Lecture 7

Energy Economics: Part I (demand)

- Introduction

Defining energy economics

- Energy economics, or the economics of energy, is a relatively new branch of economics that studies energy resources and their allocation among the different sectors to cover the needs of the society. It does so, applying methods and tools from a number of economic fields, primarily from Econometrics, Environmental and Resource economics, Finance, Industrial organization, Micro and Macroeconomics.

- Given the complexity of the energy industries and their importance, the study of the energy problems requires a truly interdisciplinary approach, part of which is economics.

Defining energy economics

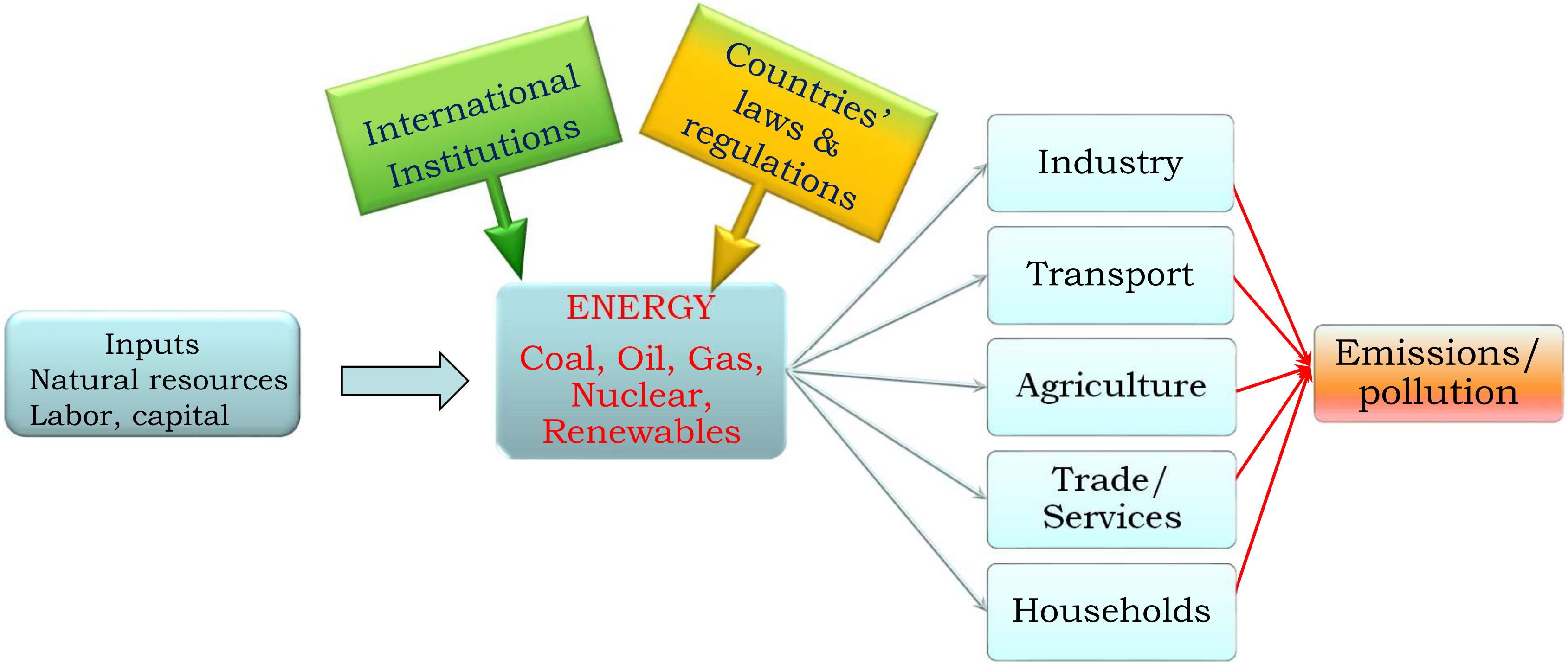
- Energy economics

Microeconomic →
- supply (early focus on expanding supply)
- demand (recent concerns lead to demand reduction)
- pricing, market liberalization (private or state owned and to what extent? Can the market secure energy supply?)
- environmental concerns (energy sector as the main contributor to major problems at the local (PM10), regional (SO_2) and global (CO_2) level)

The present course is focusing mainly on the microeconomic aspects

Macroeconomic →
- investment
- financing
- economic linkages wtr economy
- global economic conditions

Defining energy economics



Microeconomic decisions		
Prices, costs	Market structure	Firms' decisions

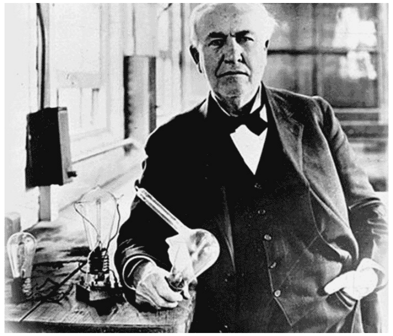
Macroeconomic developments		
Demand (GDP, growth rates)	Investment (interest rate inflation)	technologies infrastructure

The various aspects of energy economics

- Energy sector

Each major phase of economic growth has been closely tied to the availability of more efficient, scalable, and higher-density energy sources, along with the technologies that enable their widespread use.

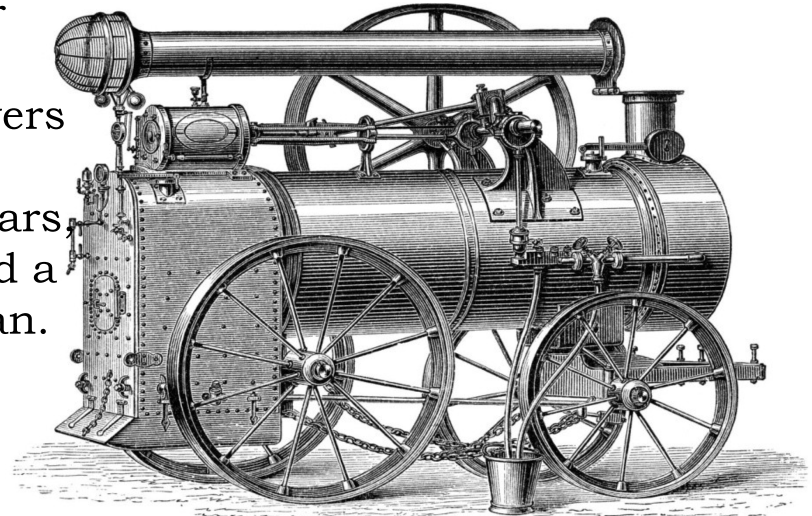
Short history



- Before the industrial revolution

- For heat: the sun, burned wood, straw, and dried dung. For transportation: horses on the ground, wind in our sails. For work: animals did jobs that we couldn't do, water and wind drove the simple machines that ground our grain and pumped our water (form ancient Alexandria we have steam machines).

- Thomas Newcomen and James Watt in the mid 1700s gave birth to the modern steam engine, opening up a world of possibility. A single steam engine, powered by coal dug from the mines of England and Appalachia, could do the work of dozens of horses. In 1880, coal powered a steam engine attached to the world's first electric generator. Thomas Edison's plant in New York City provided the first electric light to Wall Street financiers and the New York Times. Only a year later, the world's first hydroelectric plant went on-line in Appleton, Wisconsin. Fast-flowing rivers that had turned wheels to grind corn were now grinding out electricity instead. Within a few years, Henry Ford hired his friend Edison to help build a small hydro plant to power his home in Michigan.



Short history

- Before the industrial revolution
- By the late 1800s, a new form of fuel was catching on: petroleum. For years it had been a nuisance, contaminating wells for drinking water. Initially sold by hucksters as medicine, oil became a valuable commodity for lighting as the whale oil industry declined. By the turn of the century, oil, processed into gasoline, was firing internal combustion engines.

Horseless carriages were a rich man's toy until Henry Ford perfected the assembly-line method of mass production for his Model T. Interestingly enough, electric cars were preferred by rich woman. Quiet and clean, electric cars started without a starter crank, an exertion that would have overtaxed the gentle ladies of the day. When gas cars adopted electric starters, their superior range quickly drove the electrics out of the market.

- Another key invention of the era was the safety bicycle, which had two wheels of the same size, putting the rider much lower to the ground than earlier bicycles. The pneumatic tire (J. Dunlop) made cycling more comfortable and bicycles became a national obsession in the 1890s.

Short history

- The industrial revolution
- With the low-cost automobile and the spread of electricity, our society's energy use changed forever. Power plants became larger and larger, until we had massive coal plants and hydroelectric dams. Power lines extended hundreds of miles between cities, bringing electricity to rural areas during the Great Depression. The cheap car made suburbs possible, which in turn made cheap cars necessary, feeding the cycle

- Energy use grew quickly, doubling every 10 years. The cost of energy production was declining steadily, and the efficient use of energy was simply not a concern.
- After World War II unleashed nuclear power, the government looked for a home for "the peaceful atom." They found it in electricity production. Over 200 nuclear power plants were planned across USA.

- Gasoline use grew unchecked as well. Cars grew larger and heavier throughout the 1950s and 1960s. By 1970, the average mileage of an American car was only 13.5 miles per gallon, and a gallon of gas cost less than a quarter.

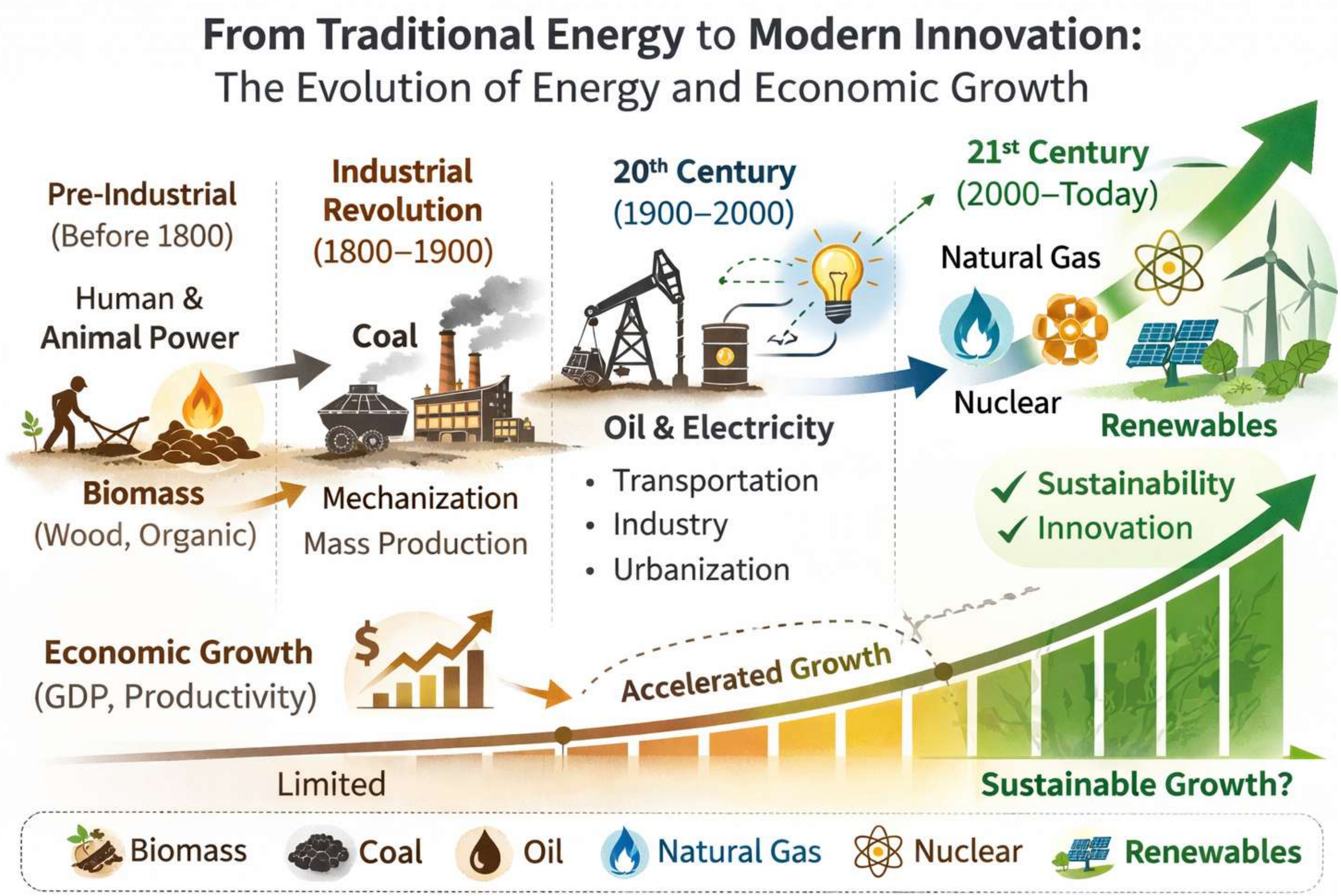
Short history

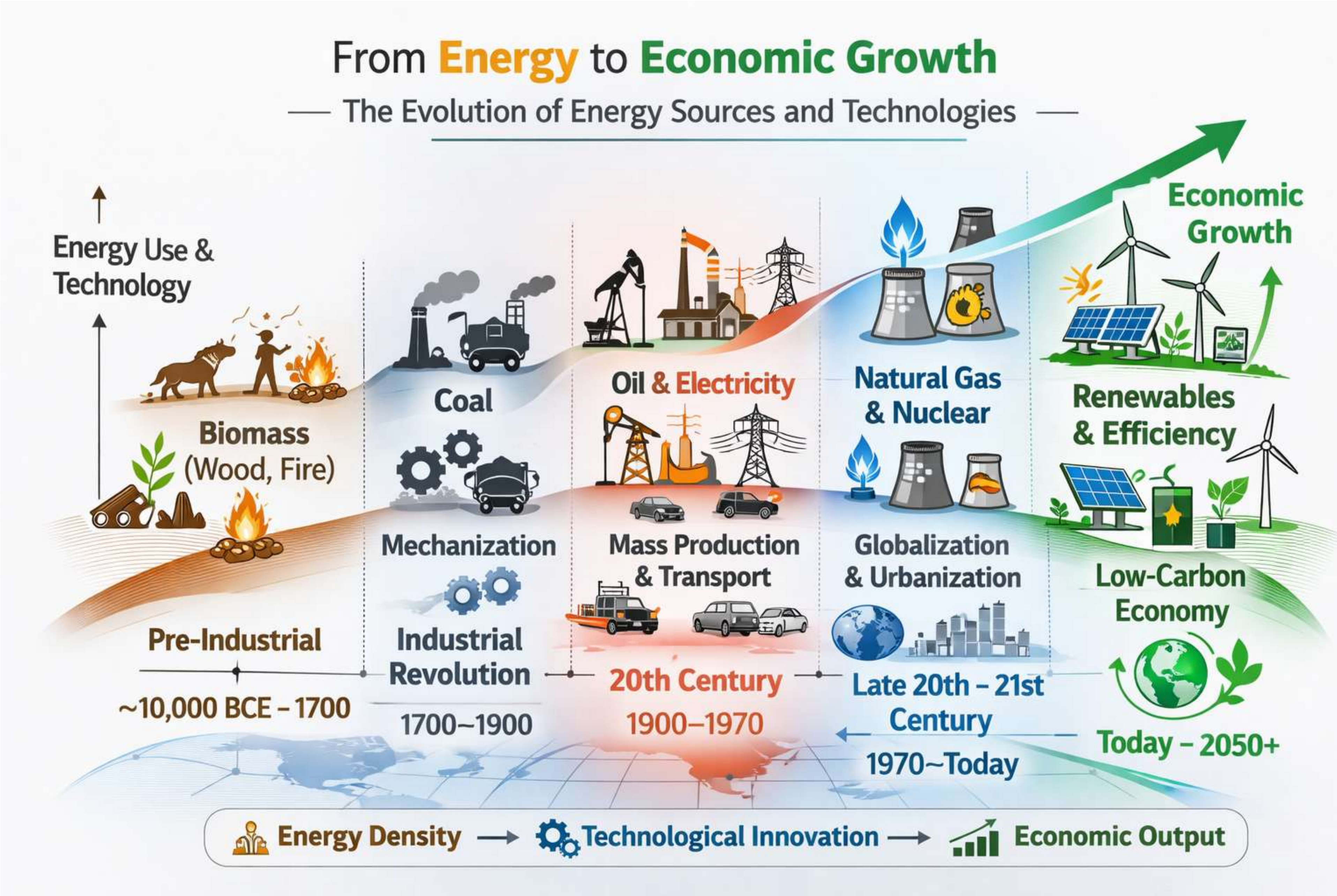
- The energy crisis

- In 1973, American support for Israel in the Arab-Israeli War led the Arab oil-producing nations to stop supplying oil to the United States and other western nations. Overnight, oil prices tripled. In 1979, when the Shah of Iran was forced out by the Ayatollah Khomeini, oil prices leaped again, rising 150 percent in a matter of weeks. Motorists lined up at gas stations to buy gasoline, and President Carter went on television to declare that energy conservation was "the moral equivalent of war." By 1980, the average price of a barrel of oil was almost $45.

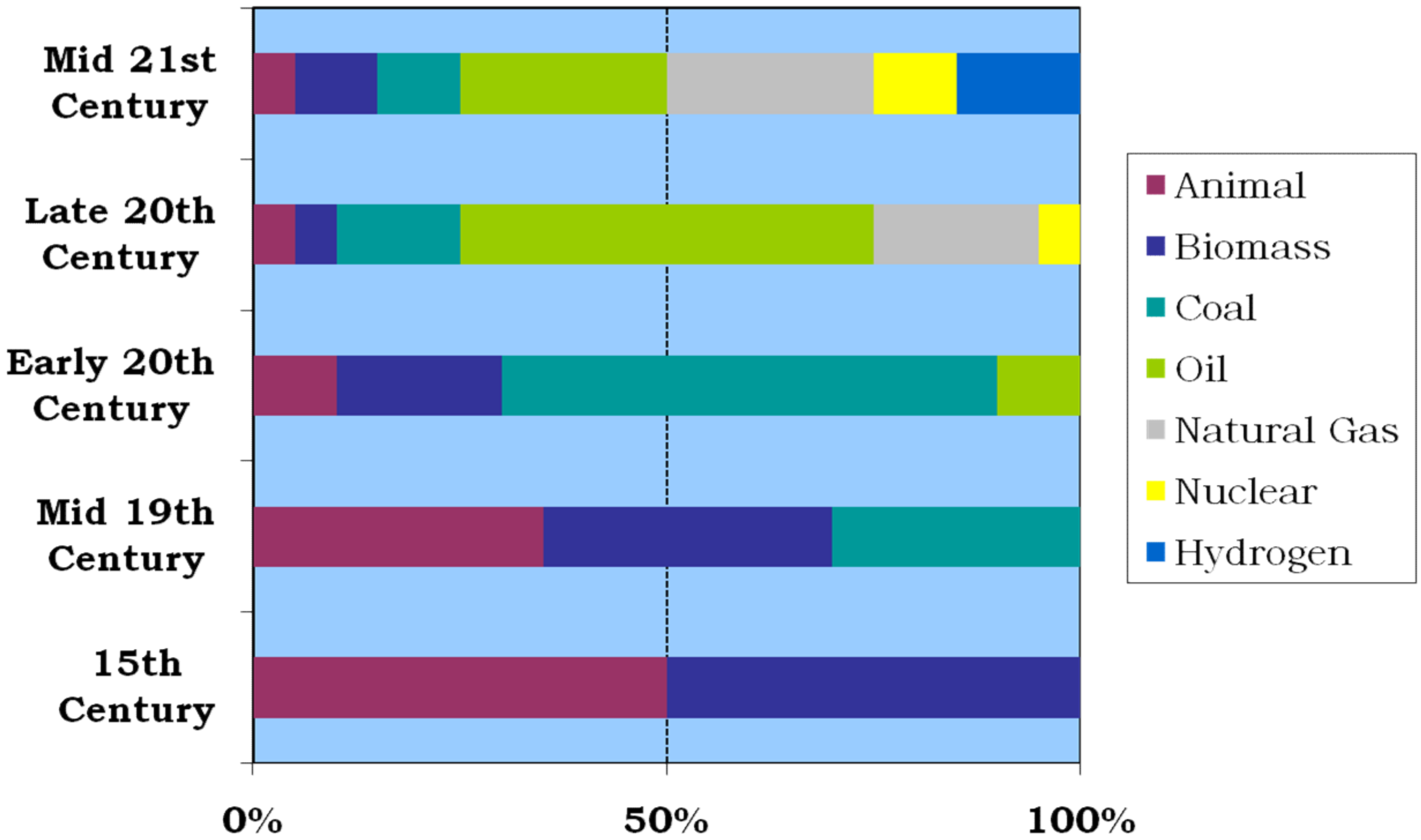
- Only three months after the fall of the Shah, the Three Mile Island nuclear power plant suffered a partial meltdown after a series of mechanical failures and operator mistakes. After years of hearing that a nuclear accident could never happen, the American public was shocked. The accident added to the sense of crisis.

