Economics of
Energy and Natural resources

Lesson 4. *Economics of Energy Resources: history and topics Energetic Mix Evolutions*

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Notion of Energy

The very notion of energy in its modern sense is relatively recent. It stems from the transformation of physics in Europe in the first half of the nineteenth century, which was closely bound up with the new technology of heat and electrodynamic engines, and the invention of the notions of mechanical work, efficiency and power by the engineer-savants. With the establishment of the mechanical theory of heat around 1840–60 and the 'Carnot principle', a new science of energy emerged, namely thermodynamics, which is based on two fundamental principles: the principle of energy conservation and the principle of energy dissipation or degradation.

Energy is a property of physical systems that can be used to perform work and usually comes inside physical objects like a hot gas or a gasoline tank.

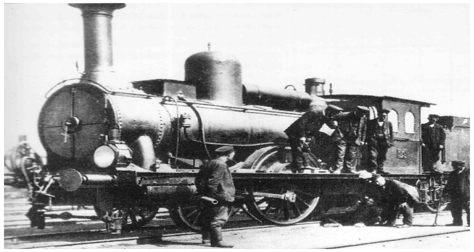
Thinking about it we can ask questions like:

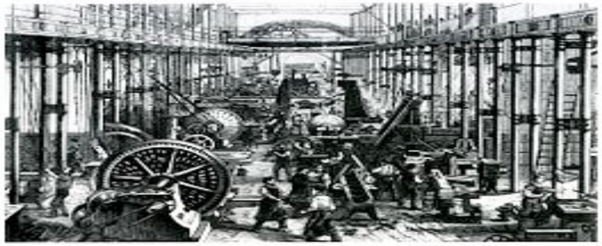
- how can we make the energy contained in a litre of gasoline to push forward a car
- how can we use the heat produced by burning coal to make the train run?

Questions like these were at the very base of the activities performed in the early seventeen hundreds by the first inventors of the so-called thermal machines. People like Thomas Newcomen (1664-1729) who built the first practical steam engine for pumping water and James Watt (1736-1819) who few decades after proposed an improved version of the same machine.

Thermal Machines

It is thanks to the work of scientists like Sadi Carnot (1796-1832) and subsequently of Émile Clapeyron (1799 - 1864), Rudolf Clausius (1822 - 1888) and William Thomson (Lord Kelvin) (1824 – 1907) that studies on the efficiency of these machines aimed at transforming heat (just a form of energy) into work brought us the notion of entropy and the laws of thermodynamics.





These laws do not tell us much about what energy is but they are very good in ruling what can we do and what we cannot do with energy. Let's briefly review them.

Nature and Sources of Energy

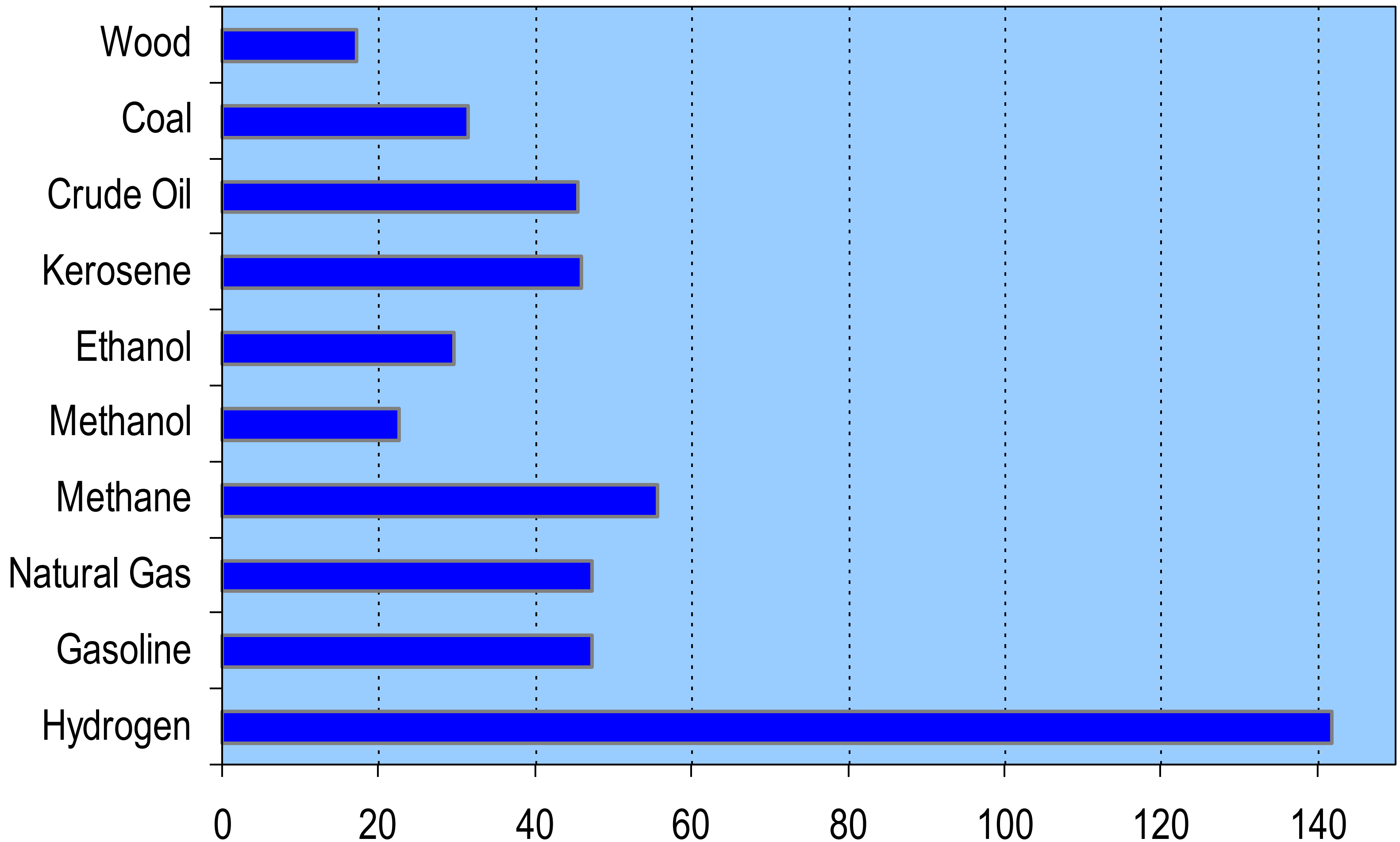
- ***Nature***
  - In physics, energy (Ancient Greek: ἐνέργεια energeia "activity, operation") is an indirectly observed quantity that is often understood as the **ability of a physical system to do work on other physical systems**
  - Capability of doing WORK... WORK = FORCE x Displacement … and so, 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).

- **The first law** of thermodynamics states that the total energy of an isolated physical system is conserved during any transformation the system can go through.
- **The second law** states that there are limitations to how much work we can get from a given amount of energy present in the form of heat.

