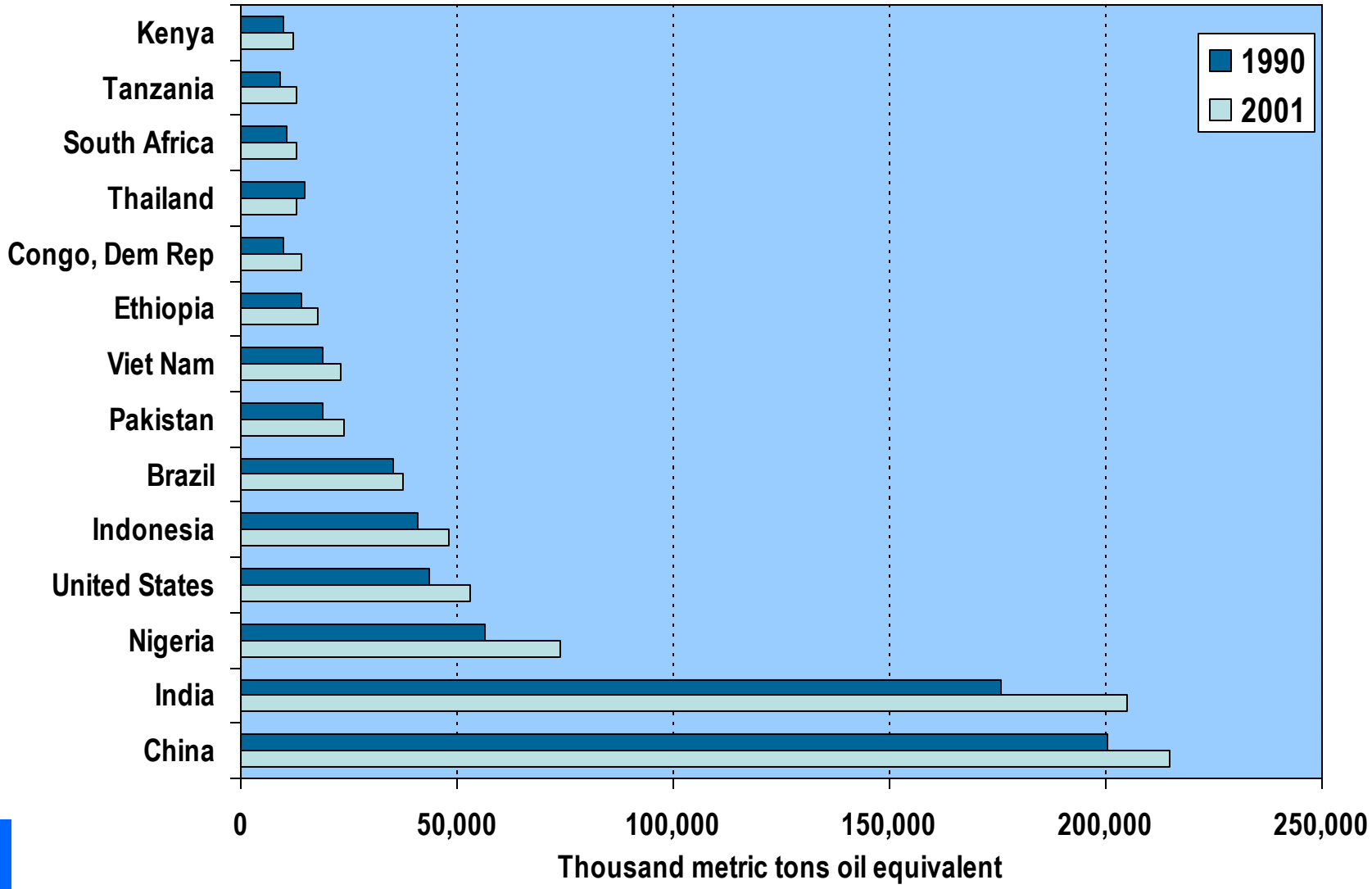


6

Biomass

- Nature
  - Biomass energy involves the growing of crops for fuel rather than for food.
  - Crops can be burned directly to release heat or be converted to useable fuels such methane, ethanol, or hydrogen.
  - Has been around for many millennia.
  - Not been used as a large-scale energy source:
    - 14% of all energy used comes from biomass fuels.
    - 65% of all wood harvested is burned as a fuel.
    - 2.4 billion people rely on primitive biomass for cooking and heating.
  - Important only in developing countries.
    - Asia and Africa: 75% of wood fuels use.
    - US: 5% comes from biomass sources.

Energy Consumption, Solid biomass (includes fuelwood)



6

Biomass

- Biofuels
  - Fuel derived from organic matter.
  - Development of biomass conversion technologies:
    - Alcohols and methane the most useful.
    - Plant materials like starch or sugar from cane.
    - Waste materials like plant stalks composed of cellulose.
- Potential and drawbacks
  - Some 20% of our energy needs could be met by biofuels without seriously compromising food supplies.
  - Competing with other agricultural products for land.

6

Biomass

- Could contribute to reducing carbon emissions while providing a cheap source of renewable energy:
  - Burning biofuels does create carbon emissions.
  - The burned biomass is that which removed carbon from the atmosphere through photosynthesis.
  - Does not represent a real increase in atmospheric carbon.
- Genetic engineering:
  - Create plants that more efficiently capture solar energy.
  - Increasing leaf size and altering leaf orientation with regard to the sun.
- Conversion technology research:
  - Seeking to enhance the efficiency rate of converting biomass into energy.
  - From the 20-25% range up to 35-45% range.
  - Would render it more cost-competitive with traditional fuels.