- But the accident at Three Mile Island was only the latest in a long line of problems plaguing the nuclear industry. New plant orders had already ceased, because of multibillion-dollar cost overruns, high inflation, and a slowdown in electricity demand growth due to the early effects of energy conservation. No new plants were ordered after 1978, and all those ordered since 1973 have been canceled.


From Traditional Energy to Modern Innovation:
The Evolution of Energy and Economic Growth
Pre-Industrial
(Before 1800)
Human &
Animal Power
Biomass
(Wood, Organic)
Industrial
Revolution
(1800–1900)
Coal
Mechanization
Mass Production
20th Century
(1900–2000)
Oil & Electricity
• Transportation
• Industry
• Urbanization
21st Century
(2000–Today)
Natural Gas
Nuclear
Renewables
✓ Sustainability
✓ Innovation
Economic Growth
(GDP, Productivity)
Accelerated Growth
Limited
Sustainable Growth?
Biomass
Coal
Oil
Natural Gas
Nuclear
Renewables


From Energy to Economic Growth
The Evolution of Energy Sources and Technologies
Energy Use & Technology
Economic Growth
Biomass (Wood, Fire)
Coal
Oil & Electricity
Natural Gas & Nuclear
Renewables & Efficiency
Mechanization
Mass Production & Transport
Globalization & Urbanization
Low-Carbon Economy
Pre-Industrial
~10,000 BCE – 1700
Industrial Revolution
1700~1900
20th Century
1900–1970
Late 20th – 21st Century
1970~Today
Today – 2050+
Energy Density → Technological Innovation → Economic Output

Evolution of Energy Sources



Sources of Energy

Energy

Non-Renewable

Chemical
- Fossil fuels (Combustion)

Nuclear
- Uranium (Fission of atoms)

Renewable

Chemical
- Muscular (Oxidization)

Nuclear
- Geothermal (Conversion)
- Fusion (Fusion of hydrogen)

Gravity
- Tidal, hydraulic (Kinetic)

Indirect Solar
- Biomass (Photosynthesis)
- Wind (Pressure differences)

Direct Solar
- Photovoltaic cell (Conversion)

The sun and energy

The energy of the **sun** is the original source of most of the energy found on earth.

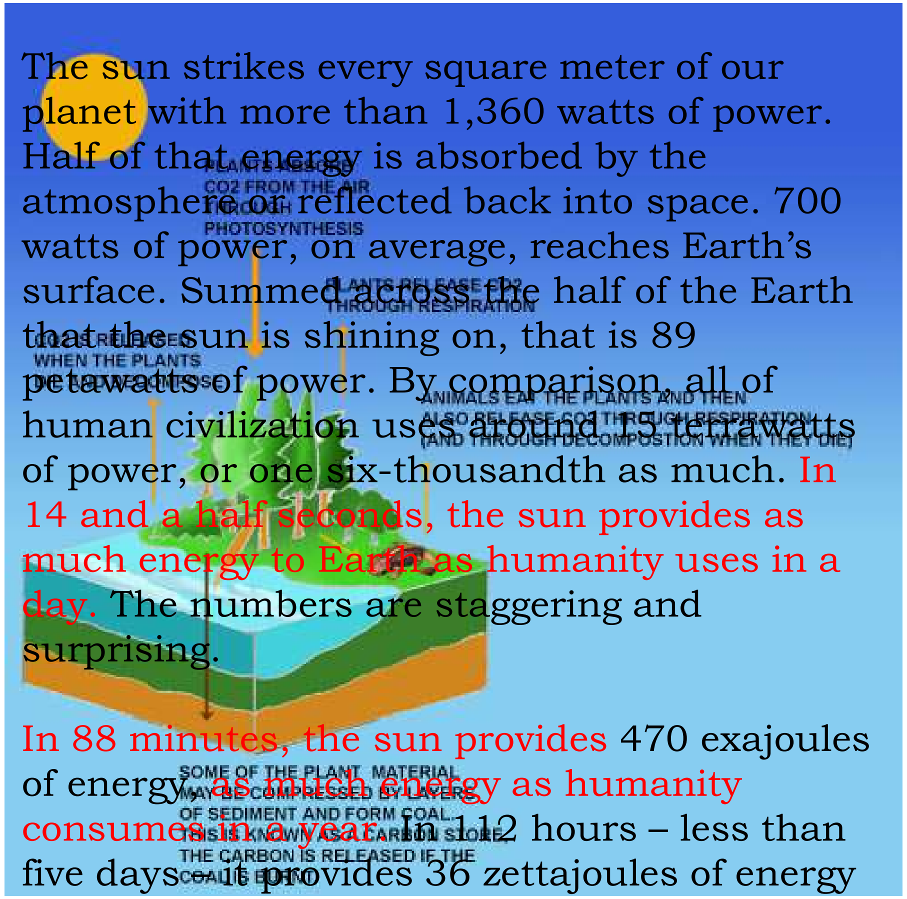
We get solar heat energy from the sun, and sunlight can also be used to produce electricity from **solar** (photovoltaic) cells. The sun heats the earth's surface and the air above it, causing **wind**.

Water evaporated by the sun forms clouds and rain to give us flowing streams and rivers. Both wind and flowing water (**hydropower**) are sources of energy.

These kinds of energy are all around us all the time, they are produced quickly, and replace themselves constantly as we use them. For this reason we say they are **renewable.**

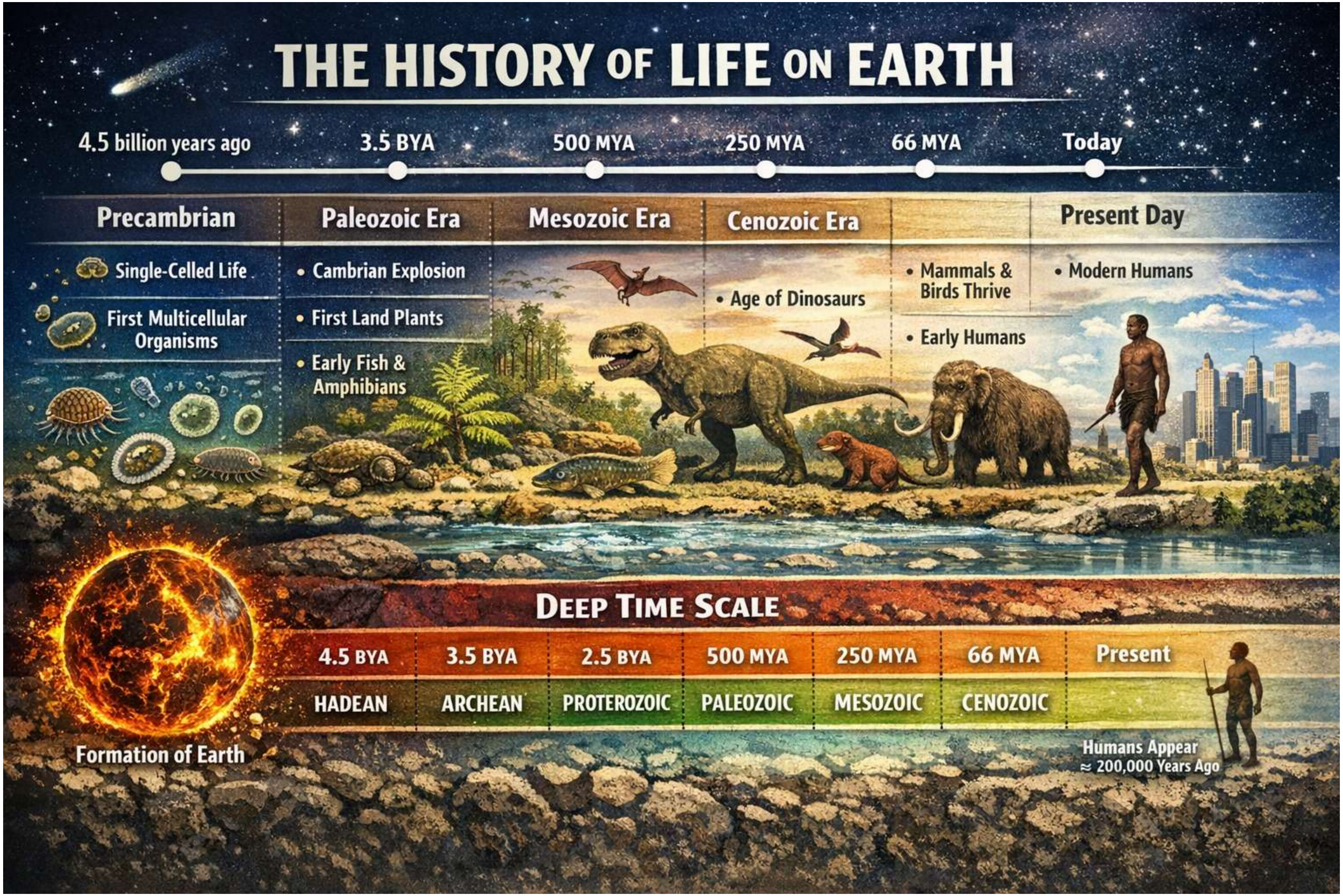
The sun's energy can also be stored. Plants store energy from the sun as they grow. Fruits, vegetables, and wood from trees, for example, all contain stored solar energy. We call it **biomass** energy, from "bio" for "life" or "living." These kinds of energy are also renewable, but of course it takes longer to grow a plant or a tree than it does to get heat directly from sunlight.

When energy is stored in a material, we call that material fuel. Food and wood are biomass fuels. When you have become old, old biomass that has become concentrated, you have what we call "**fossil fuel**.“ Given the time they require to form, they are **non-renewable.**



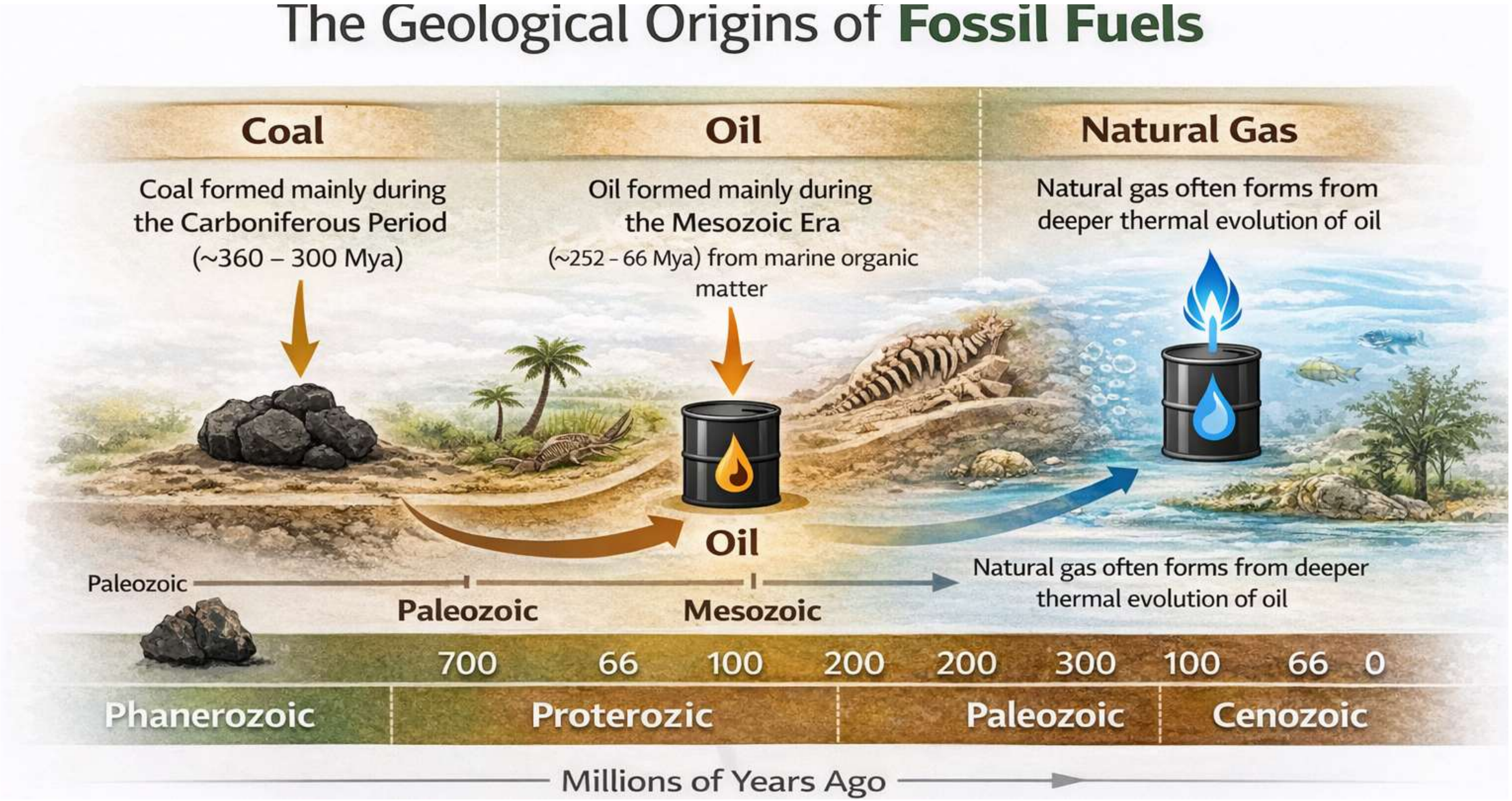
The sun strikes every square meter of our planet with more than 1,360 watts of power. Half of that energy is absorbed by the atmosphere or reflected back into space. 700 watts of power, on average, reaches Earth’s surface. Summed across the half of the Earth that the sun is shining on, that is 89 petawatts of power. By comparison, all of human civilization uses around 15 terrawatts of power, or one six-thousandth as much. In 14 and a half seconds, the sun provides as much energy to Earth as humanity uses in a day. The numbers are staggering and surprising.

In 88 minutes, the sun provides 470 exajoules of energy, as much energy as humanity consumes in a year. In 112 hours – less than five days – it provides 36 zettajoules of energy – as much energy as is contained in all proven reserves of oil, coal, and natural gas on this planet.



The geological timeline

Source: The Norwegian Petroleum Directorate



The fossil fuels we use today were formed over very long geological periods, mainly during specific eras of Earth's history:

❀ Coal formed primarily during the Carboniferous Period (about 359–299 million years ago) This was a time of vast swamp forests; dead plant material accumulated and, under pressure and heat, transformed into coal

🛢 Oil (Petroleum) mostly formed during the Mesozoic Era (about 252–66 million years ago). Originates from microscopic marine organisms (plankton) buried in ocean sediments and transformed over millions of years

💧 Natural Gas often formed alongside oil, during the same Mesozoic Era, but can also form later. Results from deeper burial and higher temperatures that further break down organic matter

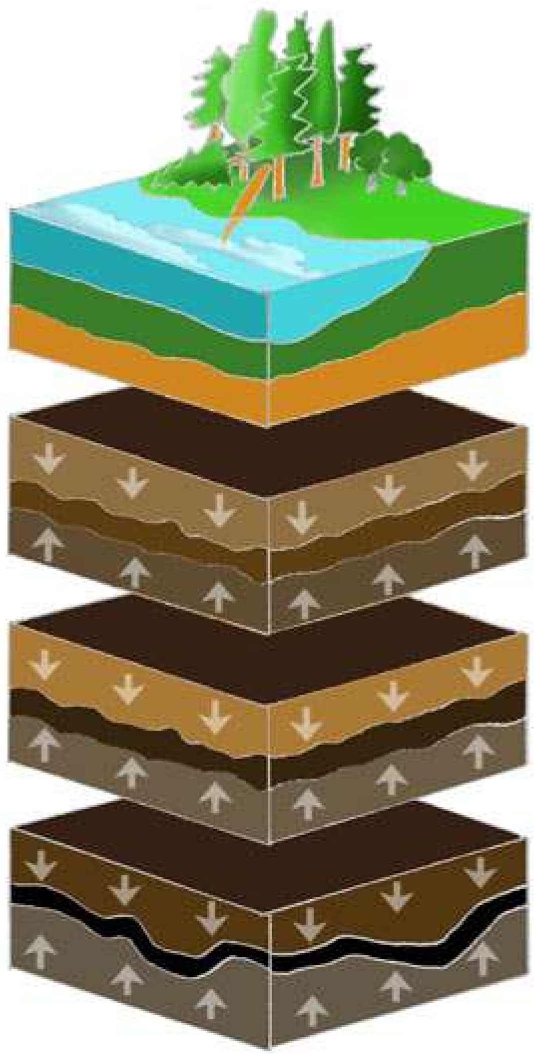
Fossil fuels formation (coal)

Coal was formed from the remains of ferns, trees, and grasses that grew in great swamps **345 million years** ago. These remains formed layers as they sank under the water of the swamps. The plant material partially decayed as these layers formed beds of peat, a **soft brown coal**: substance that is up to 30% carbon. Peat is the earliest stage of coal formation.

Shallow seas later covered the swamps and slowly deposited layers of sand and mud over the peat. These sediments exerted pressure on the peat over thousands of years. Slowly chemical changes took place transforming it to **lignite or brown coal**, which is about 40% carbon.

Millions of years later, increasing pressure and heat changed the lignite into **bituminous or soft coal** (about 66% carbon) and finally into **anthracite or hard coal** (over 90% carbon).

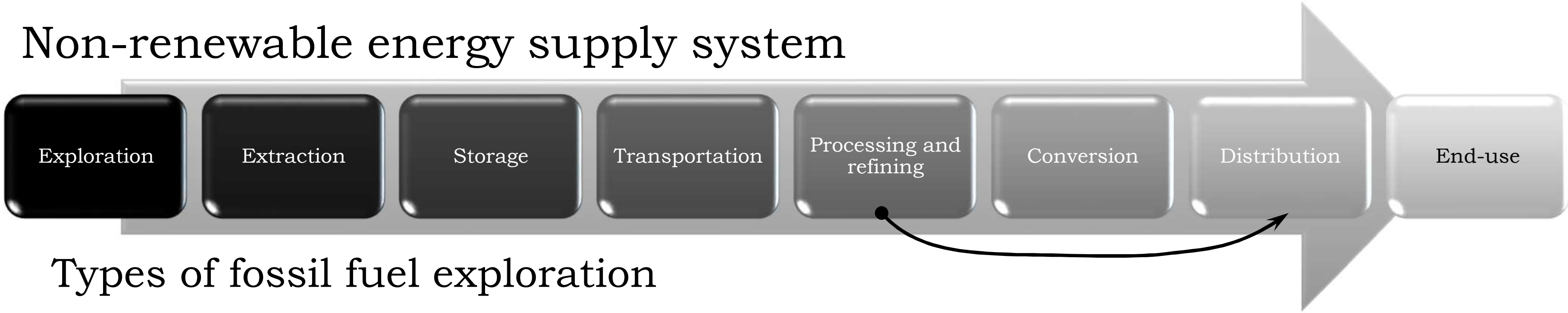
See: vimeo.com/19478872



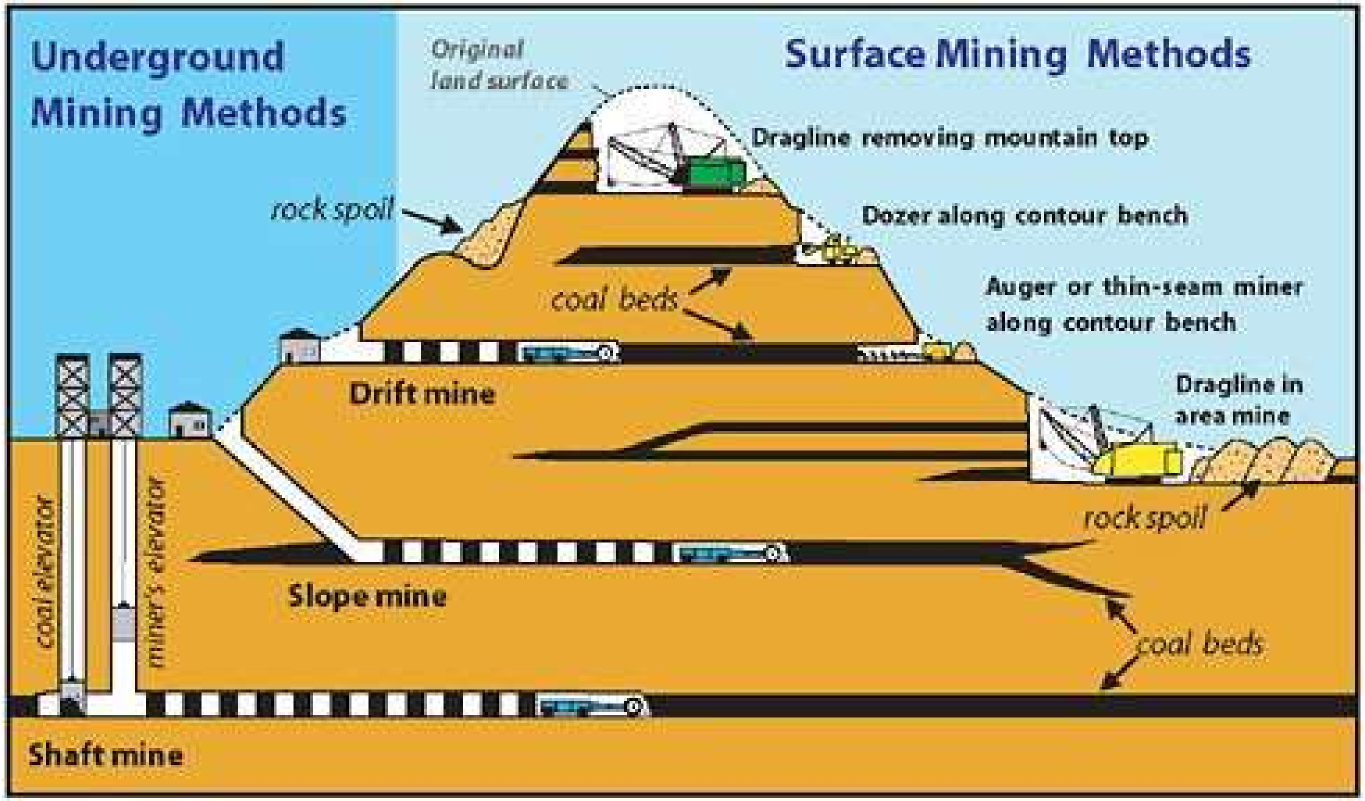
Conditions:
Saturated, anaerobic
High pressure and temperature