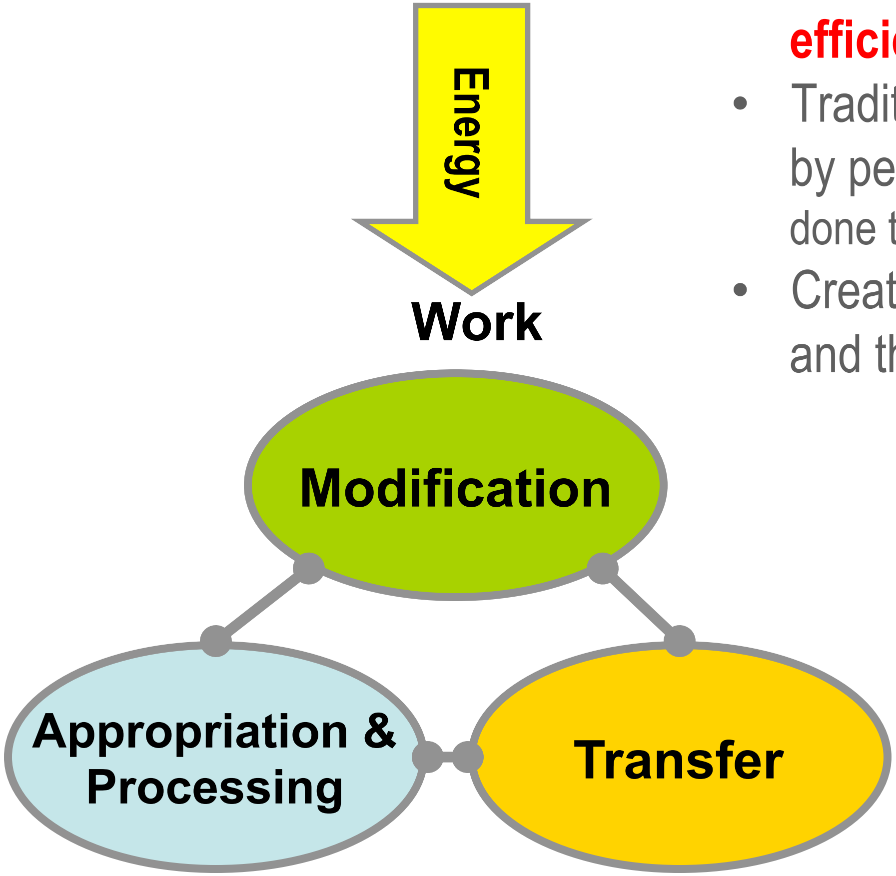
An important consequence of the second law is that there is a limit to ***the efficiency of a thermal machine****. This limit was discovered by Sadi Carnot in 1824 when he was only 28. He introduced the concept of thermal machine, generalizing the concept popular at that time of "steam engine", and showing that the efficiency of any thermal machine operating between two temperatures is bounded by a quantity that is a function of the two temperatures only.*
*Few years after the work of Carnot, Clausius used this result to introduce a quantity that is useful in describing how much heat can be changed into work during a transformation. He proposed the name "****entropy****" for his quantity.*

- Importanceof Energy
  - 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.

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



Energy and work



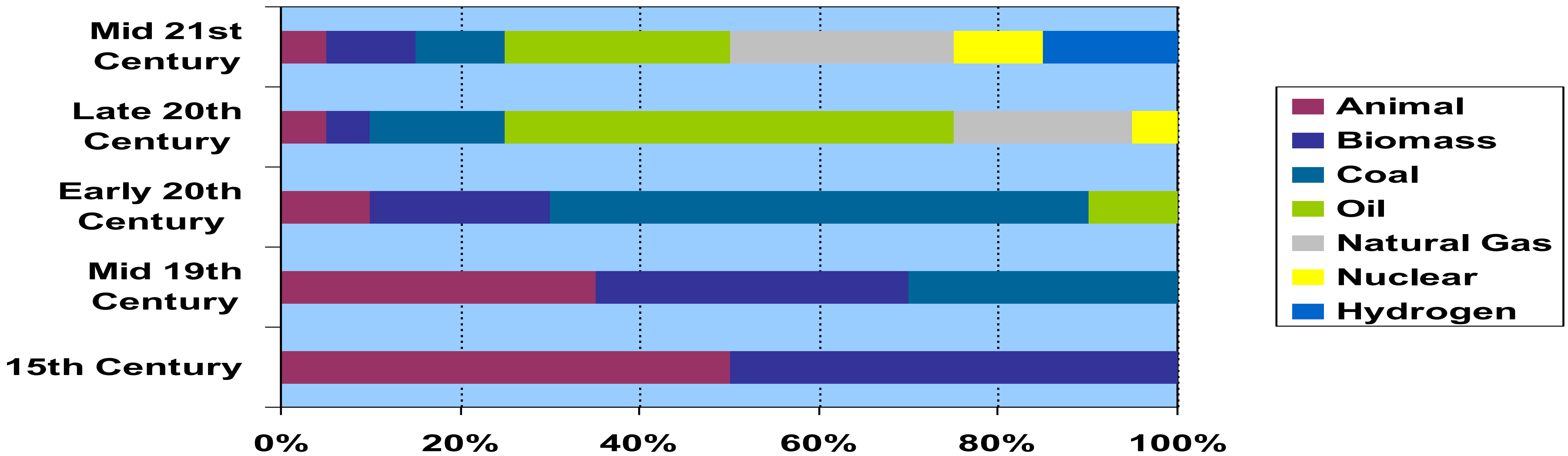
- Energy provides **work**.
- Technology enables to **use energy more efficiently** and for ***more purposes***.
- Traditionally, most of the work was performed by people. Historically, many efforts have been done to **alleviate work**.
- Creating more work performed by machines and the usage of even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