Fossil fuels supply stages

- Non-renewable energy supply system



Types of fossil fuel exploration



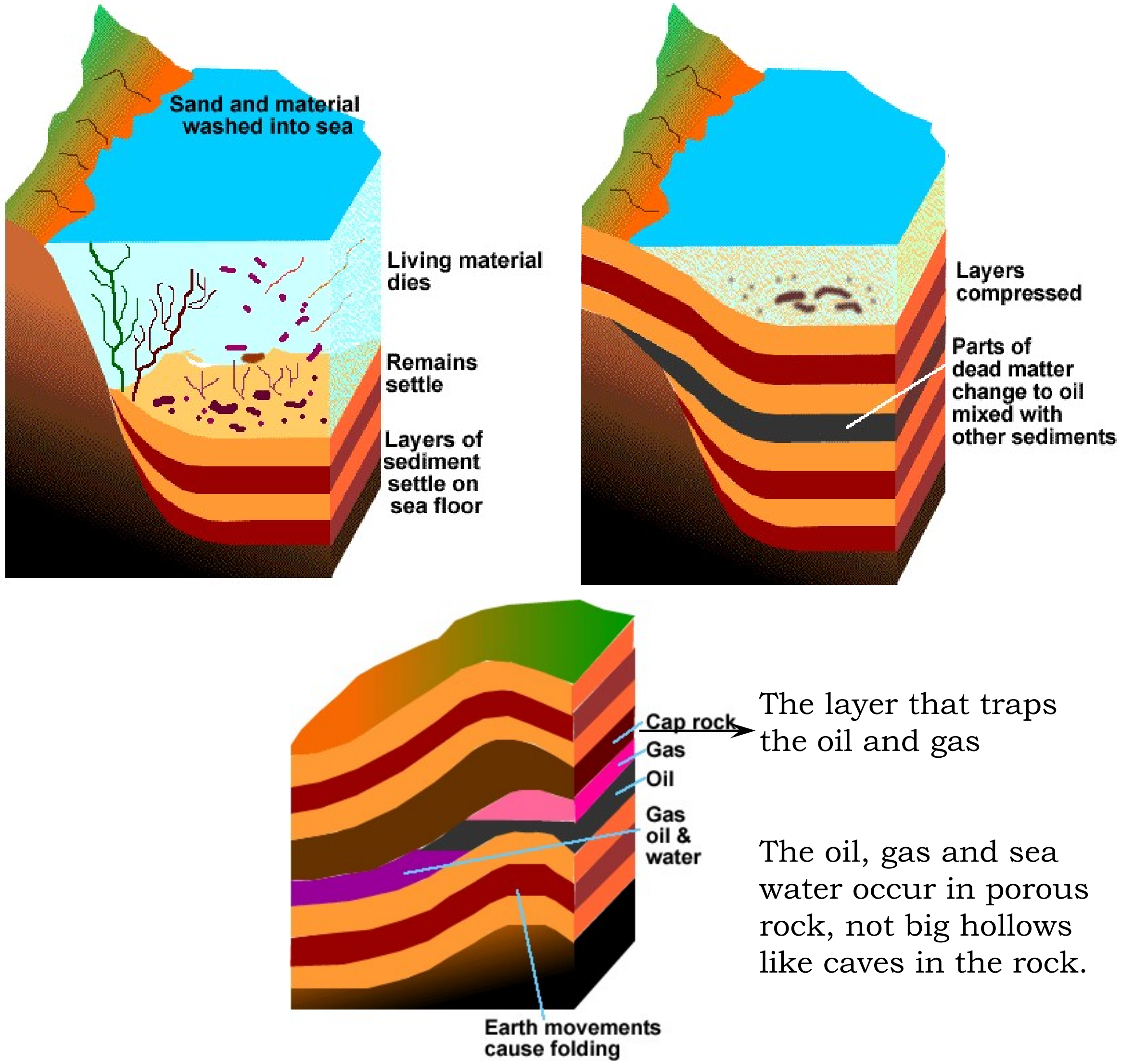
Fossil fuels formation (oil, natural gas)

Oil and natural gas are also found in beds of sedimentary rock. The sediments were deposited by shallow seas millions of years ago.

The remains of plants and animals living in the seas settled to the bottom and were buried under layers of sediment.

These layers were subjected to heat and pressure over millions of years.

The sediments were transformed into beds of rock, and the plant and animal remains underwent slow chemical change and formed oil and natural gas.



Fossil fuels formation

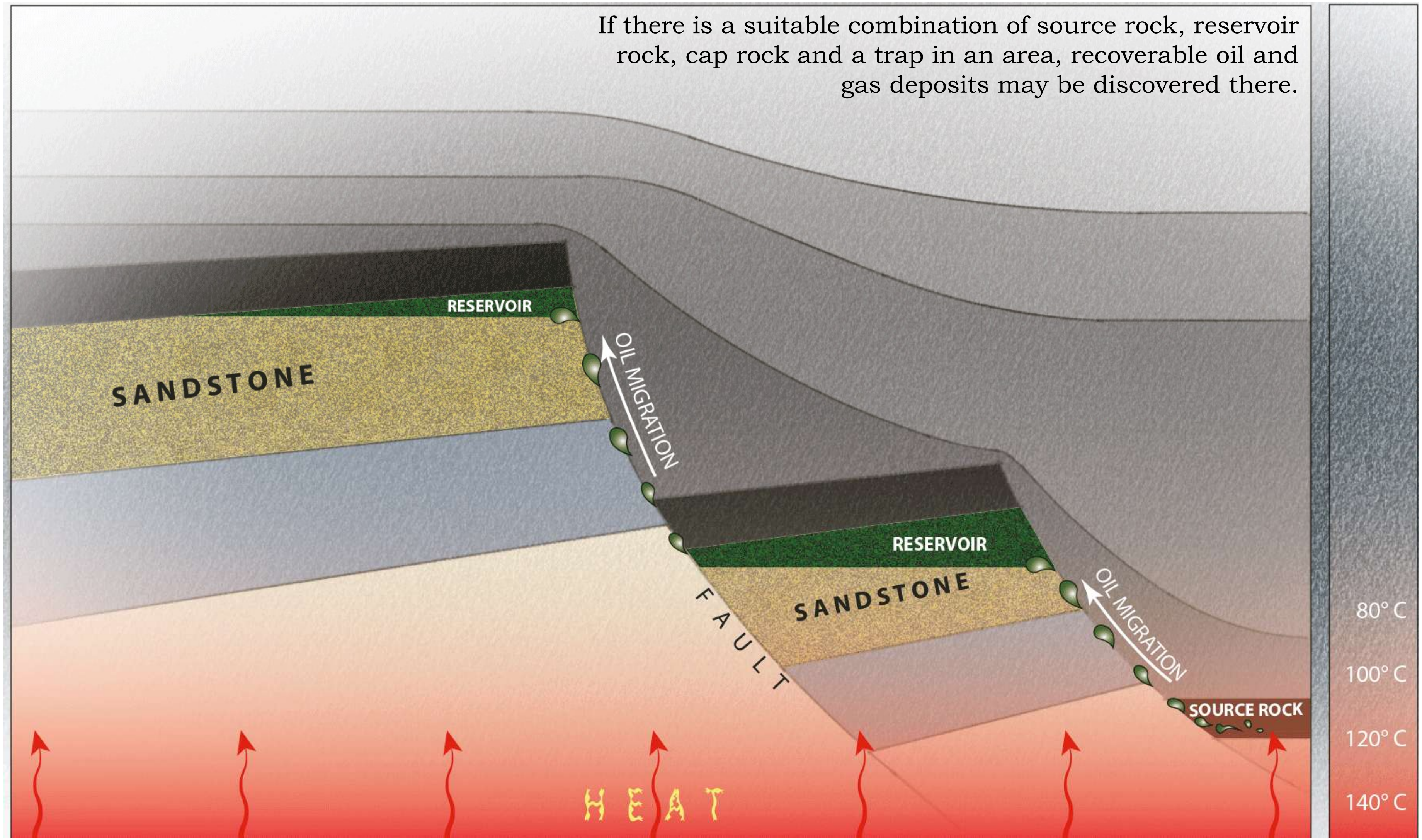
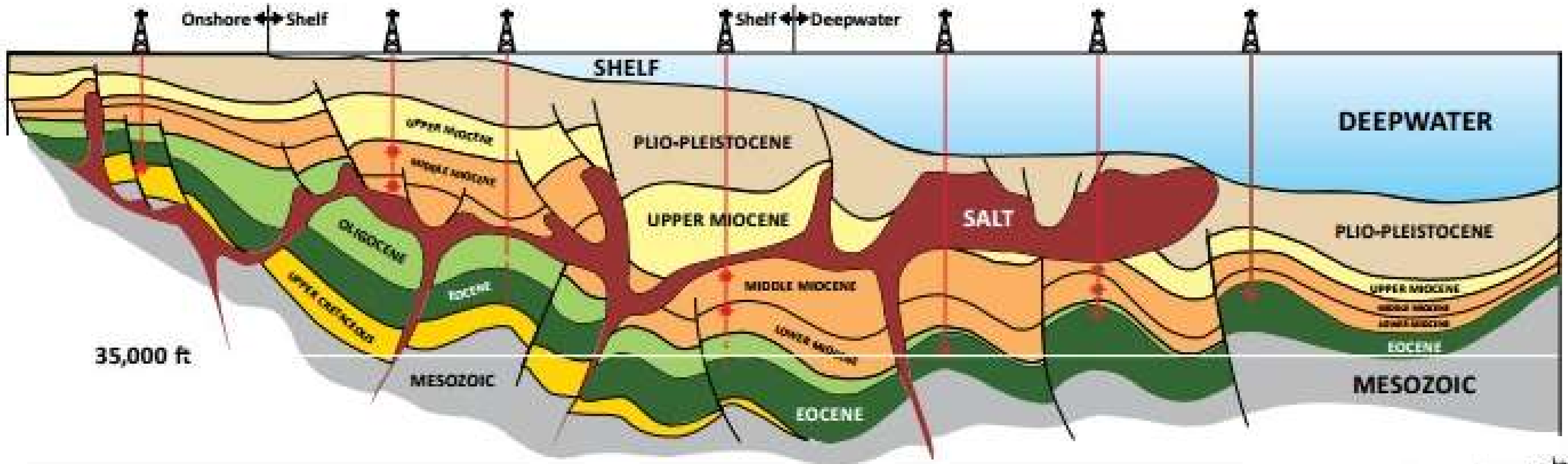
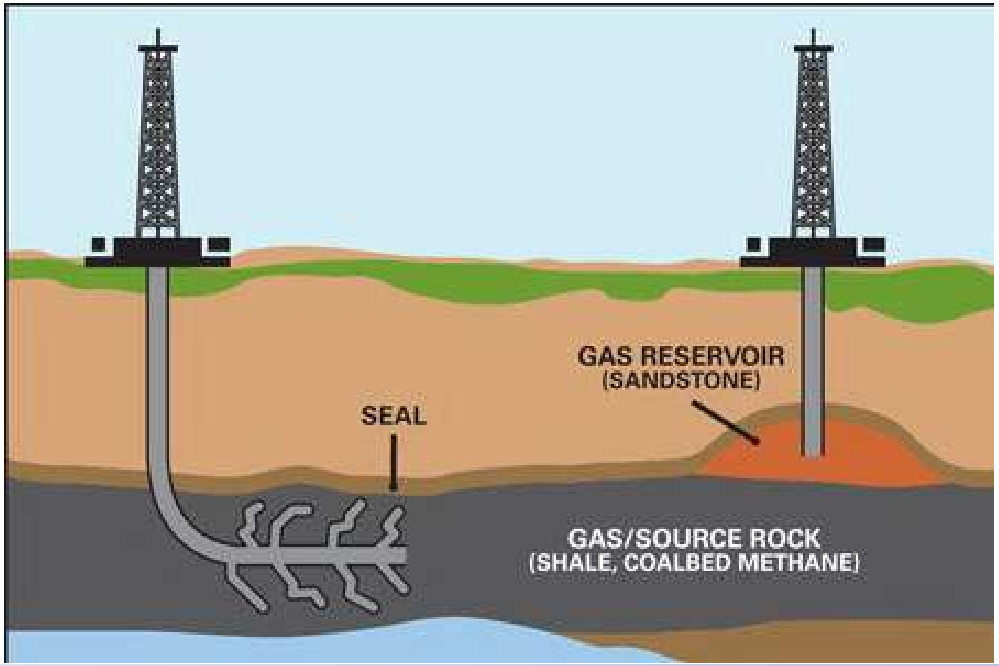


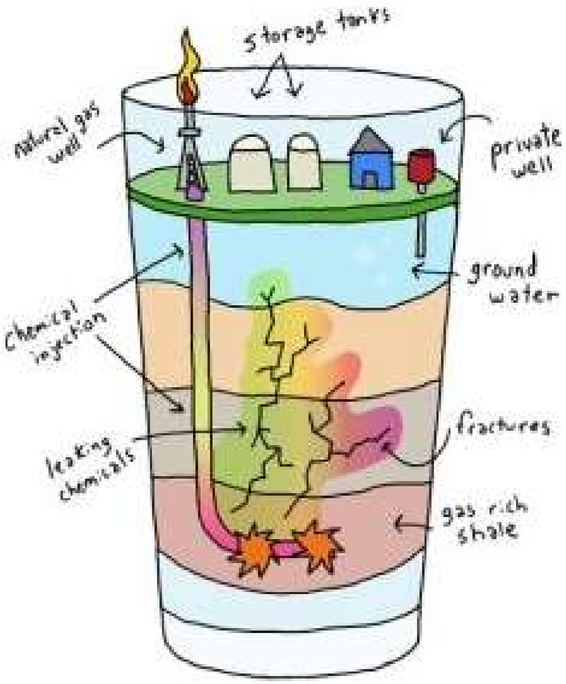
Illustration of how oil and gas reservoirs are formed

Source: The Norwegian Petroleum Directorate

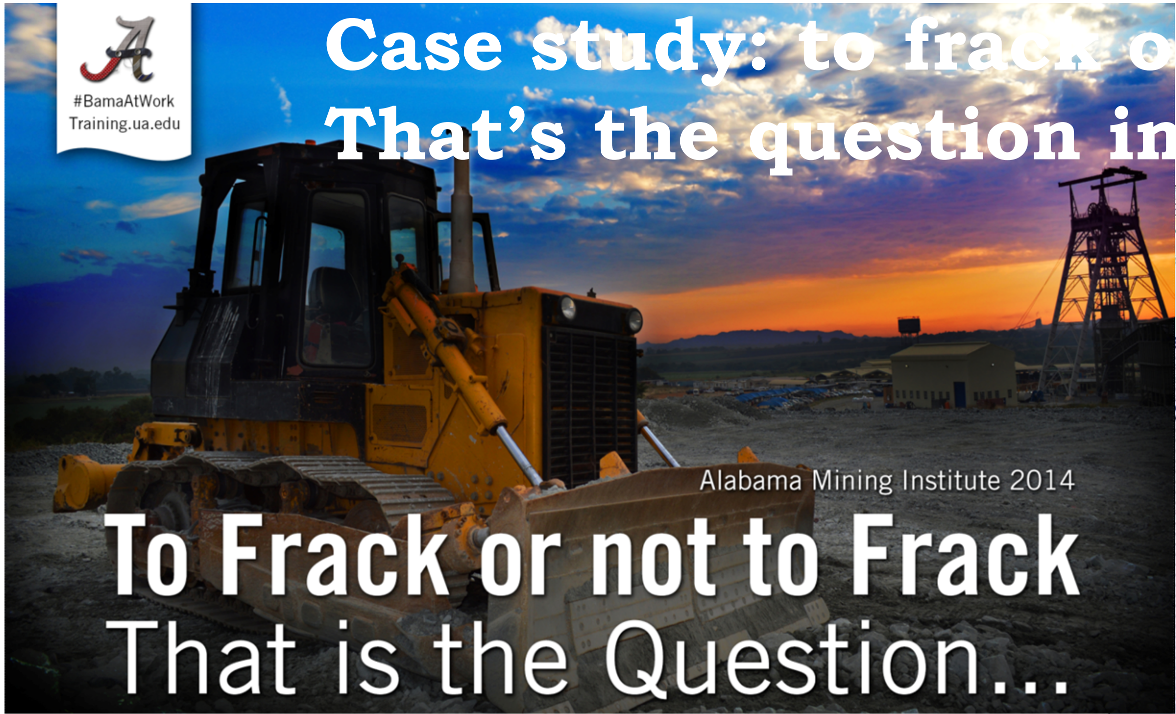
Fossil fuels supply stages

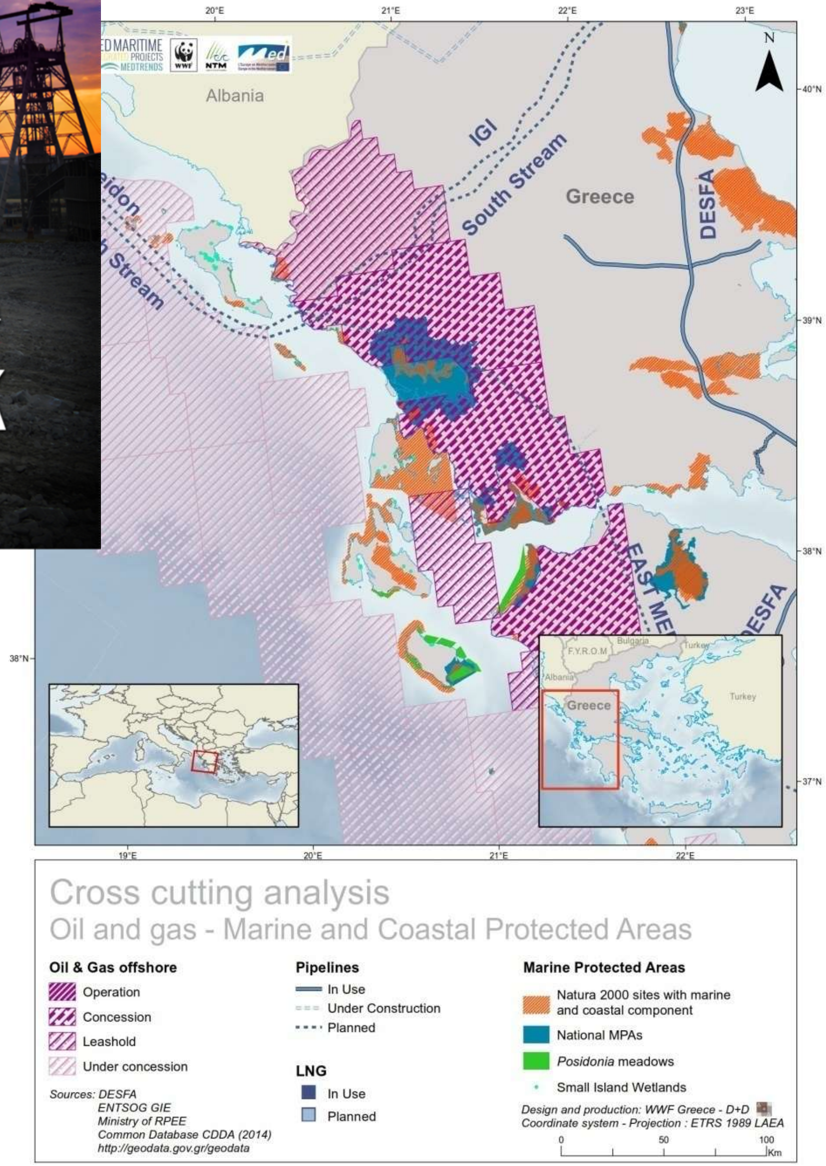






Case study: to frack or not to frack? That's the question in Ioannina

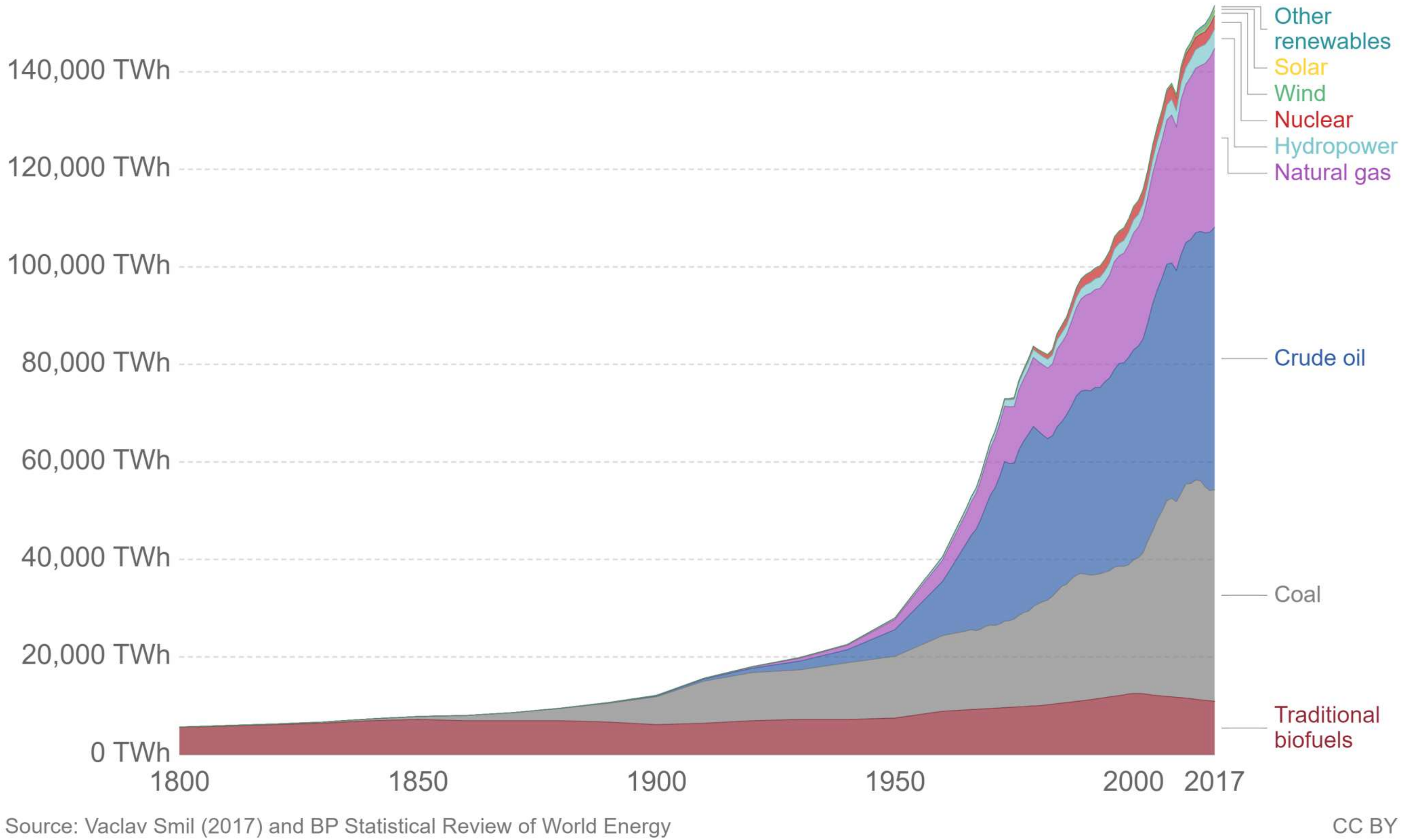




Ioannina attracts special attention due to the possibility of fracking for shale gas and the fact that the concession area includes ecologically significant areas. The annual lease price has been set at 10 EUR/ km^2, 15 EUR / km2 and 20 EUR/ km^2 for each of the three research phases, which include seismic tests and exploratory drillings. Fracking for shale gas is not forbidden by Greek law within protected areas, whereas in 2012 the Institute for Geological and Mineral Exploration indicated the presence of significant hydrocarbon shale reserves in Ioannina.

https://www.wwf.gr/crisis-watch/crisis-watch/biodiversity-natural-resources/biodiversity/hydrocarbon-frenzy-in-greece

Some data



Global primary energy consumption in TWh/year

https://ourworldindata.org/energy-production-and-changing-energy-sources

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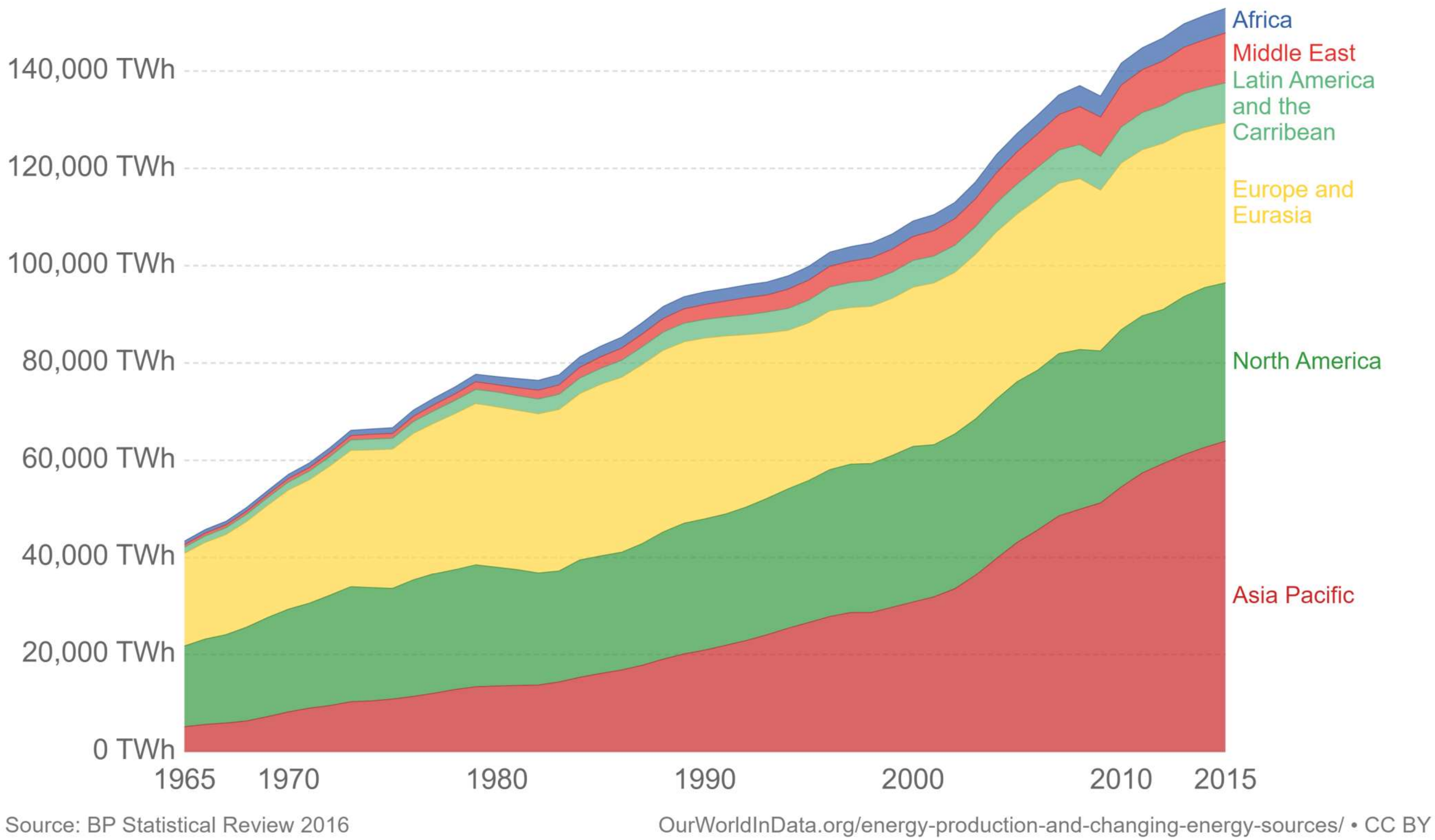

Global primary energy consumption by region

https://ourworldindata.org/energy-production-and-changing-energy-sources

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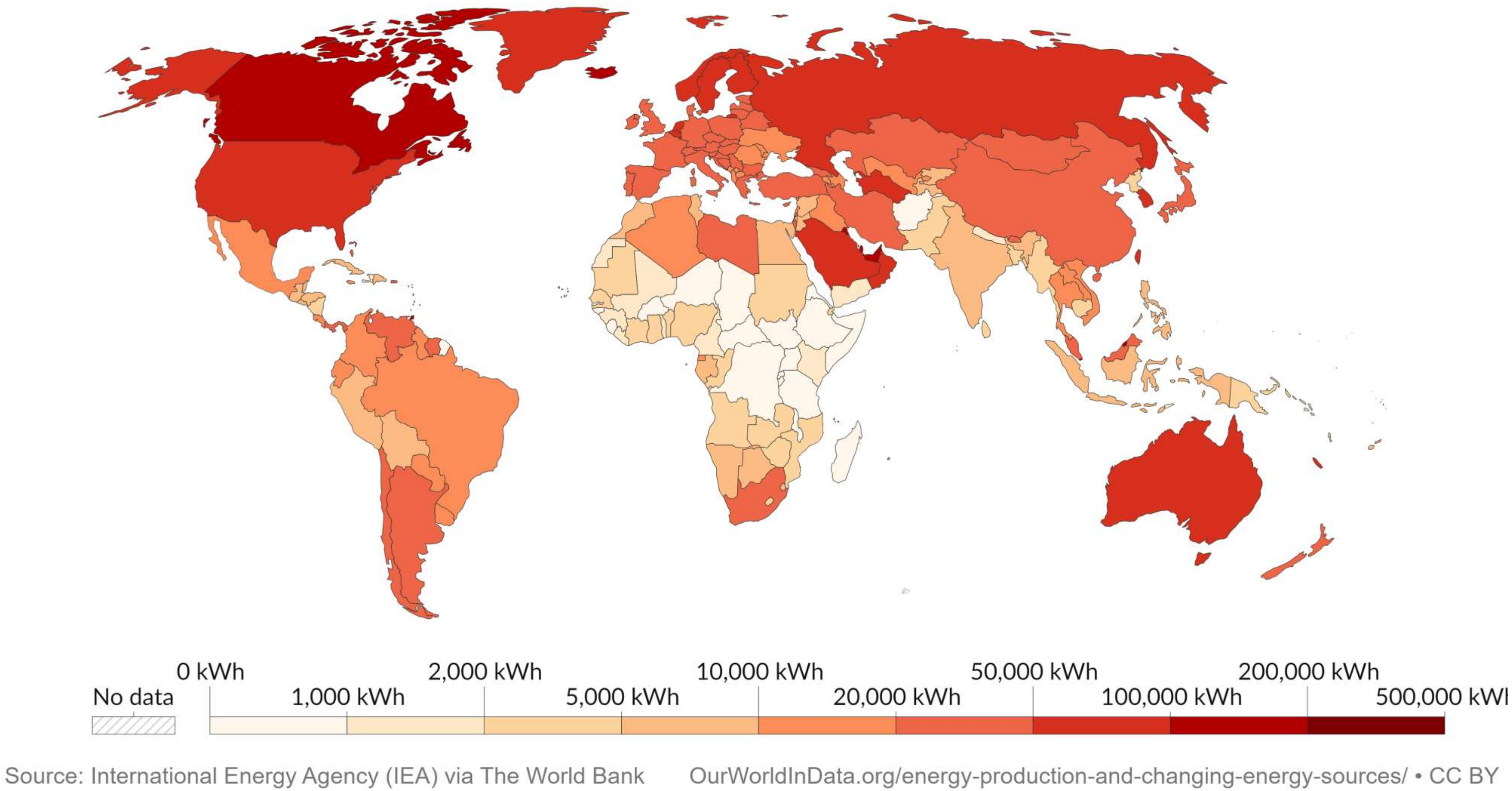

Energy use per capita (KWh/person/year) (2022)

Despite the decline in high-income countries, large global inequalities still exist. The average US citizen still consumes more than ten times the energy of the average Indian, 4-5 times that of a Brazilian, and three times more than China.

https://ourworldindata.org/energy-production-and-changing-energy-sources

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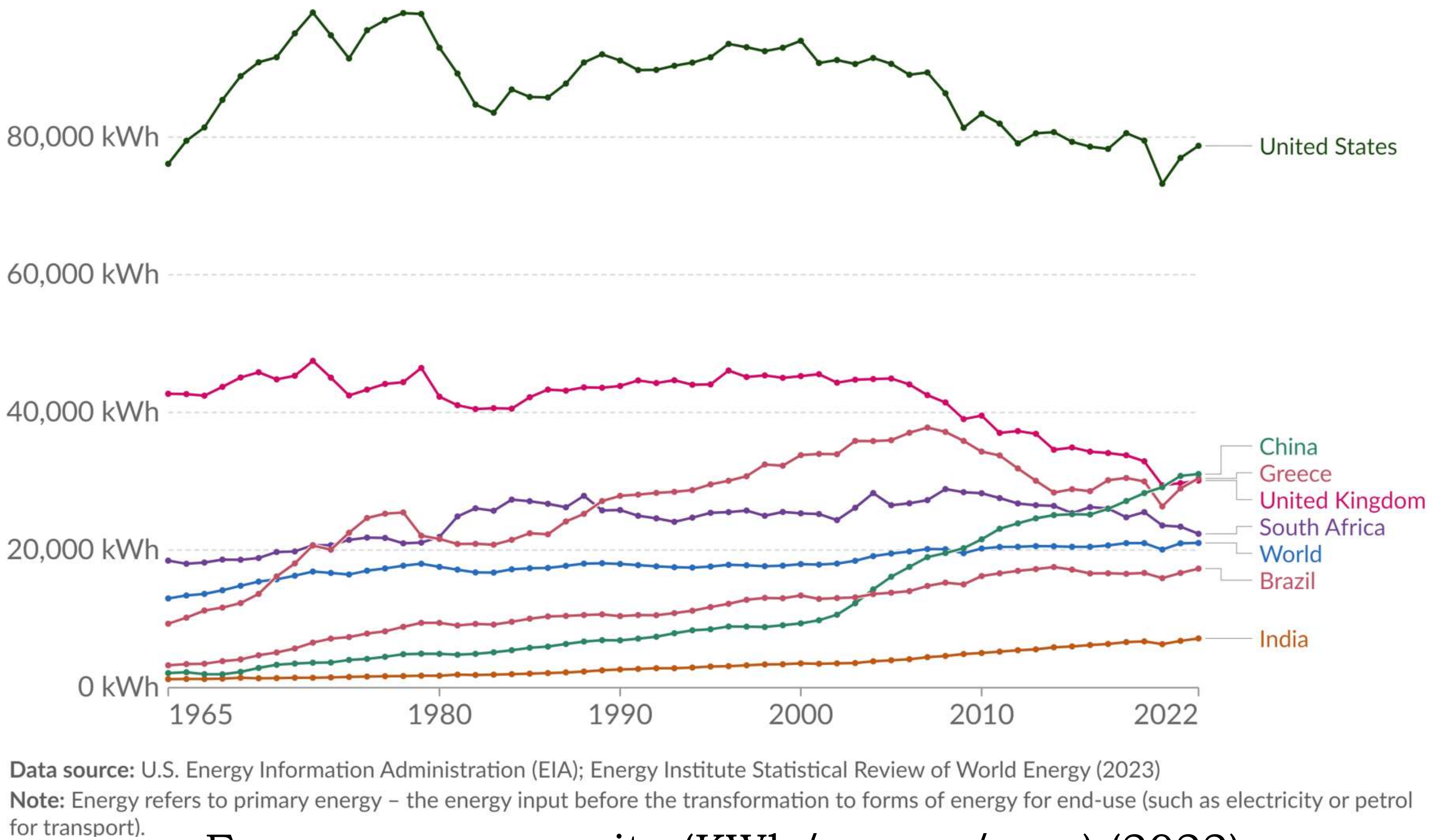

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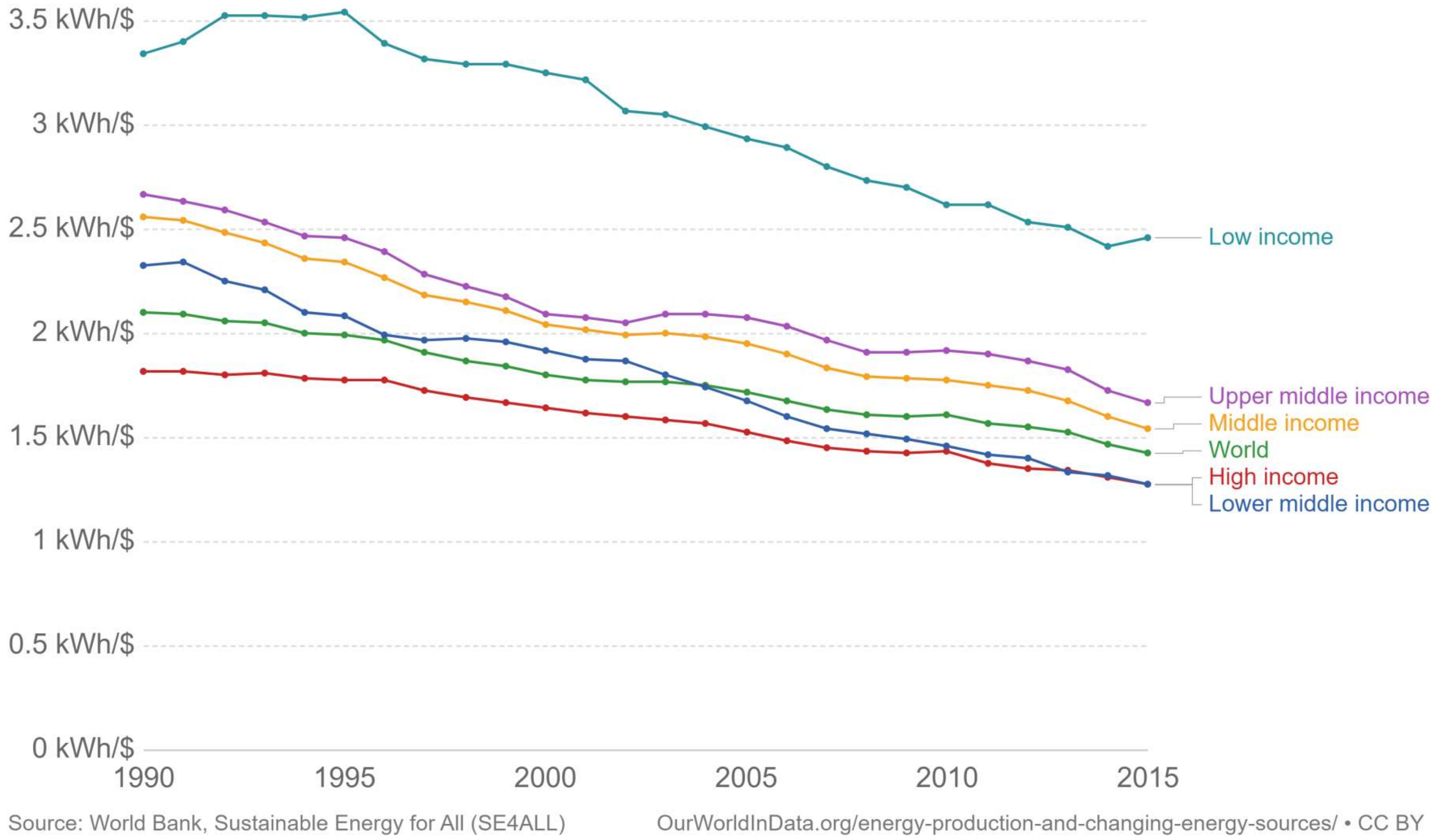
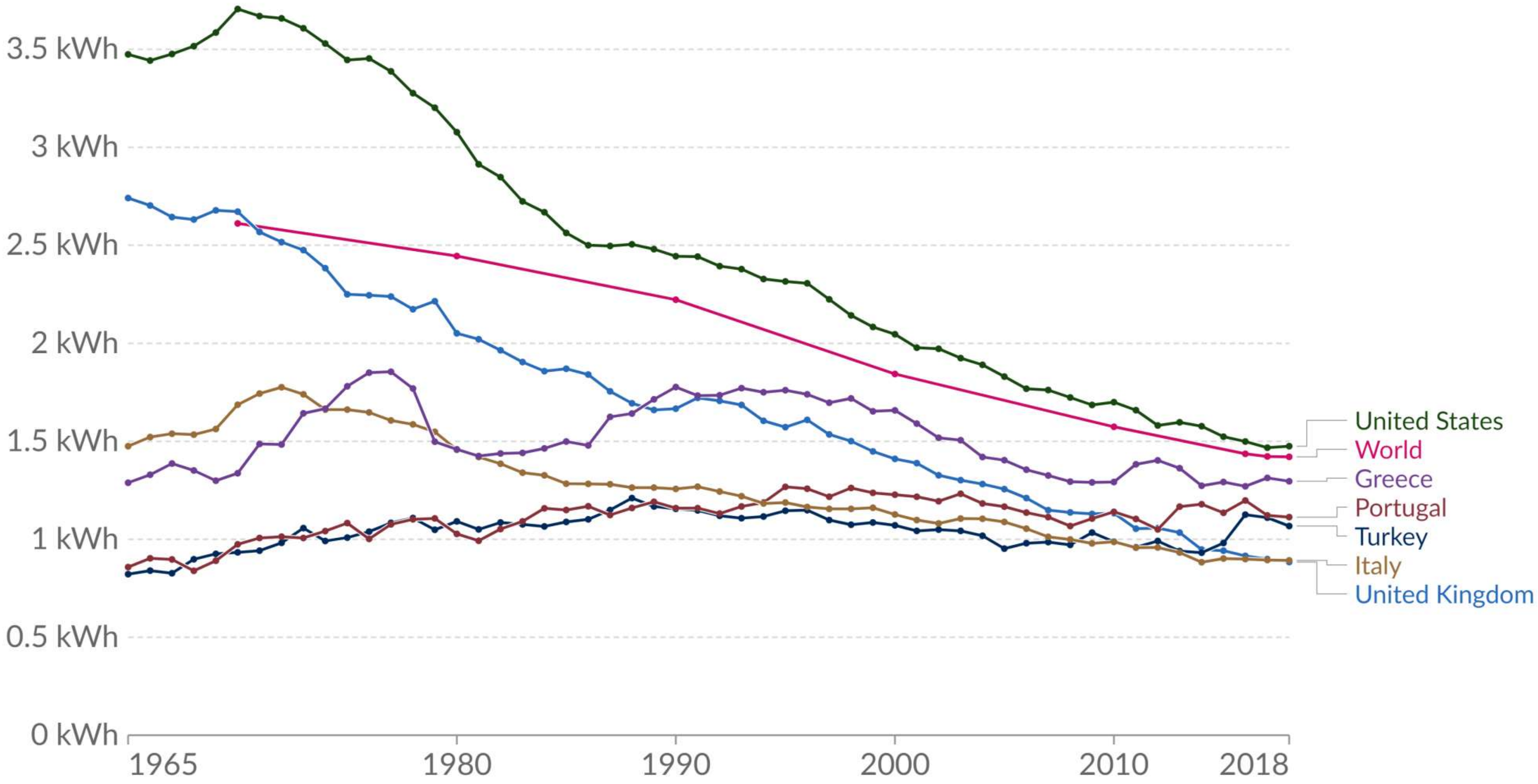