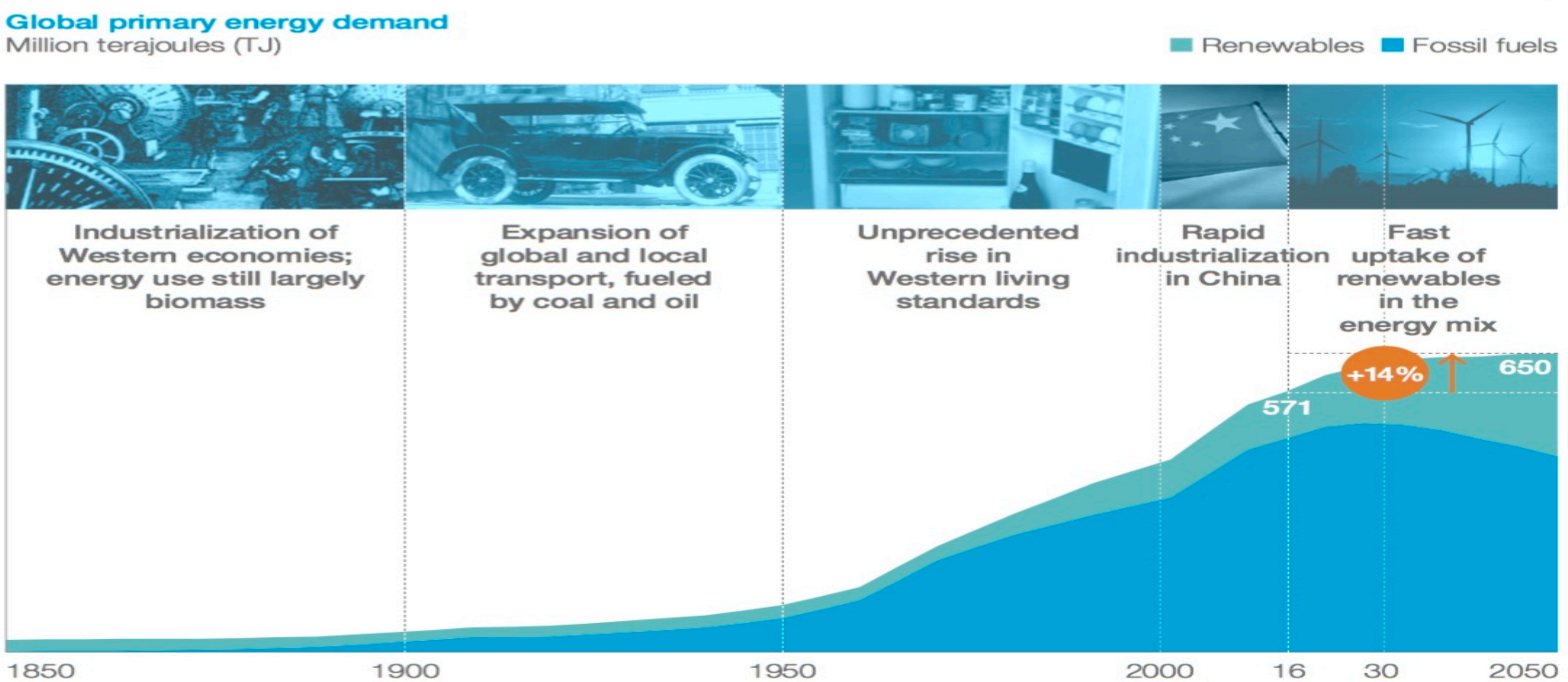
History

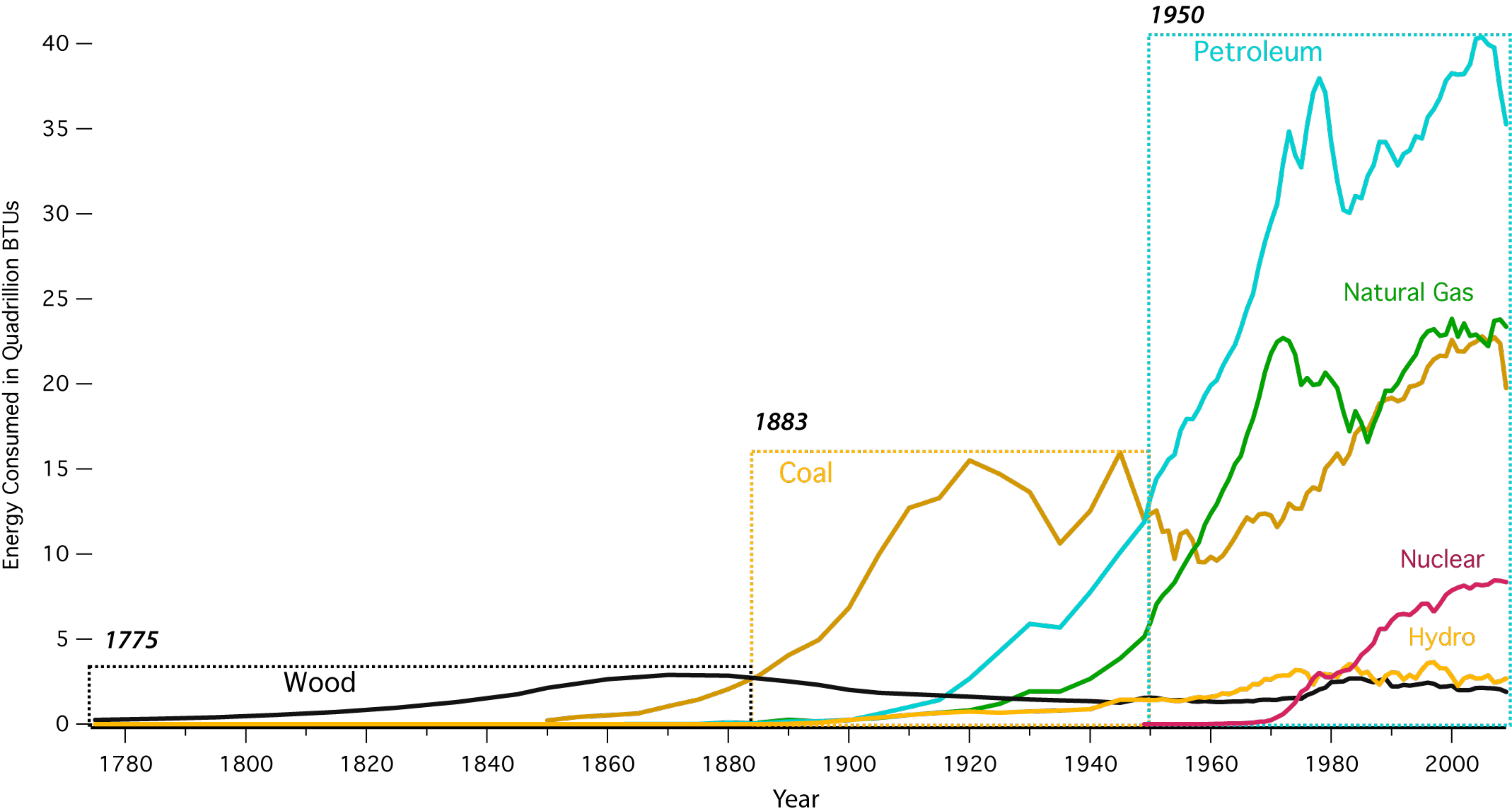
Some historians trace the genesis of the link between energy and human development right back to the domestication of fire some 500,000 years ago. Initial energy transfer occurs through photosynthesis. Very early in history humans began to exploit additional energy sources to make life more comfortable. Energy provided by burning wood enabled people to cook food, heat living areas, and develop primitive metallurgy. The **primitive man** found in East Africa 1,000,000 years ago, who had yet to discover fire, had access only to the food he ate so his daily energy consumption has been estimated at **2,000 Kcal or 2,000 dietary calories**. Energy consumption of the **hunting man** found in Europe about 100,000 years ago was about **2.5 times** that of the primitive man because he had better methods of acquiring food and also burned wood for both heating and cooking. Energy consumption increased again by almost 2.5 times as man evolved into the primitive **agricultural man** of about 5,000 years ago who harnessed draft animals to aid in growing crops. The **advanced agricultural man** of 1400 A.D. northwestern Europe again doubled the amount of energy consumption as he began inventing devices to tap the power of wind and water, began to utilize small amounts of coal for heating and harnessed animals to provide transportation. Cook's estimate of the daily per capita energy consumption for people in northwestern Europe circa 1400 was **26,000 kilocalories** (about 109 megajoules).

The dawn of the **age of industrialization**, ushered in by the invention of the steam engine, caused a 3-fold increase in energy consumption by 1875. Prior to the Industrial Revolution, goods were manufactured on a small scale in private homes. Expanding factories needed larger labor pools, thus people began congregating around factories and cities. During the Industrial Revolution, machines replaced human and animal labor in the manufacture and transportation of goods. Steam engines converting heat energy into forward motion were central to this transformation. Among other things, the steam engine allowed man to unlock the Earth's vast concentrated storage deposits of solar energy: coal, gas and oil so he no longer was limited to natural energy flows. Countries or regions without large coal deposits were consequently left behind. Within 200 years, daily per capita energy consumption of industrialized nations increased eightfold. Industrial Revolution Cook's estimate of the daily per capita energy consumption for people in England 1875 was 77,000 kilocalories (about 322 megajoules). The development of internal combustion engines, and applications of electricity. Internal combustion engines can vary widely in size and use oil. The transportation system in use today evolved as a result of the development of internal combustion engines. Electricity generation and distribution systems made the widespread use of electric motors and electric lights possible. Cook's estimate of the daily per capita energy consumption for people in the United States in 1970 was 230,000 kilocalories (about 962 megajoules).