Energy intensity (energy supply/GDP in PPP)

Measures how much energy is needed to produce one unit of output.

https://ourworldindata.org/energy-production-and-changing-energy-sources

Some data



Data source: U.S. Energy Information Administration (EIA); Energy Institute Statistical Review of World Energy (2023); Maddison Project Database 2020 (Bolt and van Zanden, 2020)

Energy intensity (energy supply/GDP in PPP)

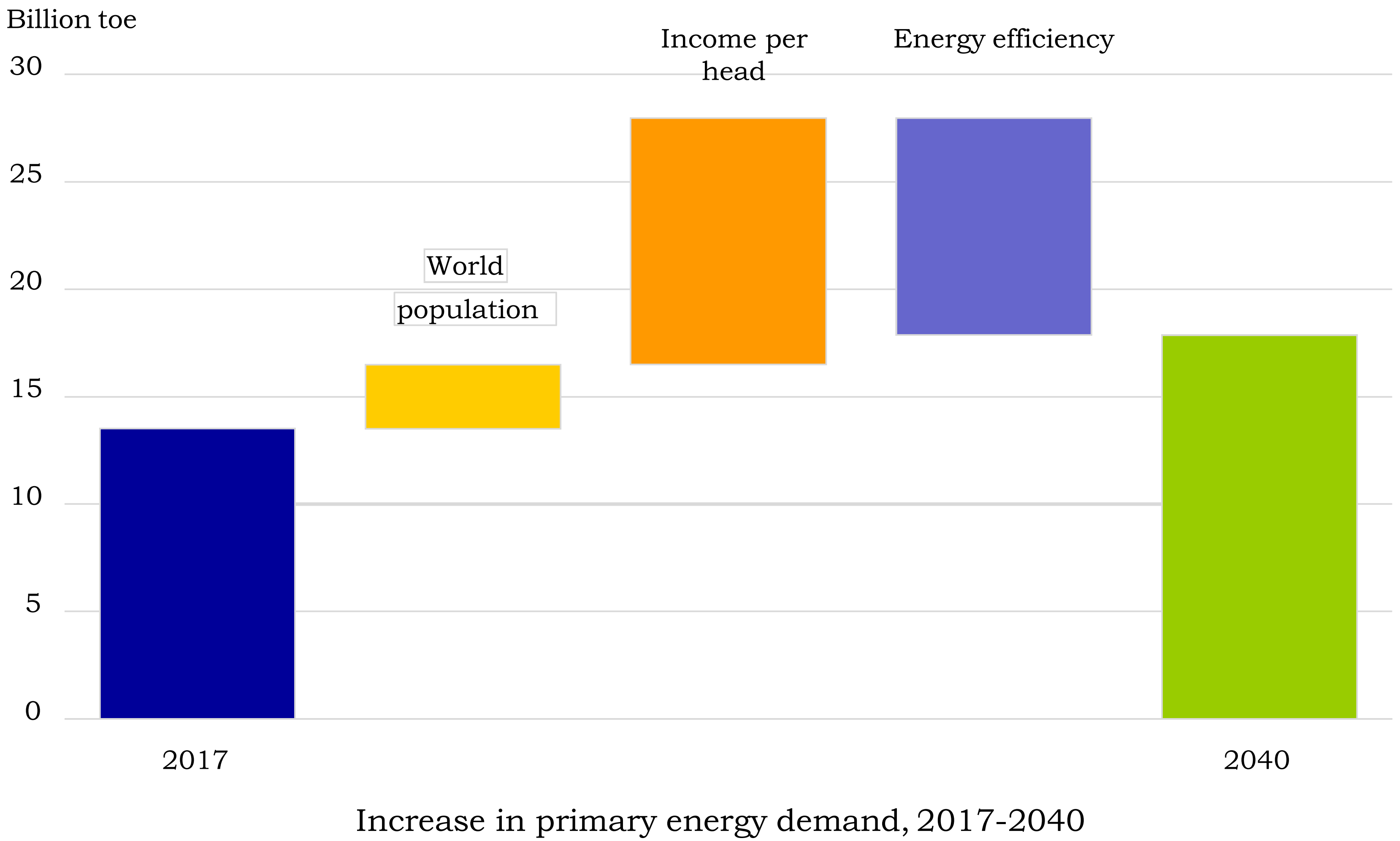
Measures how much energy is needed to produce one unit of output.

https://ourworldindata.org/energy-production-and-changing-energy-sources

Future: Important questions

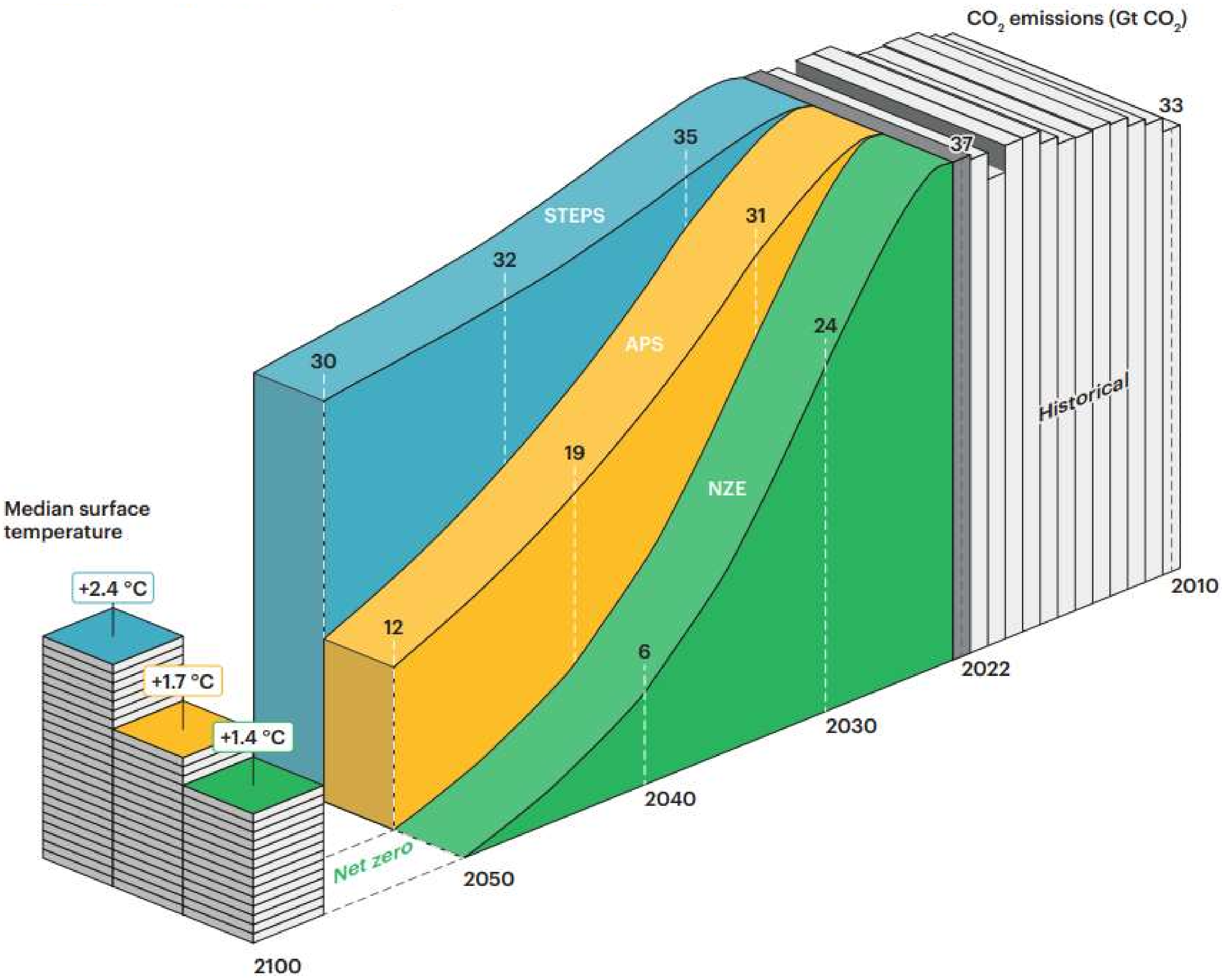
- How much 'more energy' does the world need?
- How important are plastics for the future of oil demand?
- What might happen if the trade disputes escalate?
- How quickly will the global energy mix evolve (How quickly could renewables grow)?
- A low-carbon energy system: what more needs to be done?
- Can the link between economic growth and increases in energy demand be broken?
- How will electric cars and new mobility technologies impact oil demand?
- How will the behaviour of low-cost oil producers change in a world of abundant oil resources and slowing oil demand?
- How fast do we expect natural gas to grow?
- What is driving this and what could cause gas demand to grow less strongly?
- Will coal demand peak in the next 20 years?
- How will China's economic transition impact global energy demand?
- How might a faster transition to a lower carbon energy system change global energy markets?

Future, some estimates: Increase in primary energy demand



2019 BP Energy Outlook, © BP p.l.c. 2019

Energy transition and temperature rise



Secure energy transitions: keep temperature rise below 1.5 °C. Today's temperature is around 1.2 °C above pre-industrial levels.

3 Scenarios:

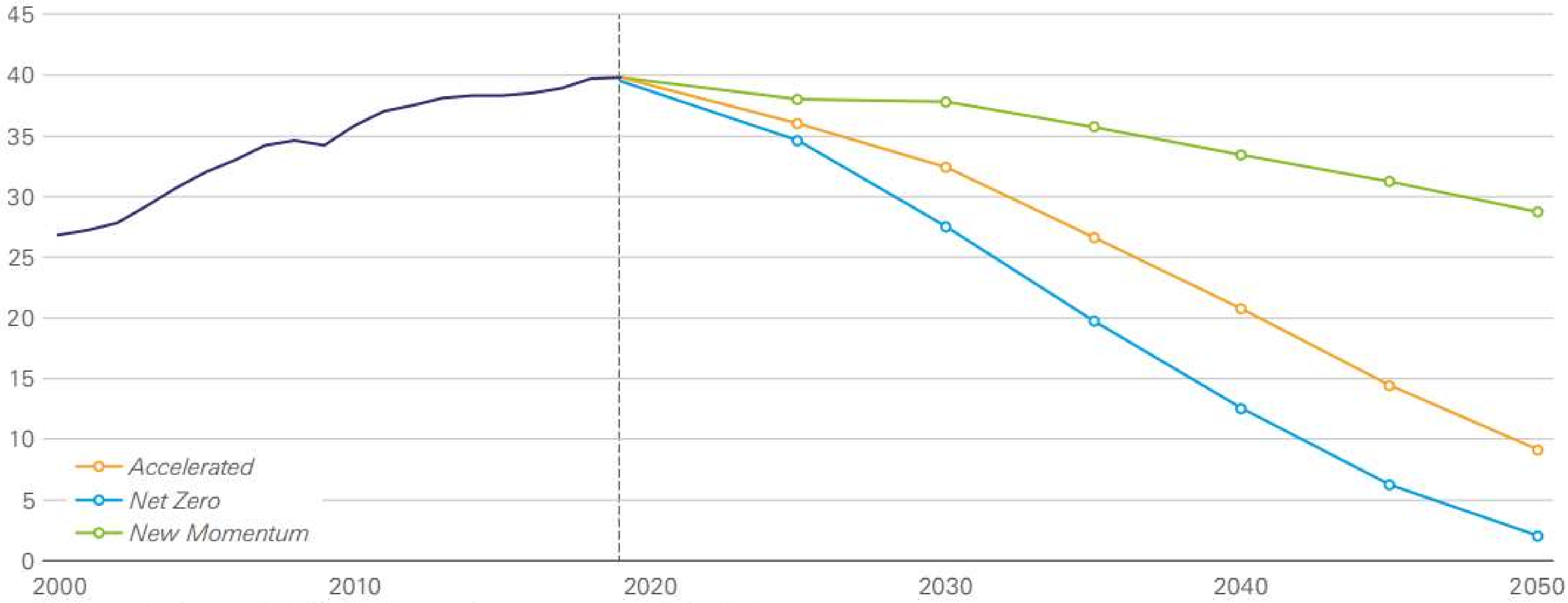
1. Stated Policies Scenario (STEPS),
2. Announced Pledges Scenario (APS),
3. Net Zero Emissions by 2050 (NZE) Scenario.

CO2 emissions and 2100 temperature rise

IEA World Energy Outlook 2023

Energy transition to 2050 (3 scenarios)

The BP Outlook examines the following three scenarios to explore the uncertainties surrounding the speed and shape of the energy transition to 2050

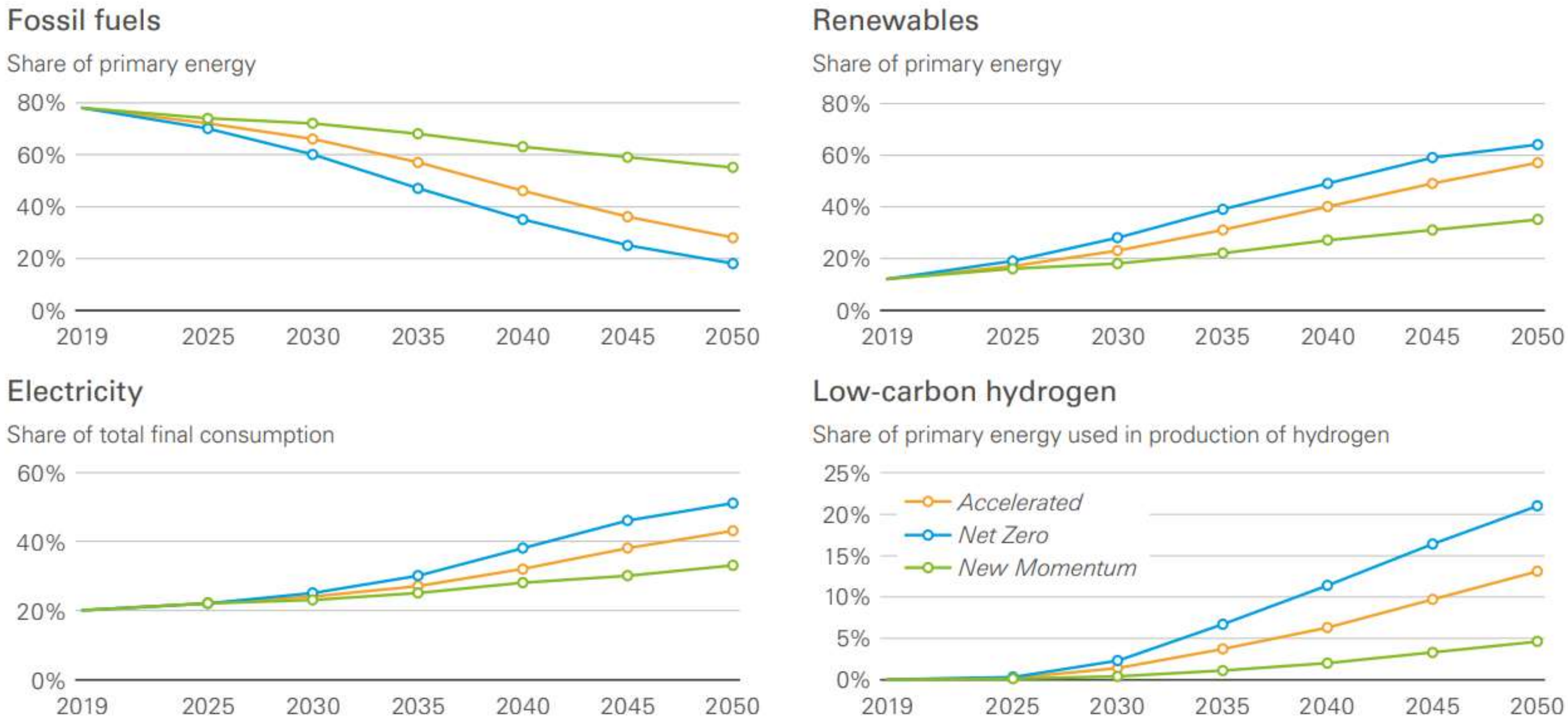


Carbon emissions include CO_2 emissions from energy use, industrial processes, natural gas flaring, and methane emissions from energy production.