Evolution of Energy Sources



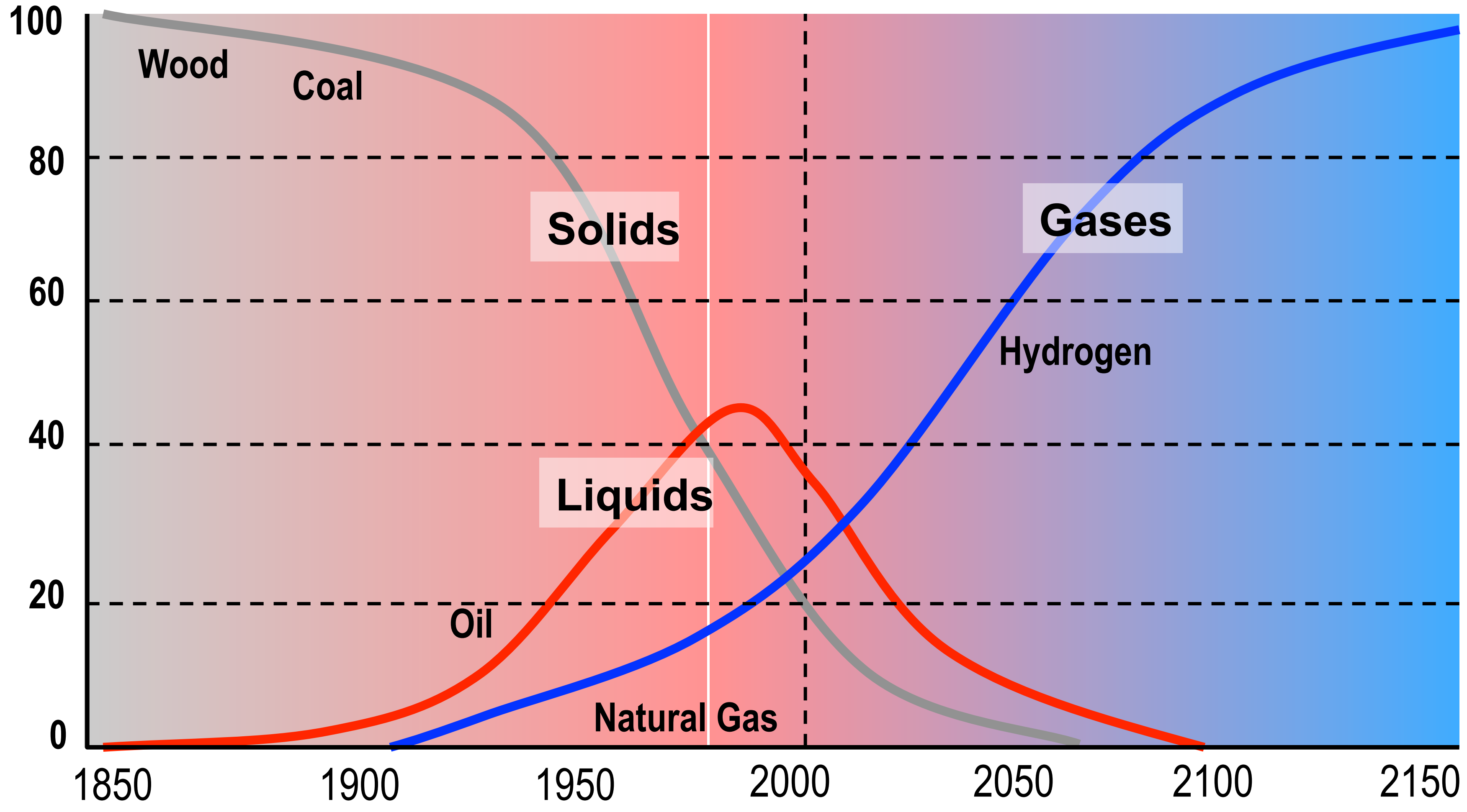



1950
Petroleum
Natural Gas
1883
Coal
Nuclear
Hydro
1775
Wood
Energy Consumed in Quadrillion BTUs
40
35
30
25
20
15
10
5
0
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
Year

Global Energy Systems Transition, (% of market)

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 (Wood, Coal) to liquids (oil) and then gazes (Natural gas and hydrogen)



Evolutionary paradigm

Applying a much debated ***evolutionary paradigm***, they frequently analyse the relationship between the gradual understanding of how to exploit the various sources of energy and the development of civilisation, eclipsing in the past the diversity of societies and civilisations. From a more recent socio-epistemological and anthropological point of view, it is the industrial revolution of the nineteenth century or, to be more precise, the '*thermo-industrial revolution*', which decisively seals the relationship between energy and modern economic development.

The rapid development of the ***modern economy is based on the invention of the internal combustion engine***, which enables cars and aeroplanes to be propelled, creating many **new technical methods of moving goods and people and accelerating the speed of transportation** in the contemporary world. This ***social invention of speed and acceleration*** commences with the steam engine mounted on wheels and metal rails, whose heyday really began between 1830 and 1850.
COLLECTIVE MOBILITY - The **railway** revolutionised the space–time relationship in Western culture in the same way as air travel does today. The steam locomotive, powered by coal or wood, therefore became the symbol of modernity and progress propagated in the colonial empires towards the end of the nineteenth century.
PRIVATE MOBILITY - The invention of the **automobile** dramatically increased the demand for oil products. The growth of the automobile industry led to roadway construction, which required energy. Better roads permitted higher speeds. Higher speeds permitted bigger, faster cars. Bigger, faster cars required better roads. Convenience of the automobile led to two-car families. Job growth in automobile-related industries. Major role in development of industrialized nations. Cars altered people's lifestyles: Vacationers could travel greater distance. ¬ People could live farther from work, leading to sprawling cities and suburbs. ¬ In the suburbs, labor-saving, energy-consuming devices became essential in the home. ¬ We expect to see Florida oranges, California lettuces, and Central American bananas in any supermarket in North America. ϖ They must be processed, refrigerated, and transported to distant locations.

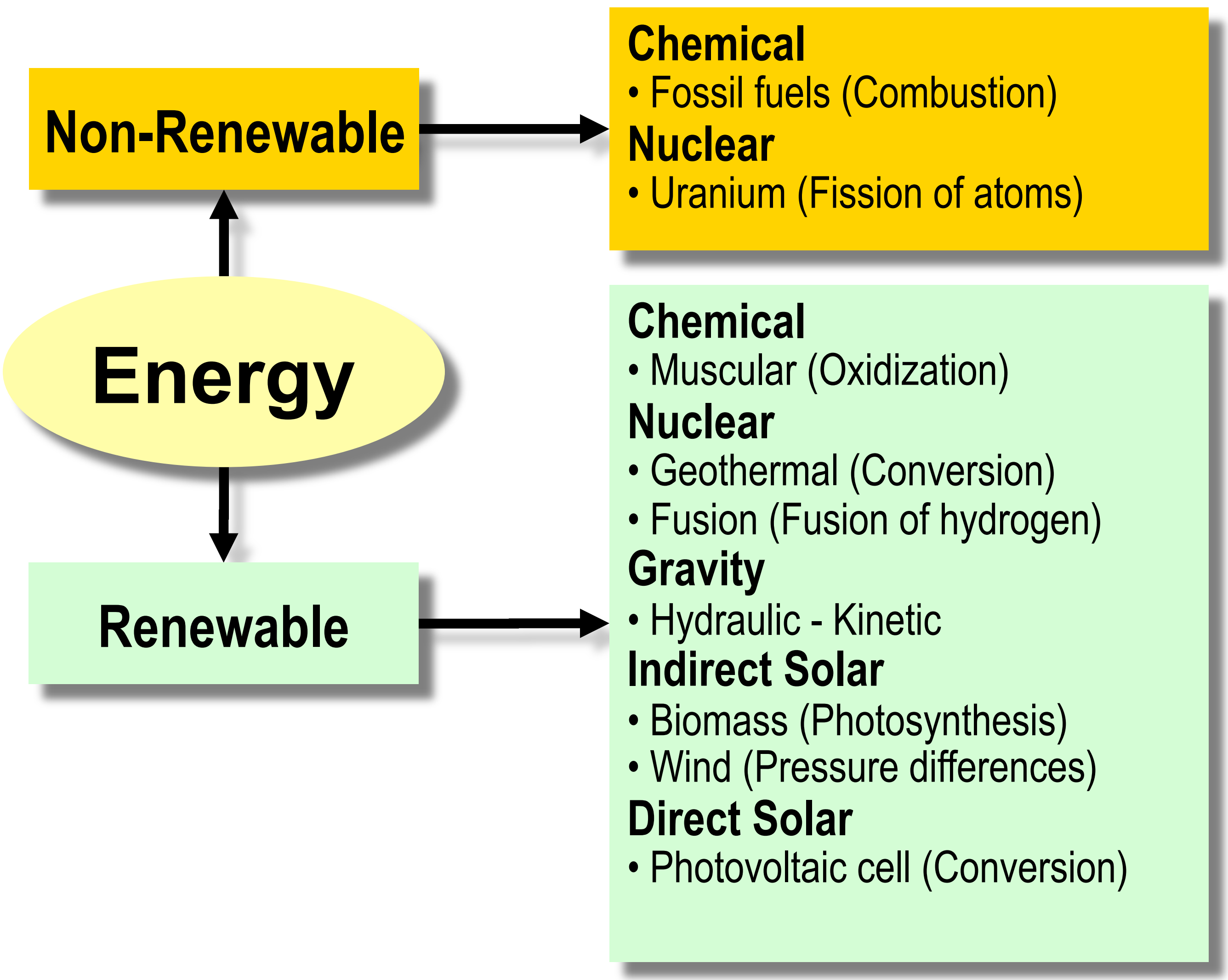
Modern economic development as we know it today, which is the product of the industrialisation process of the last two centuries, is fuelled primarily by non-renewable mineral resources extracted from the lithosphere (the outermost shell of Earth). It benefits from relatively abundant and low-cost energy obtained from fossil fuels, namely oil, natural gas and coal, and, to a much lesser degree, fissile fuels such as uranium. The other, traditional sources of energy such as biomass, wind and water power have been marginalised in the energy mix of the industrialised countries.
Crude oil, with its exceptional qualities, has become the primary source of industrial and military power, replacing coal as reference energy. Liquid, easy to transport and store as well as a very intense form of energy, black gold has become the invisible engine of growth, particularly since the 1950s and 1960s. Equally, it has been a stake in many armed conflicts. Oil is extracted from rare oil fields located in sedimentary rocks of biogeochemical origin. It is the main source of fuels for continental and maritime transport and the only source for aviation. This raw material lies at the very heart of the way of life of the majority of human beings, in terms not just of energy that it provides, of course, but also of objects, food production and even health.
Again, there was the exploration and discovery of oil deposits. Although the existence of oil has been known since very ancient times, crude oil was not utilised for industrial purposes until the 1850s, first in Baku and Romania, then from 1859 onwards in the United States (US) with the famous drilling of Colonel Drake in Titusville, Pennsylvania. The golden age of oil, characterised by a hitherto unprecedented abundance of energy supply, began in earnest in the 1950s, following the major oil discoveries made since the start of the twentieth century

The area of social sciences that focuses on development has not yet taken full account of the importance of oil in the extraordinary phase of growth experienced by mankind – albeit in a very unequal way – in the twentieth century. This is an unprecedented phenomenon in the history of humanity and in the geological and biological history of Earth. The development model based on high levels of energy consumption and which facilitated the demographic and scientific-technological explosion of the twentieth century is encountering three constraints which, combined, are becoming increasingly problematic: peak oil and its implications, the rapid demographic and economic growth in the global South, and the degradation of the environment and disturbance of the biosphere's climate system. Since the 1970s debate has been raging between the optimists who trust market forces and man's capacity for innovation and technological ingenuity to overcome these obstacles, on the one hand, and the pessimists (who nonetheless would describe themselves as realists) who believe that there is an urgent need to take seriously the dual threat of post-peak oil and global warming, on the other.

Although the process of industrialisation implies breaking away from a certain 'state-of-nature society', it has its roots in a deeply ingrained, historical momentum. Europe was industrious long before it was industrial; so was China. The very long history of mediaeval and proto-industrial hydraulics is a reminder of this. However, the Vitruvian paradigm of hydraulic technology is well and truly blown out of the water by the revolution of 'fire-engines' and the increasingly rapid spread of the industrial use of fossil fuels, namely coal, oil and natural gas. The technically minded civilisation of Europe, with its quest to master natural forces to increase its mobility and its productivity, owes its rapid development to a constant stream of inventions and innovations in the energy sphere: wind power (first for sailing and then for windmills), animal power (with the invention of stirrups and harnesses), water mills (an ancient invention, but a technical and social revolution in mediaeval times, the hydropower harnessed by monasteries being a prime example), then the improvements to water wheels and turbines which for many years staved off competition from steam engines. However, these forms of power, which are biospheric and organic in origin, are subject to major geographical and meteorological constraints, not to mention the fact that animals and people suffer from fatigue. They only enable limited rates of growth and certainly not the exponential growth over a long period delivered by the golden age of oil. It was artisans and technicians – many of whom had no involvement in scientific circles – who learned the art of exploiting mechanical energy. But **we must not forget the vital importance of the rise of the engineering profession** which for many years was dedicated to the military tradition and the formation of modern states. Specialising initially in the construction of fortifications and designing war machines, at the end of the revolutionary and Napoleonic wars the engineers turned to civil engineering. They became key players in the industrial revolution and colonial expansion. A highly qualified workforce, participating themselves in developments in physical–mathematical sciences, they were responsible for developing the old machines into increasingly complex technical systems by incorporating into them ever more powerful motors.

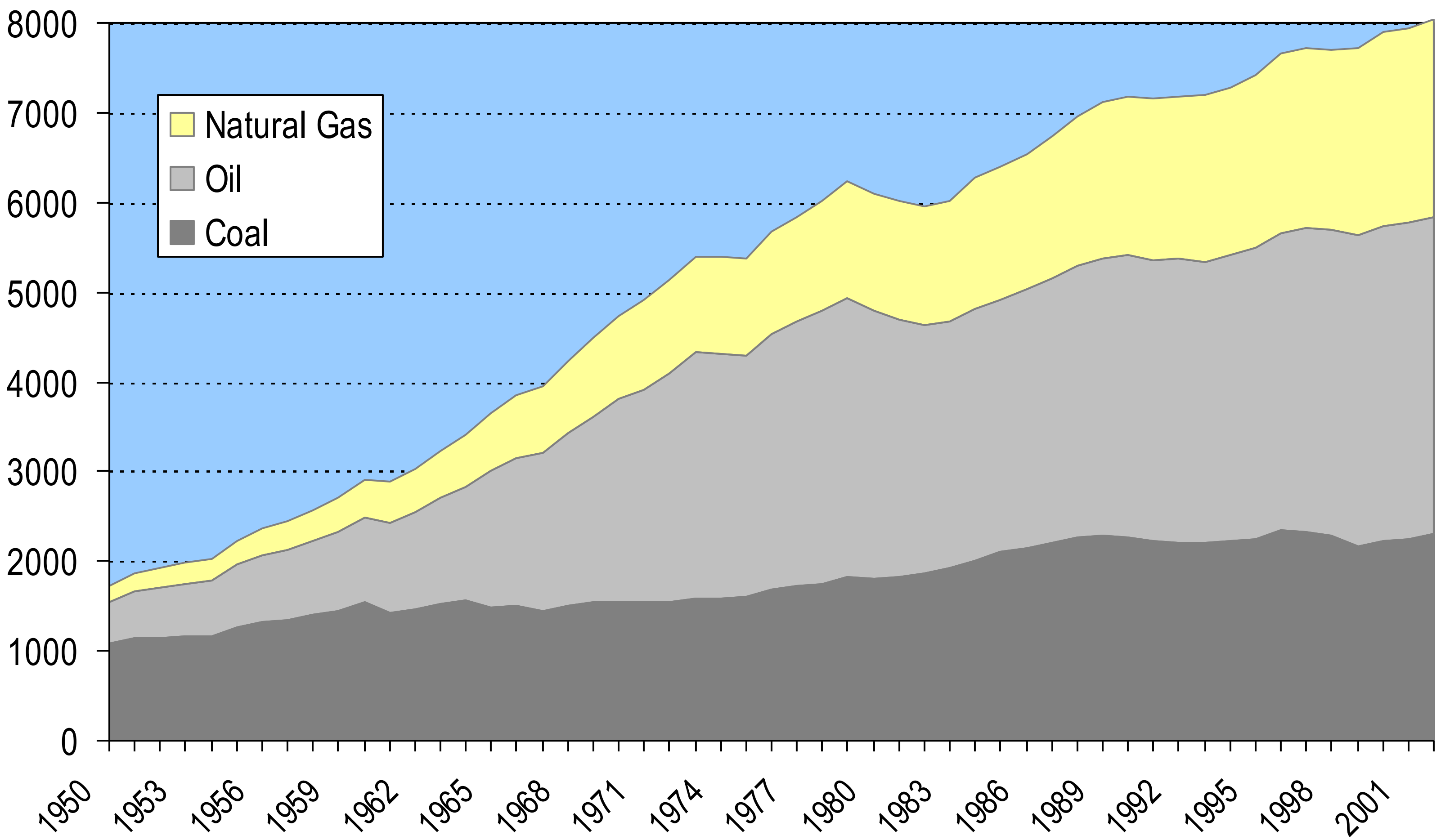
However, the mass-scale use of fossil energies, which dates back to the nineteenth century, spread only gradually until the 1920s. The trend in annual global emissions of CO2, established over a long series starting in the pre-industrial period, perfectly illustrates the acceleration of the thermo-industrial revolution from 1850 onwards. Until then the use of energy which was biological or biospheric in origin did not affect the stability of the carbon cycle. Massive reliance on non-renewable fossil energies, and oil in particular, became the pillar of economic growth after the end of the Second World War, the result of a combination of factors and circumstances.