Carbon emissions (Gtn of CO2 e), 2000-2050
under three scenarios

2023 BP Energy Outlook, © BP p.l.c. 2023

Main trends of global energy



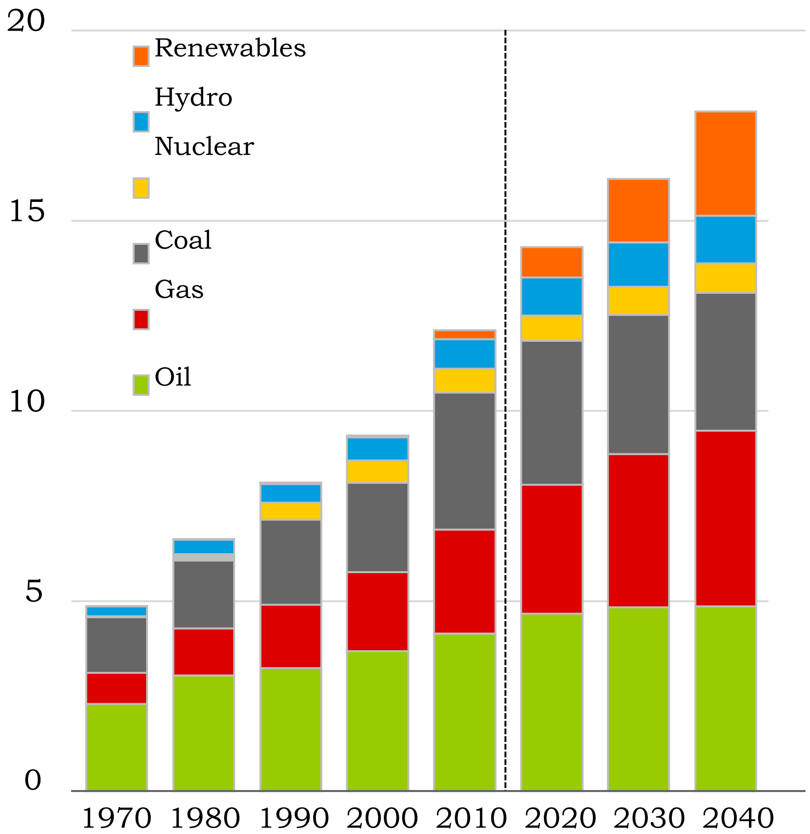
Under the three scenarios, in the previous slide, the above graphs illustrate the paths of the four main trends that (according to BP Outlook 2023) will dominate the future of global energy: (1) declining role for hydrocarbons, (2) rapid expansion in renewables, (3) increasing electrification, and (4) growing use of low-carbon hydrogen

2023 BP Energy Outlook, © BP p.l.c. 2023

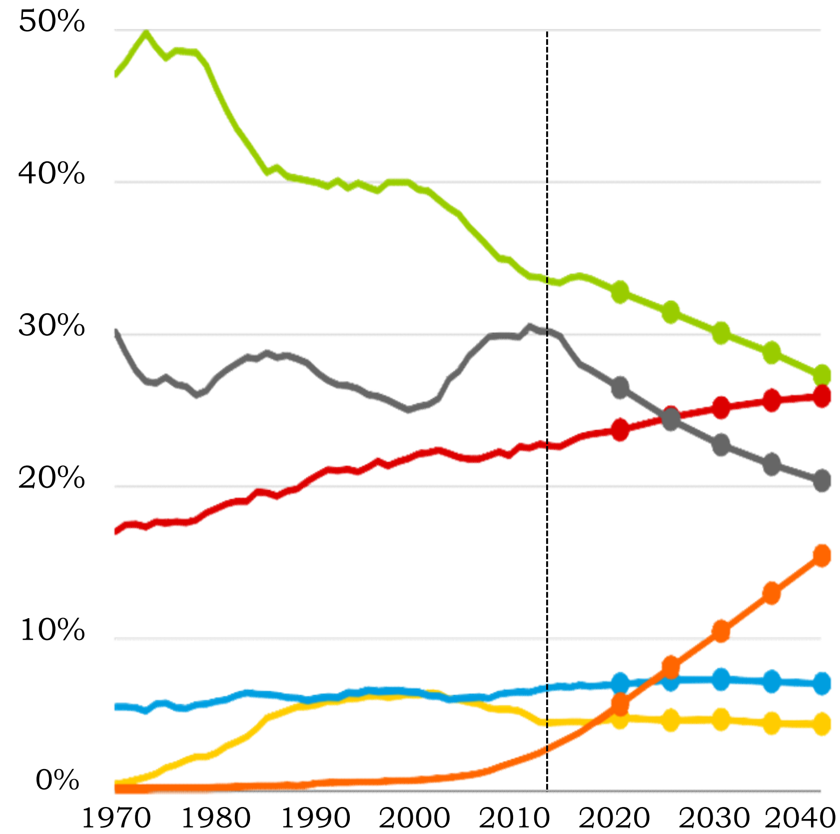
Future, some estimates: Global energy damand by fuel type

Primary energy consumption by fuel

Billion toe



Shares of primary energy



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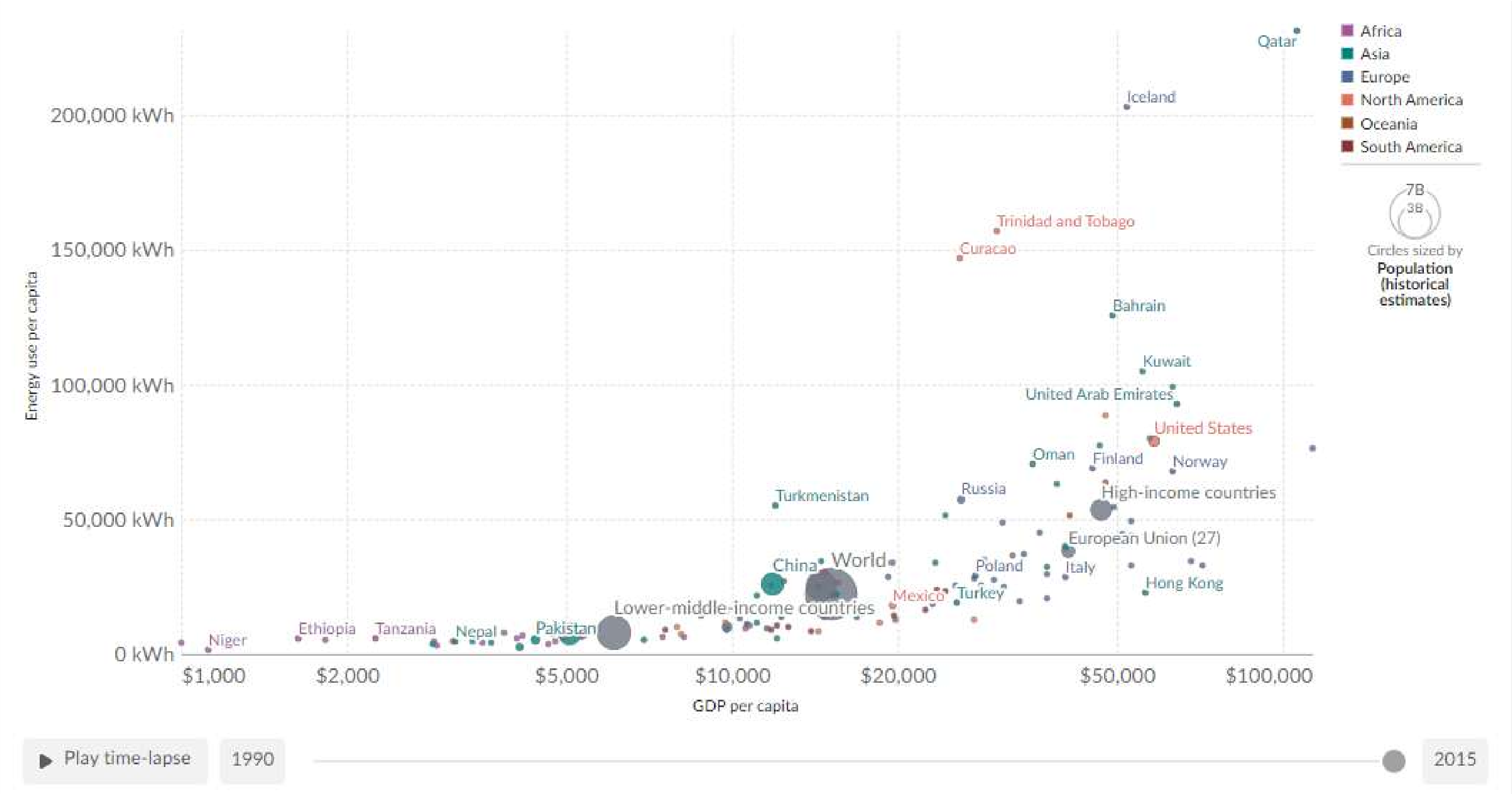
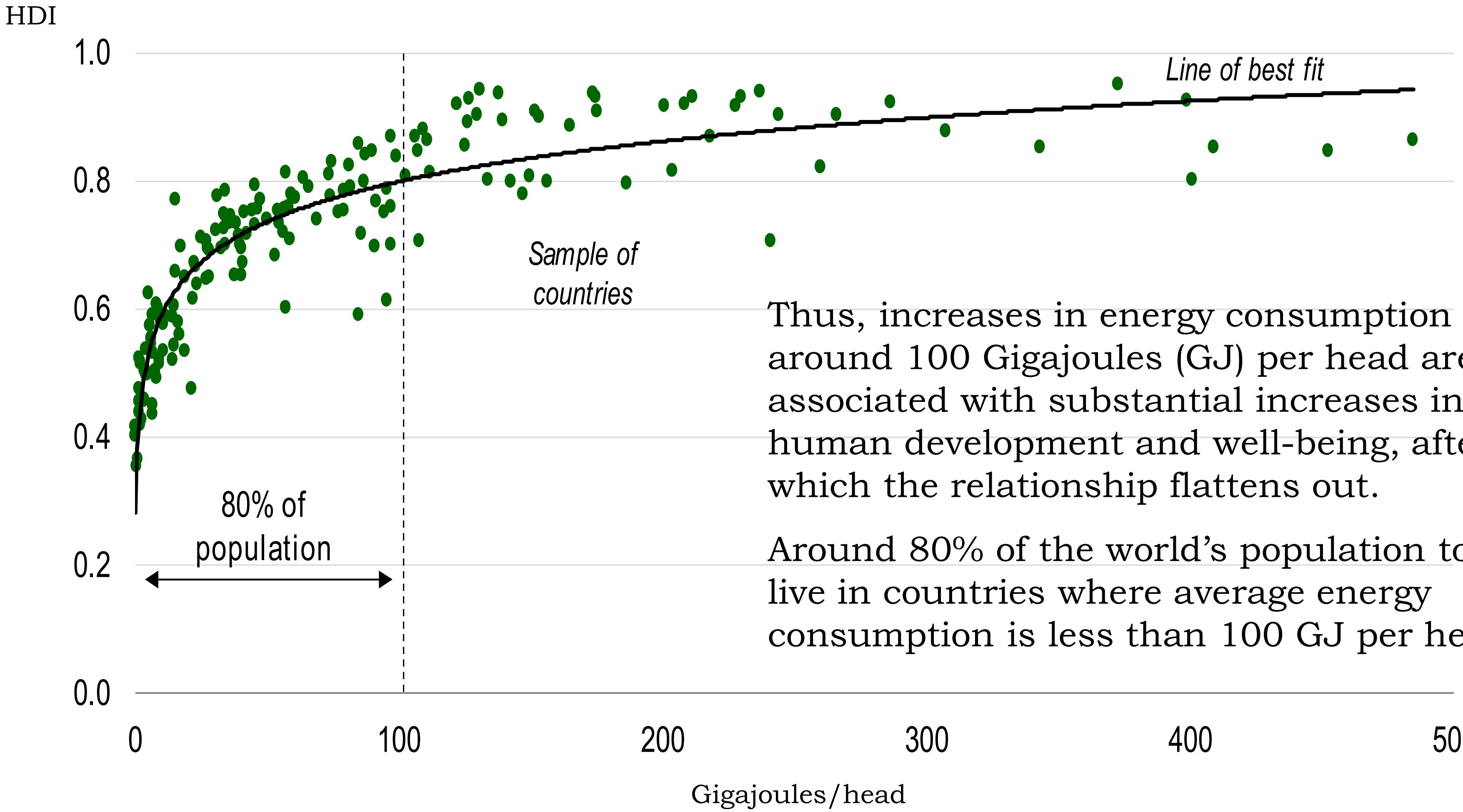
GDP and energy consumption



GDP per capita vs. energy use, 2015

Annual energy use per capita, measured in kilowatt-hours per person vs. gross domestic product (GDP) per capita, measured as constantinternational-$.

Human development and energy consumption



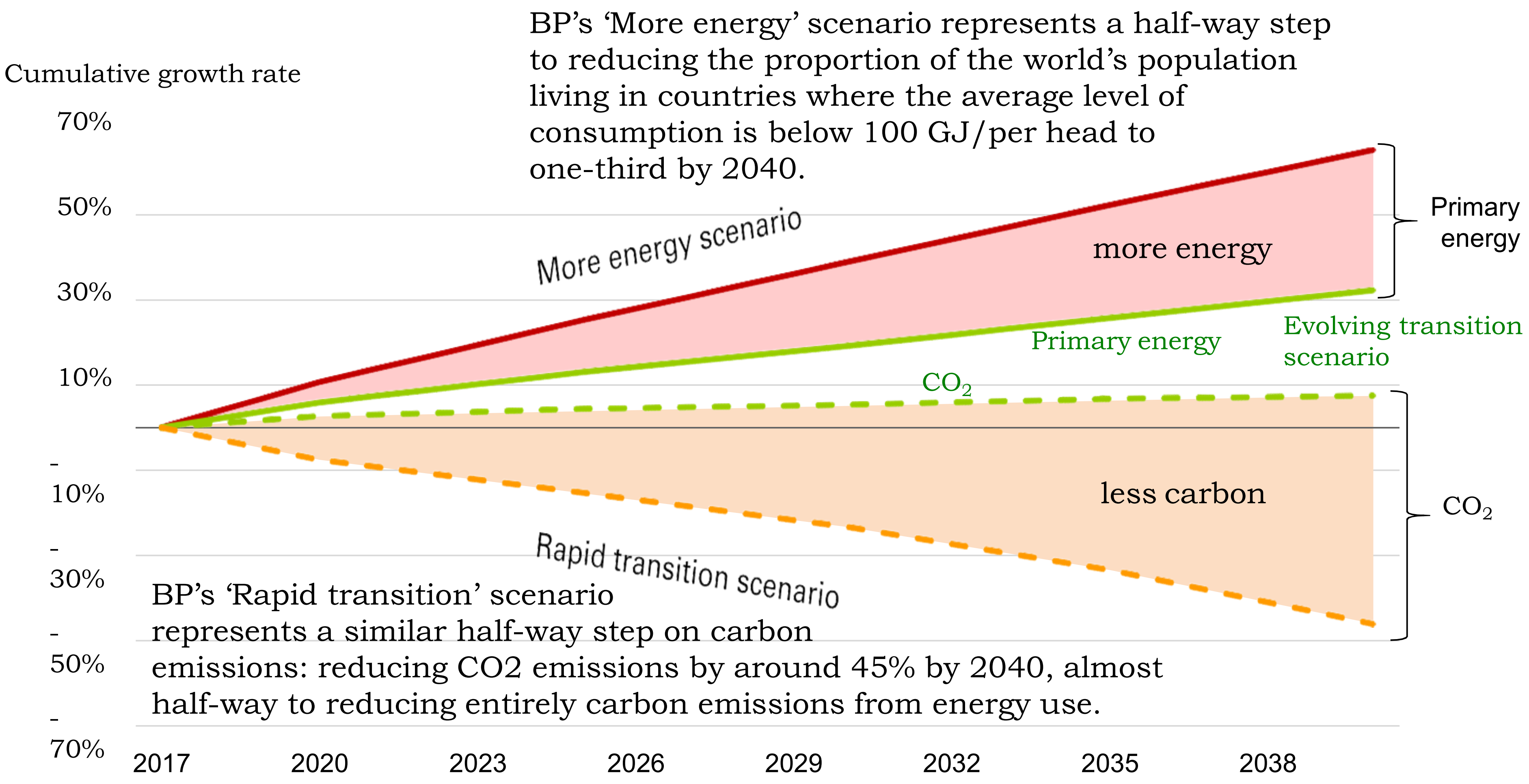
Thus, increases in energy consumption up to around 100 Gigajoules (GJ) per head are associated with substantial increases in human development and well-being, after which the relationship flattens out.

Around 80% of the world's population today live in countries where average energy consumption is less than 100 GJ per head.

UN Human Development Index and energy consumption, 2017

The Human Development Index (HDI) is a summary measure of key dimensions of human development: along and healthy life, a good education, and a decent standard of living. Higher values indicate higher human development.

Dual challenge: more energy, less carbon



Primary energy demand and carbon emissions

2019 BP Energy Outlook, © BP p.l.c. 2019

Key issues for the energy sector

- Main goals

National

- reducing vulnerability to supply disruptions and price shocks (security)

conflict

- reducing pollution and adverse health effects of energy use (environment)
- meeting the challenge of global climate change

conflict

- keeping prices low to bolster global economic growth, creating jobs, promoting new industries or technologies, and raising revenue. (security)

International

Policy options:
- supply-side (technology new methods)
- demand-side (efficiency & conservation)

- Energy security

Energy security

- The first challenge the energy sector is facing is providing security.
- **Energy security** refers to the need for securing cheap energy at the national and international level, since energy is essential to the functioning of modern economies and to global economic growth.
- The goal is to provide SECURE, SAFE and AFFORDABLE energy for citizens and businesses
- The problem is that the supply is not where the demand is.
- Thus, nations facing energy deficits have to develop policies to secure energy supply (at affordable prices)

Energy security

- Energy security has geopolitical, military, technical and economic dimensions.

- It is defined differently in the short-run (risks of disruption to existing supplies due to nature, technical or political problems) and in the long-term (securing future energy supply).

- Indicators used in the supply security literature:
  - Indicators of dependence
    - Import dependence
    - Fuel Mix
    - Stocks of critical fuels
  - Indicators of vulnerability
    - concentration of supply

Global energy demand and supply

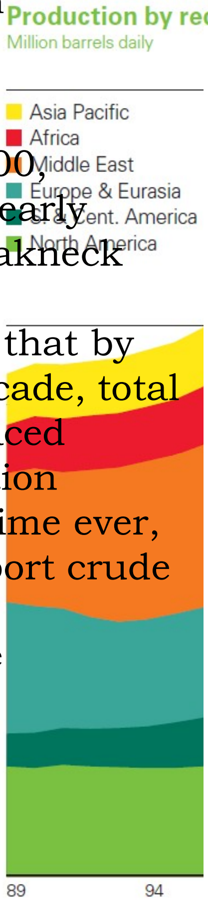
Demand: the light up area (satellite photo is used)

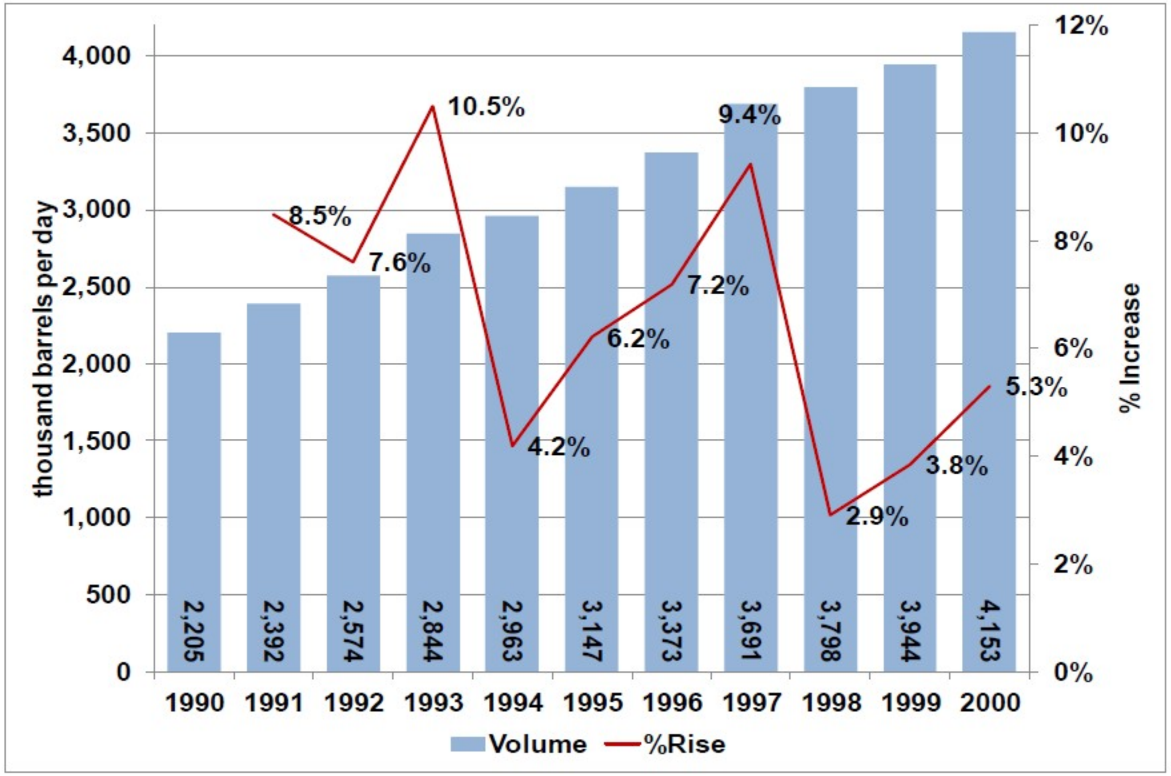
Global energy demand and supply

- There is a huge regional disparity between production and consumption of **oil**
- All of the net growth came from emerging economies in Asia, South & Central America, and the Middle East, offsetting declines in Europe and North America.

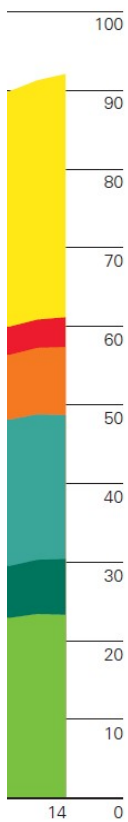
World oil production in 2014 exceeded consumption , rising by 2.1 million b/d; all growth was in non-OPEC countries. US output grew by 1.6 million b/d, its largest increase on record. Global consumption increased by 840,000 b/d, with emerging economies accounting for all of the growth; China saw a below-average increase but still accounted for the largest increment to consumption.