Sources of Energy

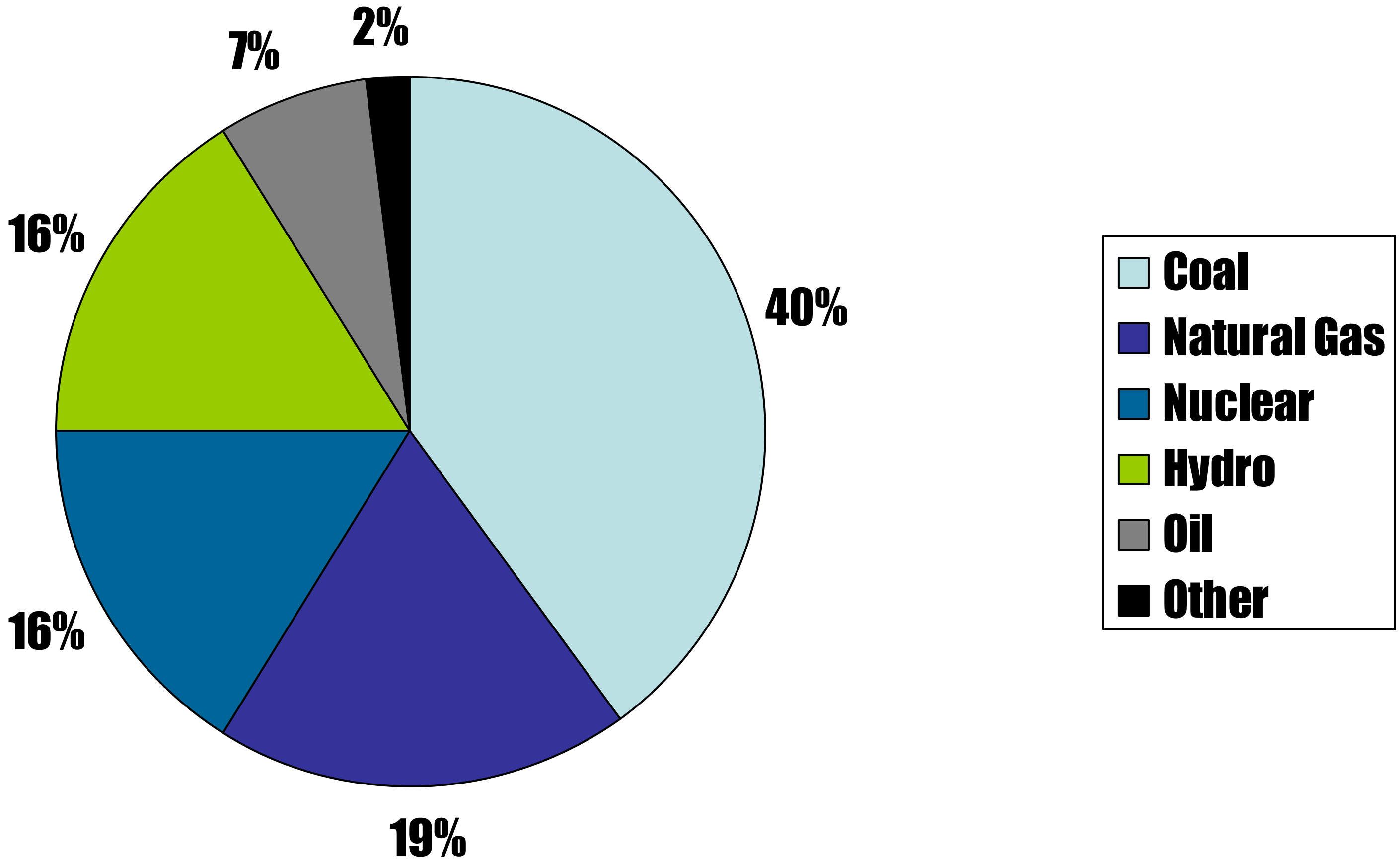


World Fossil Fuel Consumption per Source

in million of tons of equivalent oil

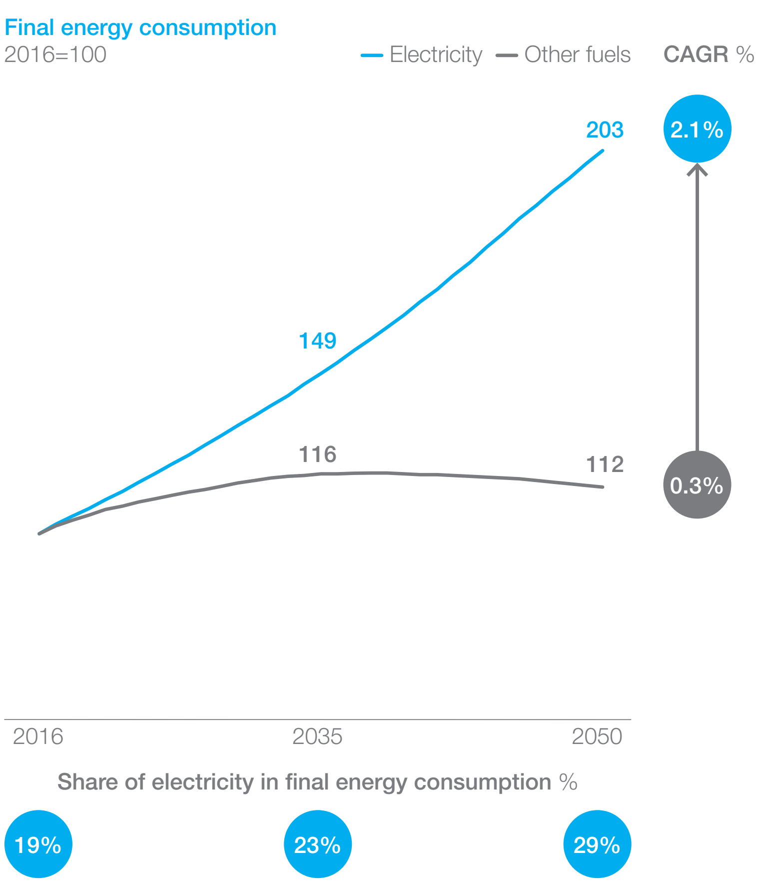


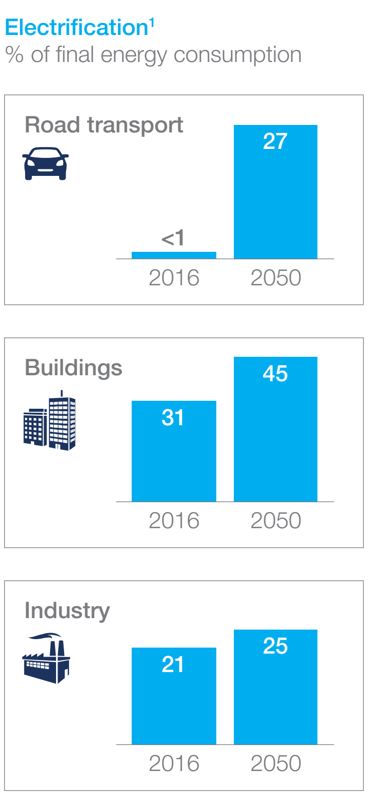
Total World Electricity Generation by Type of Fuel, 2002



Electrification across key end uses, particularly in buildings and road transport, drives a doubling of electricity demand by 2050

- Electricity demand doubles until 2050 and grows its share in total final energy consumption from 19% today to 29% by 2050, as demand for other fuels combined flattens
- Uptake of EVs accelerates in all road segments as cost parity of EVs is reached by the early to mid-2020s
- Higher living standards in non-OECD countries—mainly China and India—support fast-rising demand for space cooling and appliances
- Further electrification in industry is limited as electrification of medium- and high-temperature heat requires low electricity prices. Electrification of low-temperature heat in industry is partially economical today





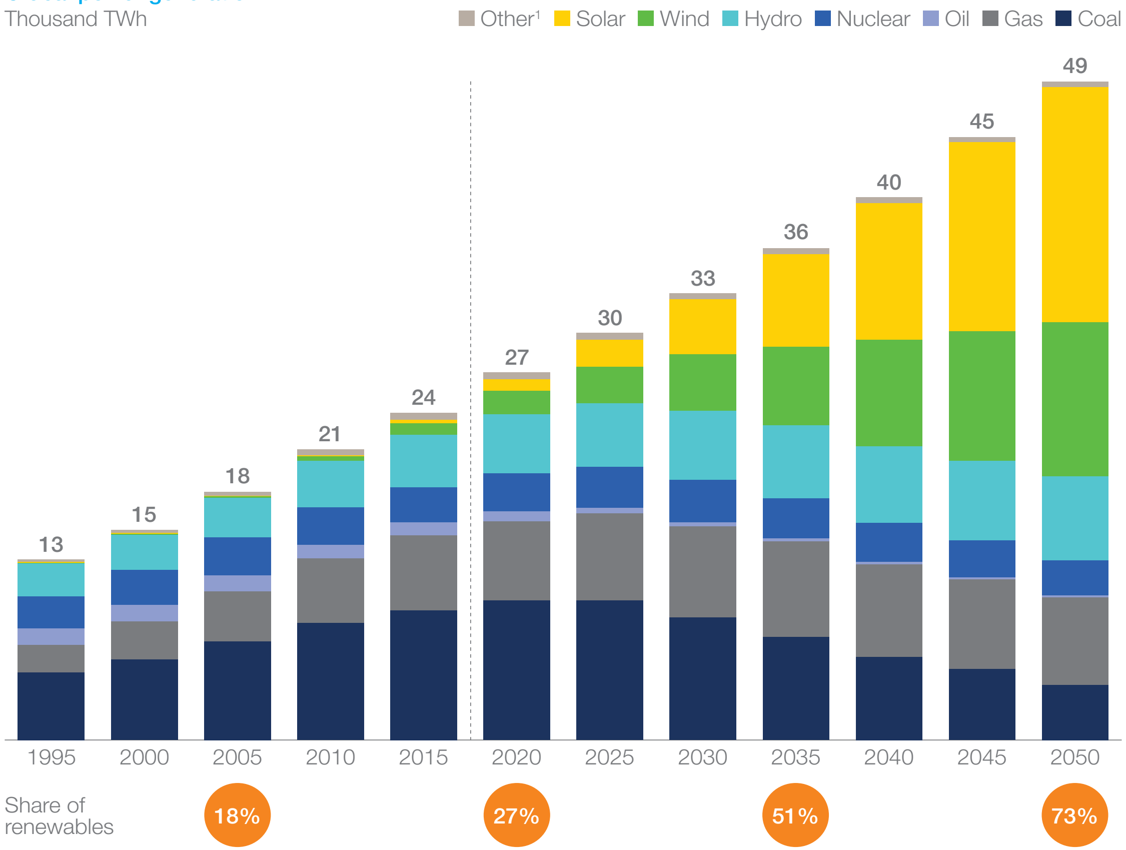
1 Buildings includes residential buildings in OECD Europe and OECD Americas; transport includes passenger cars, trucks, vans, buses, and 2- and 3-wheelers

Source: McKinsey Energy Insights' Global Energy Perspective, January 2019

Renewable generation accounts for more than 50% of power supply post-2035, a clear trend break from historical fossil fuel-based generation

- The role of renewable resources in power generation grows at an accelerated pace. From around 25% today, renewables will grow their share of global generation to around 50% by 2035 and to close to 75% by mid-century
- Coal and oil generation decrease rapidly, partially substituted by renewables, partially by gas-based alternatives with lower cost or lower carbon emissions
- Gas generation often remains to act as a stable baseload and dispatchable capacity provider in a renewable-heavy system but does see a peak around 2035

Global power generation
Thousand TWh



1 Other includes biomass, geothermal, and marine
Source: McKinsey Energy Insights' Global Energy Perspective, January 2019

In a relatively **optimistic scenario**, the International Energy Agency (IEA) predicts that:

- **global primary energy demand will increase** by 36 per cent between 2008 and 2035, or 1.2 per cent per year, rising from 12,300 million tonnes of oil equivalent (Mtoe) to over 16,700 Mtoe (IEA, 2010).
- The share of renewable energies could rise from 7 per cent to 14 per cent of total energy demand between 2008 and 2035;
- The share of nuclear energy will increase from 6 to 8 per cent.
- The share of non-conventional oils – tar sands and oil shales and extra heavy oil in particular – could rise from 3 per cent to more than 10 per cent of global oil supply in 2035, with a considerable impact on the environment because of the vast amount of greenhouse gas (GHG) emitted and the intensive use of water.
- The IEA estimates, finally, that global oil production (all categories) will reach a peak between 2020 and 2035.

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:

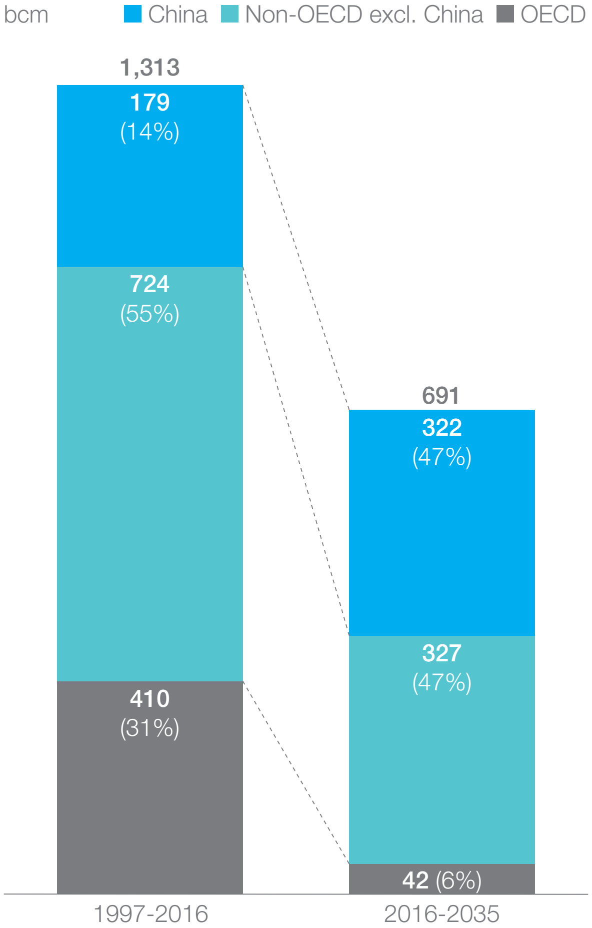
- Transportation.
- Industrial processes.
- Appliances.