From 1990 to 2000, Chinese oil use nearly doubled. The breakneck growth of the 1990s meant that by the end of the decade, total oil demand outpaced domestic production and for the first time ever, China had to import crude oil.





Source: APEC.



Source: BP Statistical Review of World Energy, 2015

Source: BP Statistical Review of World Energy, 2012

The national aspect of energy security

- At the national level, energy is a vital element both for households and businesses and an important aspect of public policy
- Households' energy demand increases continuously and is extremely important for their everyday operation
- Energy is an essential input for businesses of every size, for energy suppliers, the transport industries, energy-intense industry and service providers. To business, energy security means confidence in its ongoing ability to access reliable and affordable energy, wherever it operates. Secure and reliable energy supply and infrastructure impacts the feasibility and costs of doing business from perspectives of competitiveness and productivity. Energy security is a vital consideration, not only for day-to-day operations, but also for long-term investment.
- Public policy should establish criteria and guidelines for safe, cleaner energy supply and responsible use of resources.

Global challenges

- Unequal distribution of energy sources creates many problems which differ in magnitude and timing
  - At the national level:
    - For some countries securing the future supply of energy is the main concern
    - For some other, securing current supply is of paramount importance
  - At the international level:
    - Extremely large demand growth due to population and income growth;
    - Demand shifting towards new centers of growth in contrast to traditional ones;
    - Globalization of wasteful consumption patterns (transmitting “western” consumption patterns);
    - Supply concentration in politically unstable regions

Energy security

- Energy security in EU

- At present, the EU imports 55% of all the energy it consumes, at a cost of an average of around €266 billion per year. Energy also makes up around 15% of total EU imports. Specifically, the EU imports:
  - 87% of its crude oil
  - 70% of its natural gas
  - 40% of its solid fossil fuels
  - 40% of enriched and manufactured nuclear fuels
  - Major suppliers: Norway, Russia, members the Organisation of Petroleum Exporting Countries (OPEC) various other countries around the world supplying liquefied natural gas (LNG) and, in the future, countries in Central Asia.

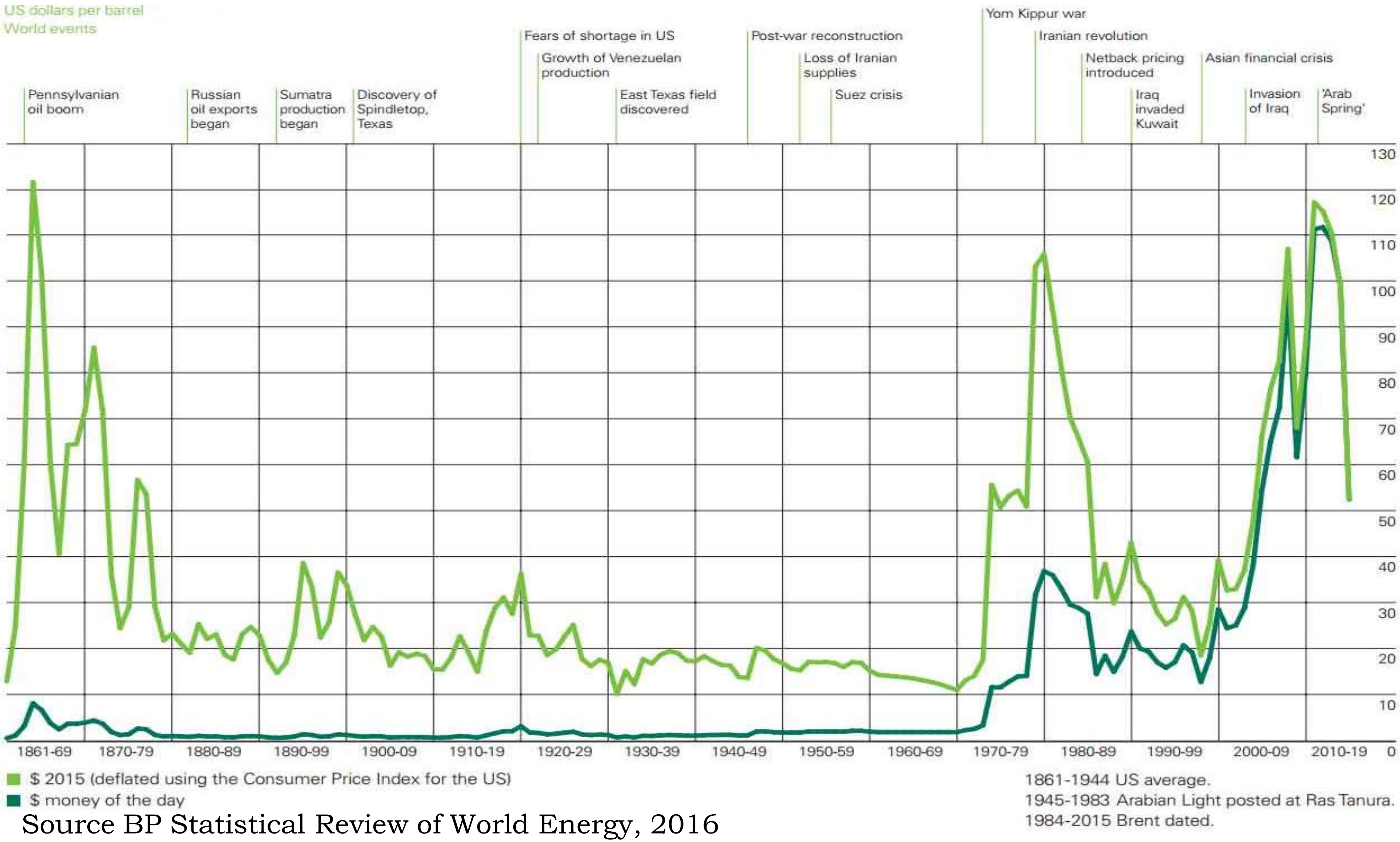
- Security of energy supply is an integral part of the Energy Union strategy. Energy supplies are exposed to risks that include disruption from countries from which the EU import fuel, but also extreme weather, industrial hazards, cyberattacks, terrorism and hybrid threats.

- Measures: (1) Gas supply: Security of Gas Supply Regulation in 2017; diversifying sources and supply routes (development of the Southern Gas Corridor), (2) Oil supply: Minimum Stocks of Crude Oil and/or Petroleum Products Directive (requirement to maintain emergency stocks of oil equal to at least 90 days of their average daily consumption or 61 days of consumption, whichever is higher); (3) electricity: Internal Electricity Market and Regulation on electricity risk preparedness as part of the 'Clean energy for all Europeans'.

https://ec.europa.eu/energy/en/topics/energy-security/overview

Energy prices

Energy prices

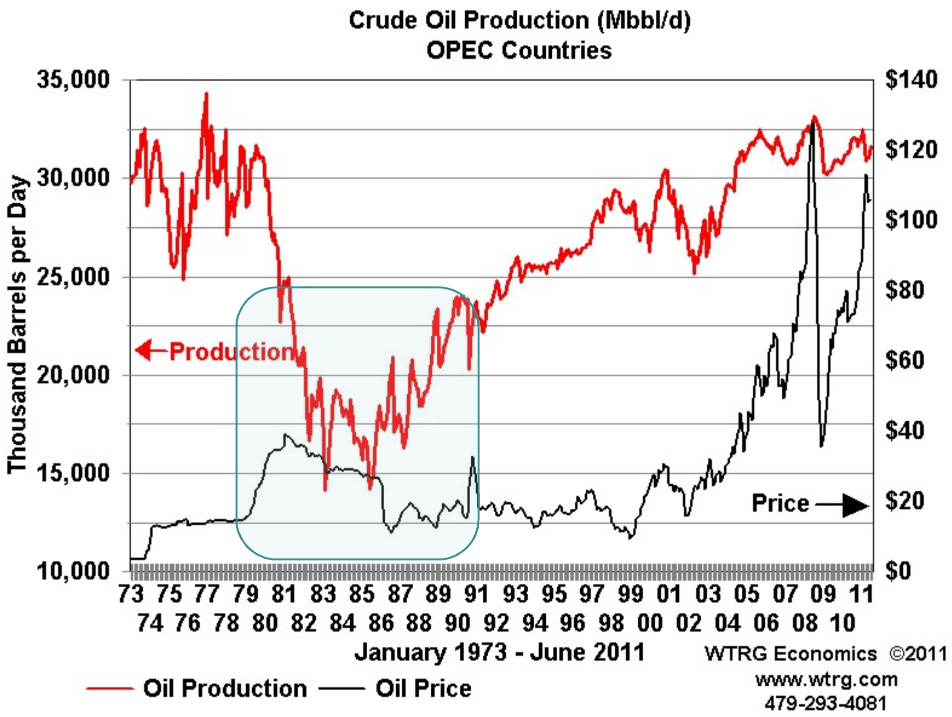


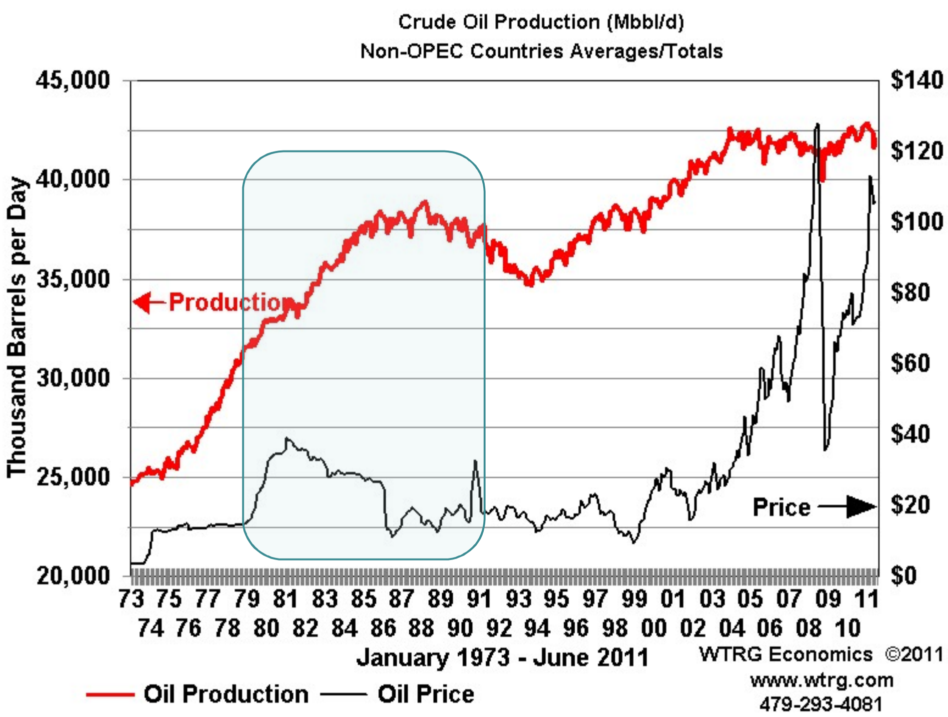
Source BP Statistical Review of World Energy, 2016

Energy prices

- It is clear that oil prices are affected by production. OPEC dominated production initially and had major effect on prices

- As price increased, the rest of the world increased production leading to stabilization of prices although demand increased





Source: http://www.wtrg.com/prices.htm

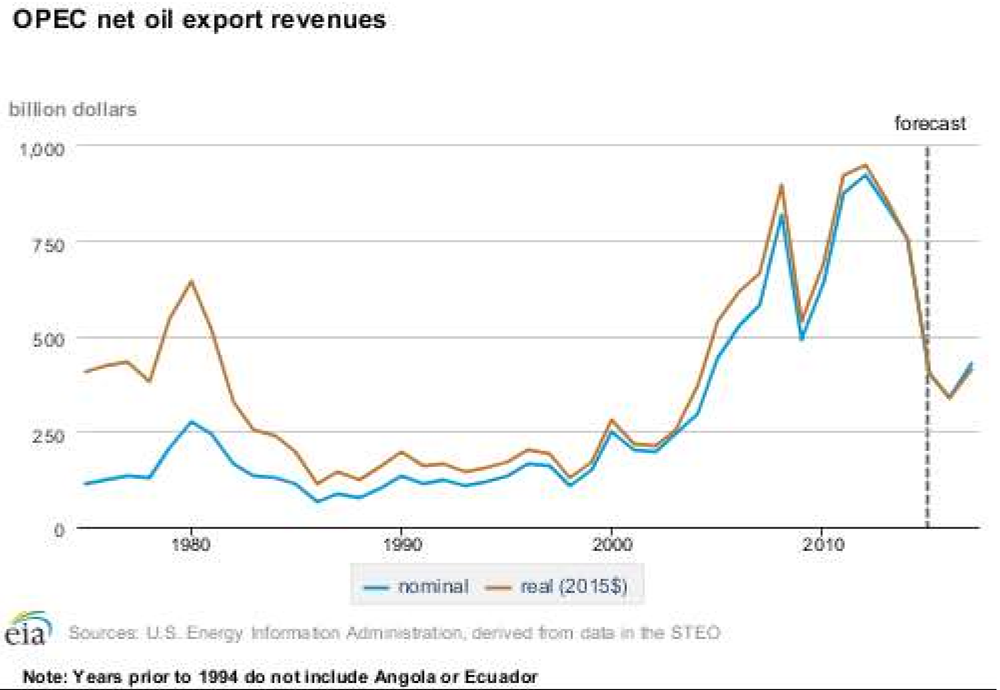
Effect of price increase on exporting

- Exporting countries
  - Price increases have resulted in extraordinary profits for the oil producing countries up until 2012
    - During each oil price shock of the 1970s and 1980s it has been recorded a transfer of US$300 million a day from oil importing countries to exporting countries.

OPEC earned almost $1 trillion in net oil export revenues in 2011, a 33% increase from 2010.
Saudi Arabia earned the largest share of these earnings, $311 billion, representing 30% of total OPEC revenues.

On a per-capita basis, OPEC net oil export earnings reached $2,683 in 2011.

After 2012 and up to 2016 there was a dramatic increase to a low of $338 billions.

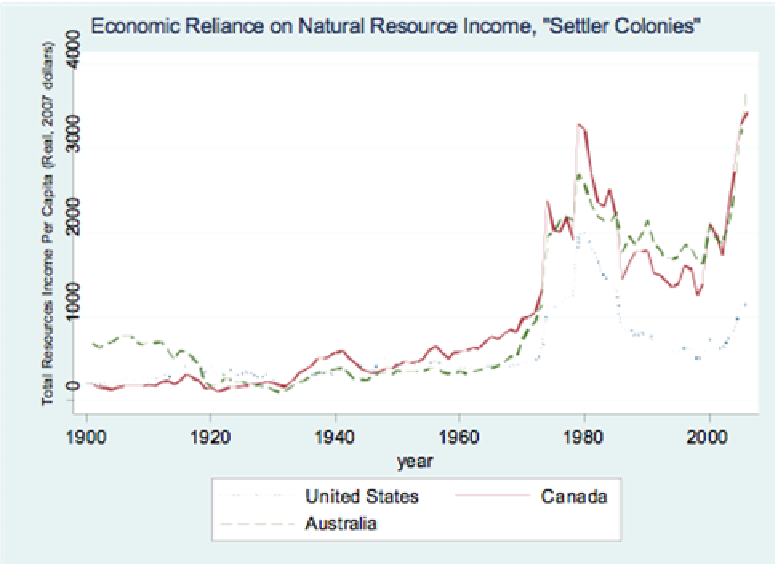


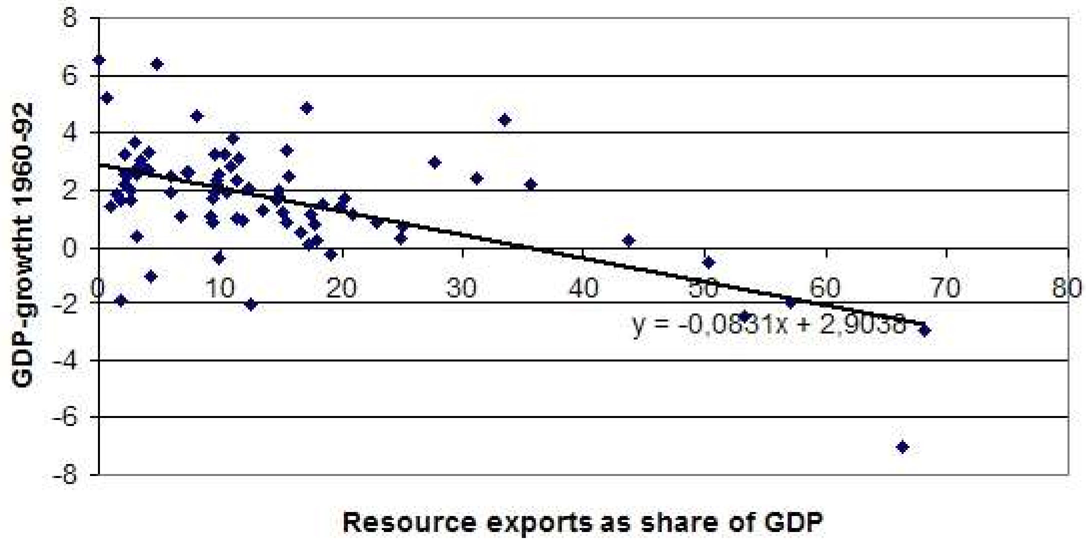
Source: US Energy Information Administration

Effect of price increase on exporting

- Apart from the revenue there are problems
  - Natural Resource curse
    - Refers to the fact that often countries with oil or other natural resource wealth have failed to grow more rapidly than those without.
    - Reasons: long-term trends in world commodity prices, volatility, crowding out of manufacturing, social division (civil wars), poor institutions (corruption), and the Dutch Disease (increased exchange rate decreases manufacturing exports).

But:





Source: Manzano and Rigobon (2008) NBER WP 8390

- Environment

Climate change

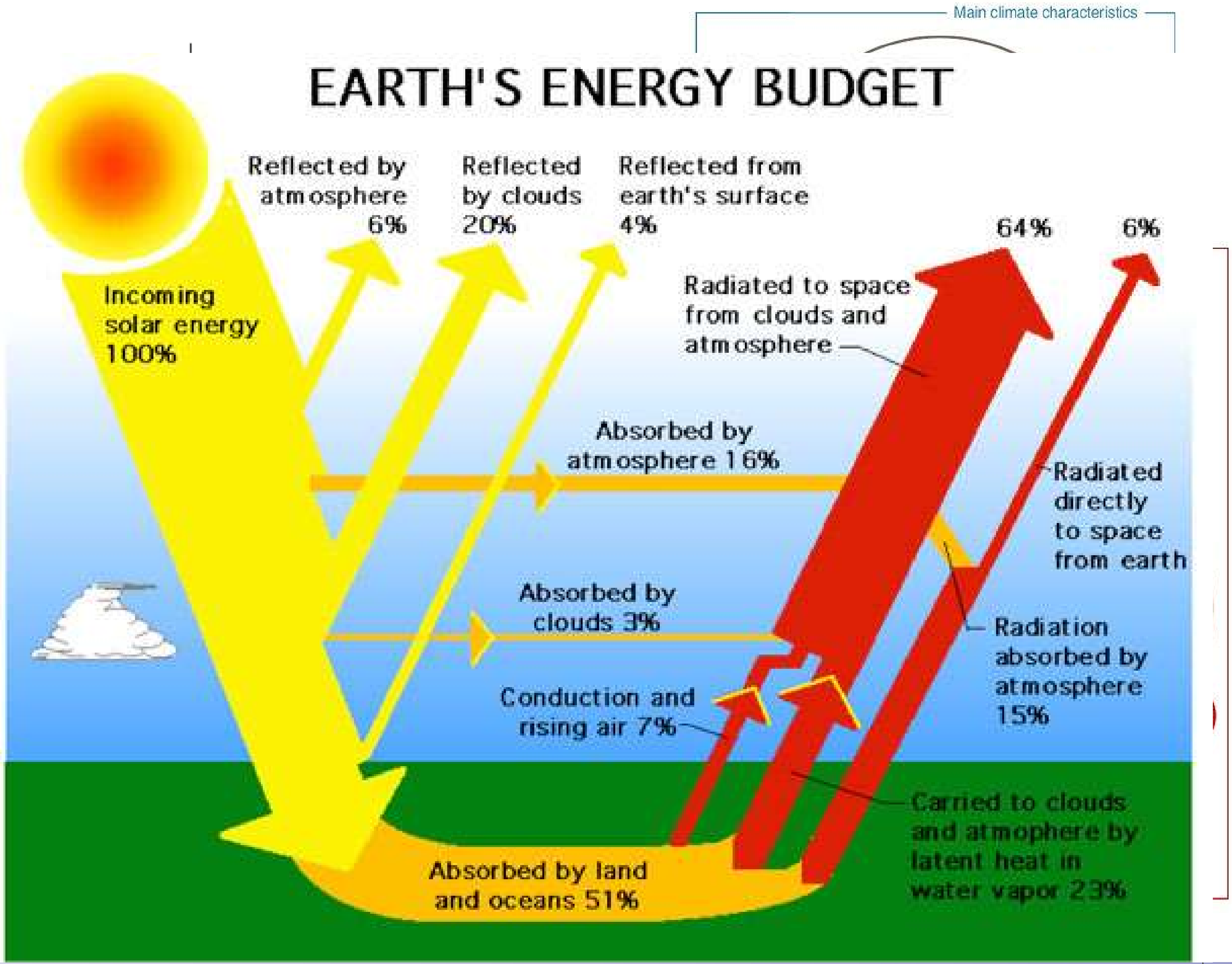
Facts:

- Over the last 2
average tempera
has increased m
be explained by
climate cycles.

- There is an agr
the causes of cli
are anthropogen

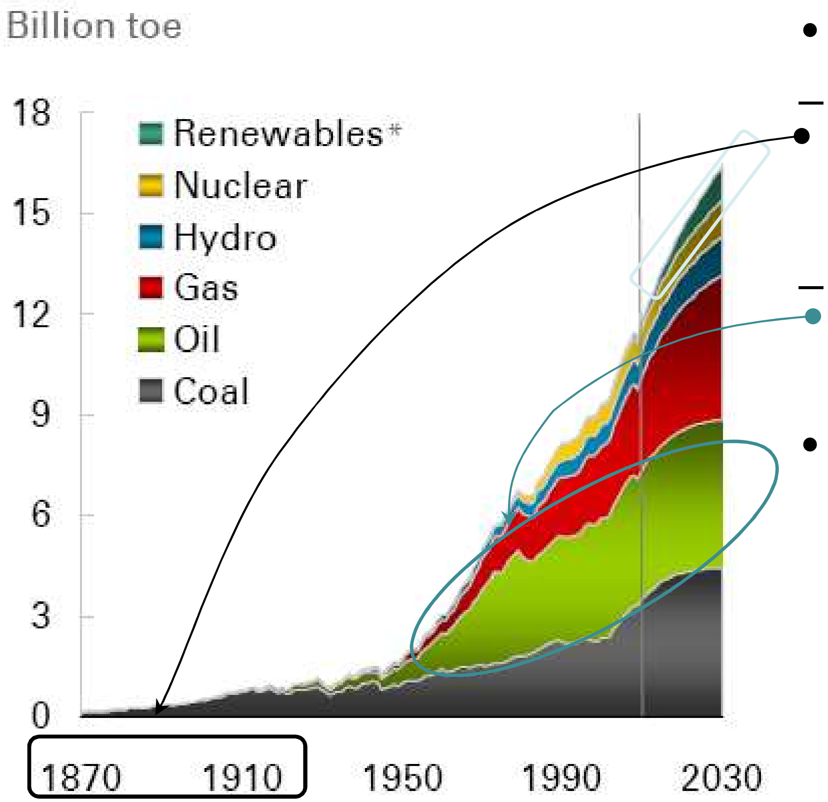
- Climate change
with industrial r
and is evolving a
accelerating rate
50 years.

- The use of foss
main energy sou
fueled industrial
the main source
problem, since G
CO_2) enhance th
effect.



Energy use, CO2 and climate

- Pre-Industrial Revolution period: low demand, energy derived mostly from the natural energy flows and human and animal power



World commercial energy use. Data and projections. BP Energy Outlook 2030

- Industrial Revolution:
  - Coal : steam engines (use in factories, locomotives and ships, leading to the transport revolution)
  - Oil: internal combustion engines (cars, buses and aircraft)
- What next? Renewables? In which form?

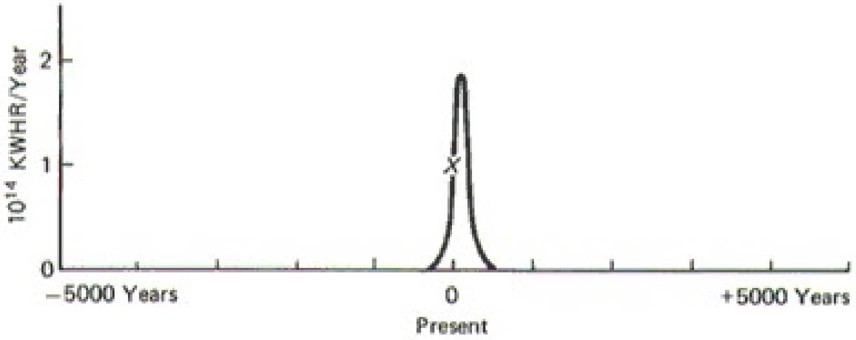
Two important changes:

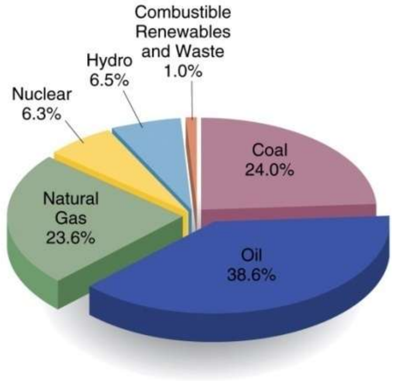
- From agriculture to industry and manufacturing to services and information-based industries.

- Urbanization led to massive relocation from rural to urban areas and changed economic activities, life styles, social values

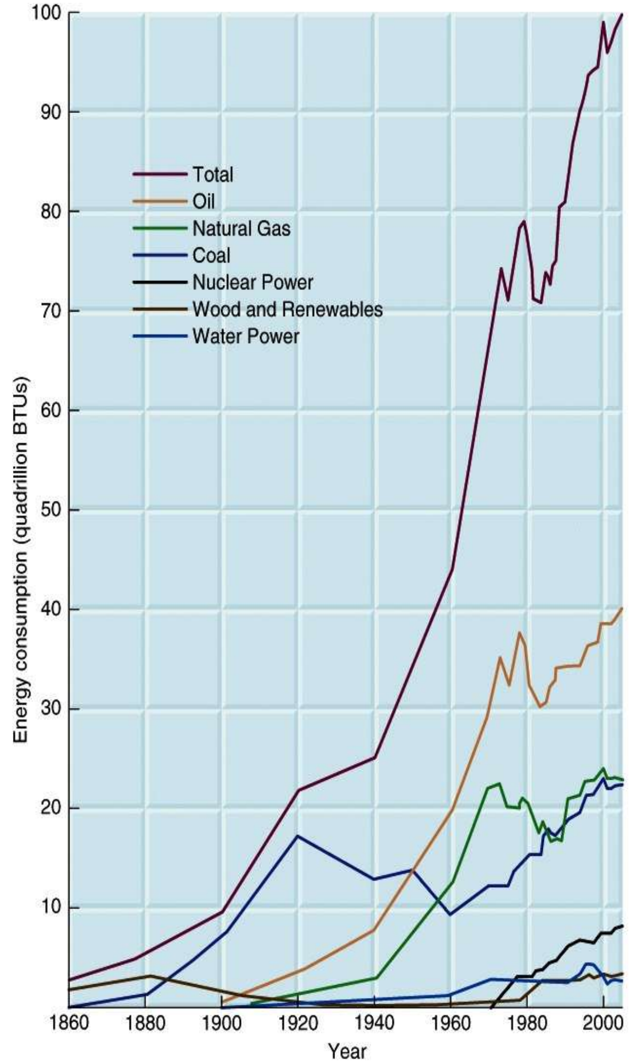
Fossil fuels consumption

The solar energy originally stored in the plant or animal is eventually converted into energy stored in carbon and hydrogen bonds of the fossil fuel. The fuels that took millions of years to make are being used at an enormously rapid rate. The Figure below presents the use of fossil fuels over time, including an estimation of how long they might last.





Energy usage worldwide



Energy consumption in the US

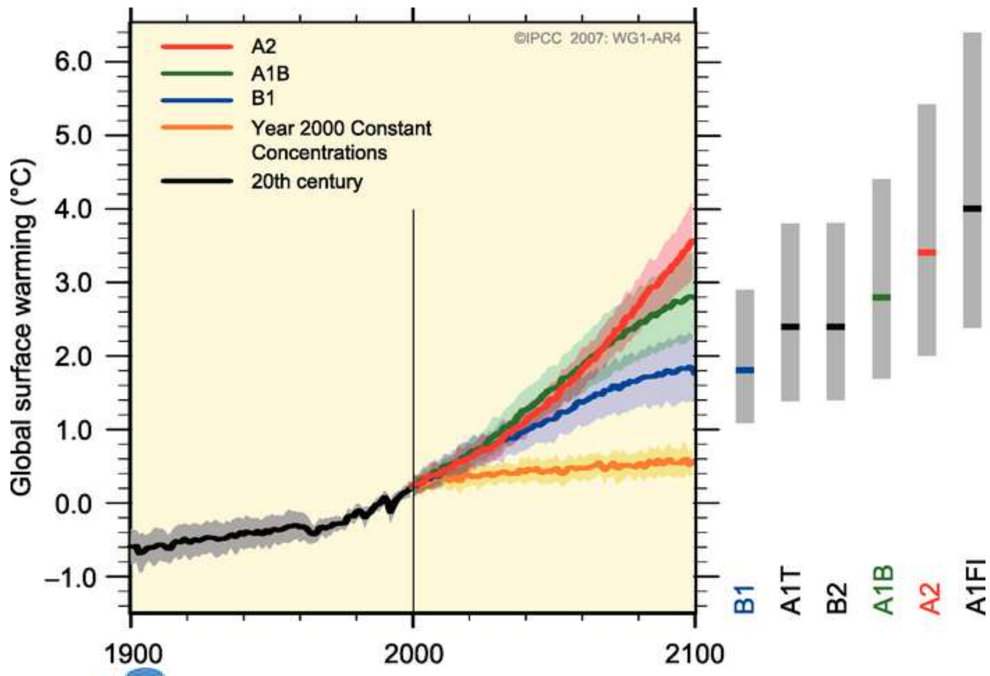
The top three sources = oil, coal and natural gas. Coal was the dominant energy source throughout most of the early 1900’s (88% of energy in 1920).

CO_2 and climate

All forecasts converge on the prediction that CO_2 concentration will soon exceed the double of the historical average (more than 450ppm).

The impacts of this dramatic increase in greenhouse gases concentrations cannot be estimated with certainty.

The best scientific forecasts available are those of the Intergovernmental Panel on Climate Change (IPCC) and they estimate that doubling GHGs concentration will result in an increase of average temperature on earth's surface which «…it is likely to be in the range 2–4.5°C with a *best estimate* of 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C *cannot be excluded*, but agreement of models with observations is not as good for those values.» Intergovernmental Panel on Climate Change (IPCC-AR4 2007)

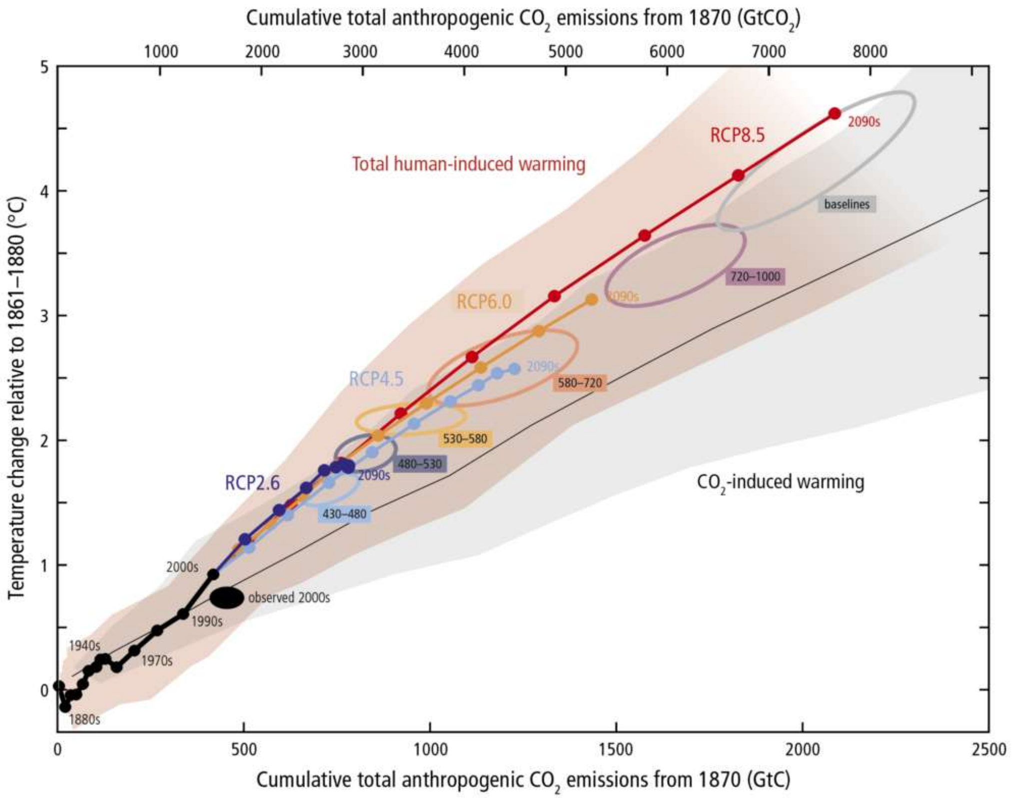


CO_2 and climate

«to limit "total human-induced warming to <2°C relative to 1861-80 with proba-bility >66%, would require cumulative CO_2 emissions from all anthropogenic sources since 1870 to remain <2900 $GtCO_2$ (carbon budget)" (IPCC, 2014).

Given the amount of CO_2 emitted up to now, raining cumulative carbon budget is 1000 $GtCO_2$. (Gignac &Matthews 2015)

Curbing CO_2 emissions requires urgently strong action. Fiscal policies (taxes, permits, etc) are not enough to fulfill the Paris pledges and most importantly, much stronger action is needed. Debt financing, using Green Bonds, can contribute substantially in addressing the problem and also inter-generational equity issues.

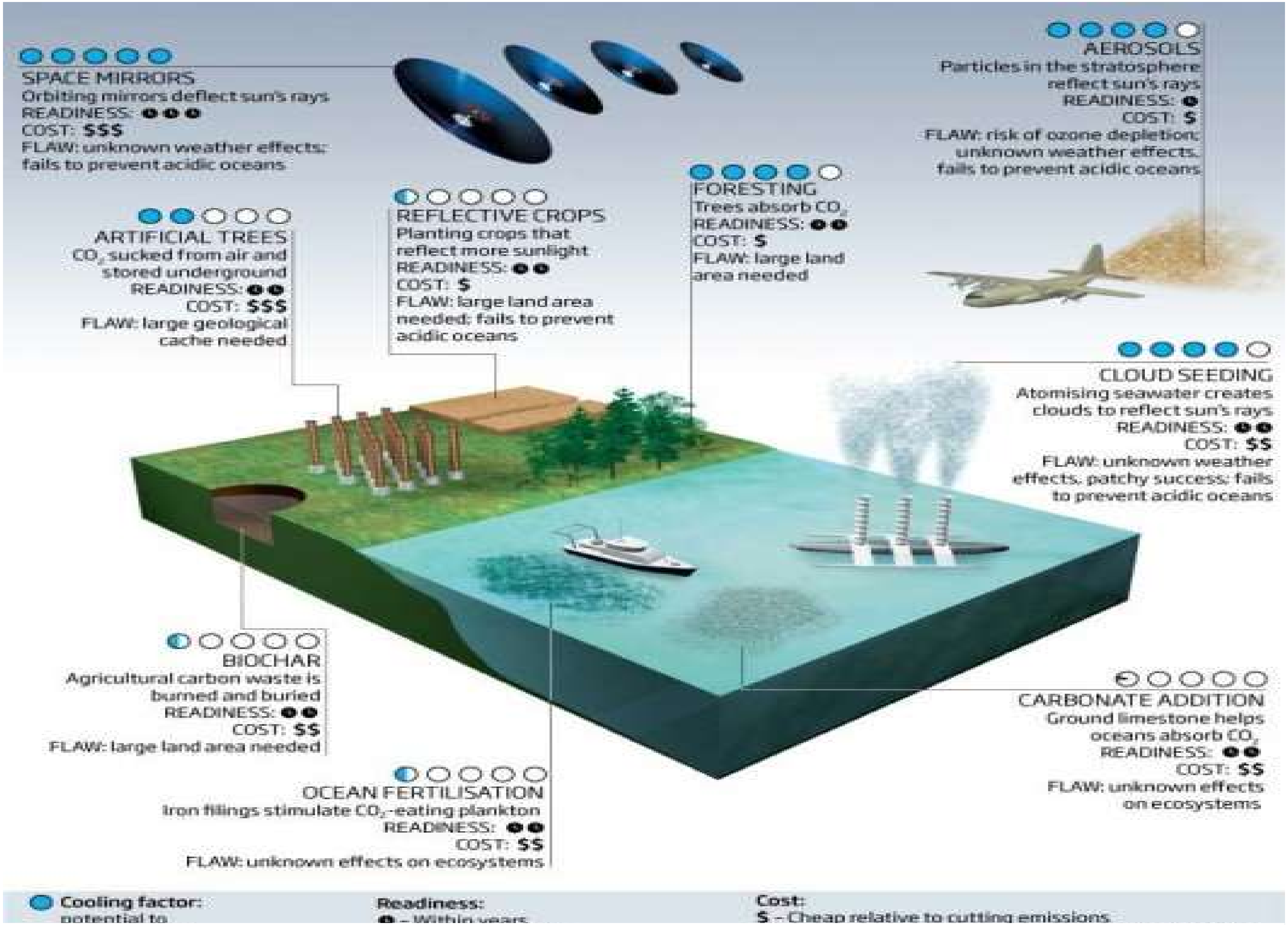


Warming versus cumulative CO2 emissions (Source: IPCC 2014, Figure SPM.5 (b))

Responces: Geoengineering

- Geoengineering is the deliberate large-scale intervention in the Earth's natural systems to counteract climate change.
- **Solar Radiation Management (SRM) or *Solar Geoengineering.*** SRM t echniques aim to reflect a small proportion of the Sun's energy back into space:
  - ***Albedo enhancement***. Increasing the reflectiveness of clouds or the land surface.
  - ***Space reflectors***. Blocking a small proportion of sunlight before it reaches the Earth.
  - ***Stratospheric aerosols***. Introducing small, reflective particles into the upper atmosphere to reflect some sunlight before it reaches the surface of the Earth.

- **Greenhouse Gas Removal (GGR) or *Carbon Geoengineering.*** GGR techniques aim to remove carbon dioxide or other greenhouse gases from the atmosphere:
  - ***Afforestation***. Engaging in a global-scale tree planting effort.
  - ***Biochar***. 'Charring' biomass and burying it so that its carbon is locked up in the soil.
  - ***Bio-energy with carbon capture and sequestration***.
  - ***Ambient Air Capture***. Building large machines that can remove carbon dioxide directly from ambient air and store it elsewhere.
  - ***Ocean Fertilisation***. Adding nutrients to the ocean in selected locations to increase primary production which draws down carbon dioxide from the atmosphere.
  - ***Enhanced Weathering***. Exposing large quantities of minerals that will react with carbon dioxide in the atmosphere and storing the resulting compound in the ocean or soil.
  - ***Ocean Alkalinity Enhancement***. Grinding up, dispersing, and dissolving rocks such as limestone, silicates, or calcium hydroxide in the ocean to increase its ability to store carbon and directly ameliorate ocean acidification.


SPACE MIRRORS
Orbiting mirrors deflect sun's rays
READINESS:
COST: $$$
FLAW: unknown weather effects; fails to prevent acidic oceans
AEROSOLS
Particles in the stratosphere reflect sun's rays
READINESS:
COST: $
FLAW: risk of ozone depletion; unknown weather effects, fails to prevent acidic oceans
FORESTING
Trees absorb CO_2
READINESS:
COST: $
FLAW: large land area needed
REFLECTIVE CROPS
Planting crops that reflect more sunlight
READINESS:
COST: $
FLAW: large land area needed; fails to prevent acidic oceans
ARTIFICIAL TREES
CO_2 sucked from air and stored underground
READINESS:
COST: $$$
FLAW: large geological cache needed
CLOUD SEEDING
Atomising seawater creates clouds to reflect sun's rays
READINESS:
COST: $$
FLAW: unknown weather effects, patchy success; fails to prevent acidic oceans
BIOCHAR
Agricultural carbon waste is burned and buried
READINESS:
COST: $$
FLAW: large land area needed
CARBONATE ADDITION
Ground limestone helps oceans absorb CO_2
READINESS:
COST: $$
FLAW: unknown effects on ecosystems
OCEAN FERTILISATION
Iron filings stimulate CO_2-eating plankton
READINESS:
COST: $$
FLAW: unknown effects on ecosystems
Cooling factor: potential to
Readiness:
– Within years
Cost:
$ – Cheap relative to cutting emissions