China's gas demand growth is greater than that of the next 10 largest growth countries, including the US, and represents nearly half of demand growth through 2035

- The pace of global growth is significantly changing; while the last two decades added more than 1,300 bcm, growth over the next two decades will be only half as much
- The growth in OECD gas demand practically disapears, despite a continued growth of more than 100 bcm in US demand
  - China counters the trend of declining growth; it is doubling the speed of its growth and adding more than 300 bcm of demand in the next 20 years. This means China's demand growth is greater than that of the next 10 largest countries combined, including the US. As a consequence, almost half of the total growth through 2035 comes from China
  - Chinese demand developments will increasingly dominate the signaling for traded gas markets globally, especially given that most of the other big growth markets are not importers
- More than 70% of gas demand decline stems from only four countries: Japan, Italy, the UAE, and the UK

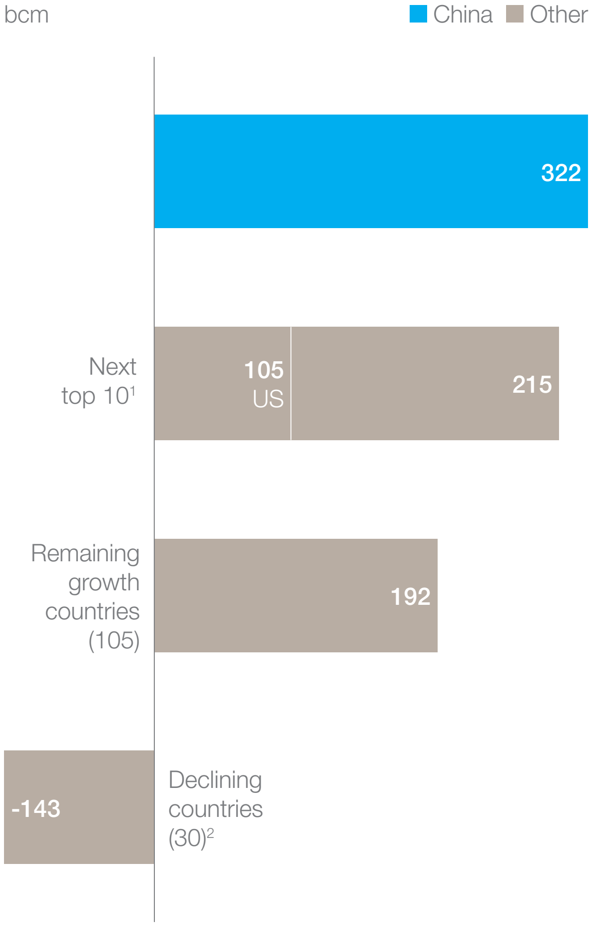
Natural gas demand growth past vs. future by region

bcm



Top growth regions for natural gas demand 2016-35

bcm



1 Besides the US, top 10 include Egypt, India, Indonesia, Iran, Nigeria, Pakistan, Qatar, Russia, and Ukraine

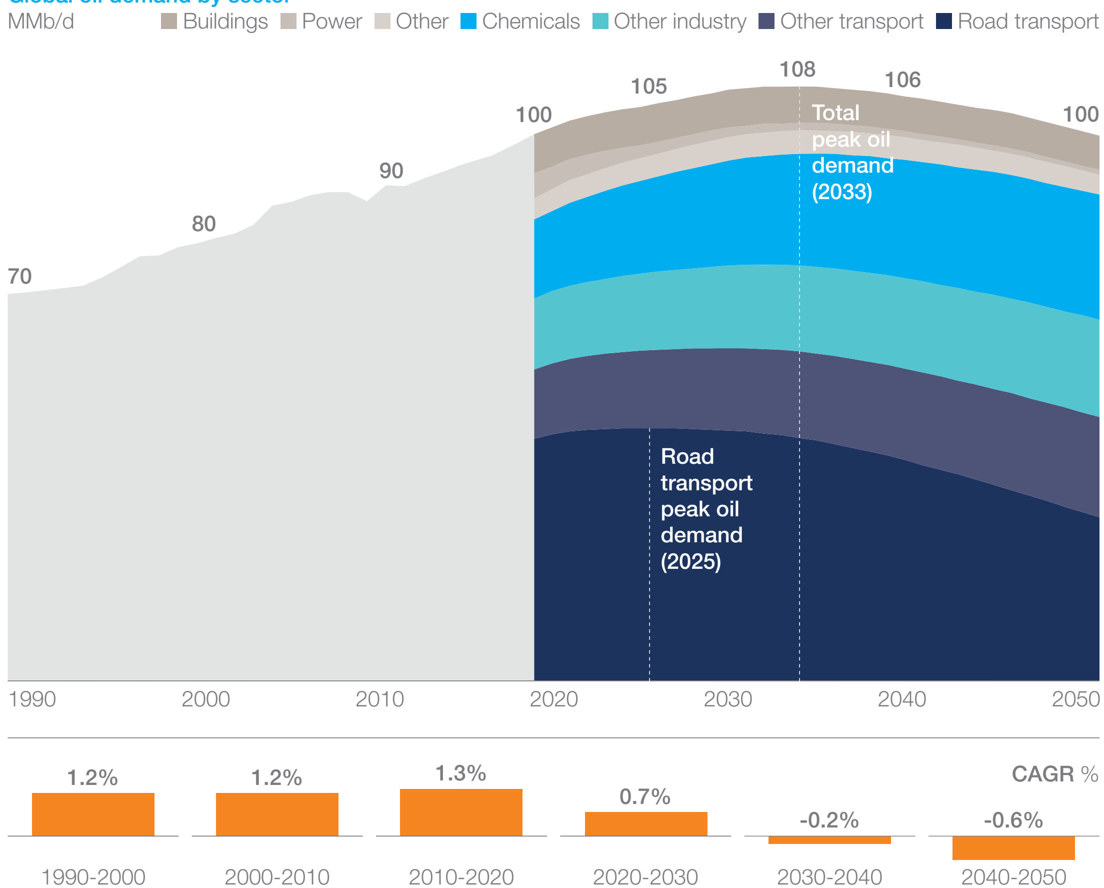
2 Main demand declines in France, Italy, Japan, United Kingdom, and United Arab Emirates

Source: McKinsey Energy Insights' Global Energy Perspective, January 2019

Despite stable historical growth of more than 1% p.a., oil demand growth is projected to slow, followed by a peak in the early 2030s at 108 MMb/d

- Oil demand has grown at more than 1% p.a. over the last three decades, but this growth is expected to slow down significantly from 2020 onward
- In our Reference Case, we project a peak in global oil demand in 2033, which is four years earlier than in last year's edition of our outlook
- Oil demand for road transport is a key driver. Triggered by an increasing adoption of EVs, oil demand for road transport peaks in 2025 and declines afterwards. By 2050, demand is projected at ~30 million barrels per day (MMb/d), which is one third below today's demand levels
- The chemicals sector, an important engine of growth for oil demand, shows a slow down in demand especially post-2030, as a result of increased recycling rates of plastics

Global oil demand by sector



Source: McKinsey Energy Insights' Global Energy Perspective, January 2019

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

In the IEA's scenario of 'new policies' presupposes that every country will implement the political undertakings and action plans which they announced for reducing their carbon dioxide (CO2) emissions. Regardless of which scenario is applied, the IEA predicts that fossil fuels will still be the predominant source of energy in 2035 and will account for more than half the increase in overall demand for primary energy. As a consequence of demographic and economic growth and urbanisation in emerging countries, 93 per cent of the additional demand will come from emerging economies and developing countries. But the IEA implicitly indicates that the peak of conventional oil production may have already been reached in 2006 at 70 million barrels per day. In 2035 today's oil fields are expected to produce about a fifth of total conventional oil production. This means that 80 per cent of the 2035 projected production will have to come from new oil fields, which seems quite an optimistic projection.

Challenges

Environment

- Provide environmentally safe sources of energy.
- Going through the energy transition (from solid to gazes).

In the following chapters, we discuss main developments for each of the fuels

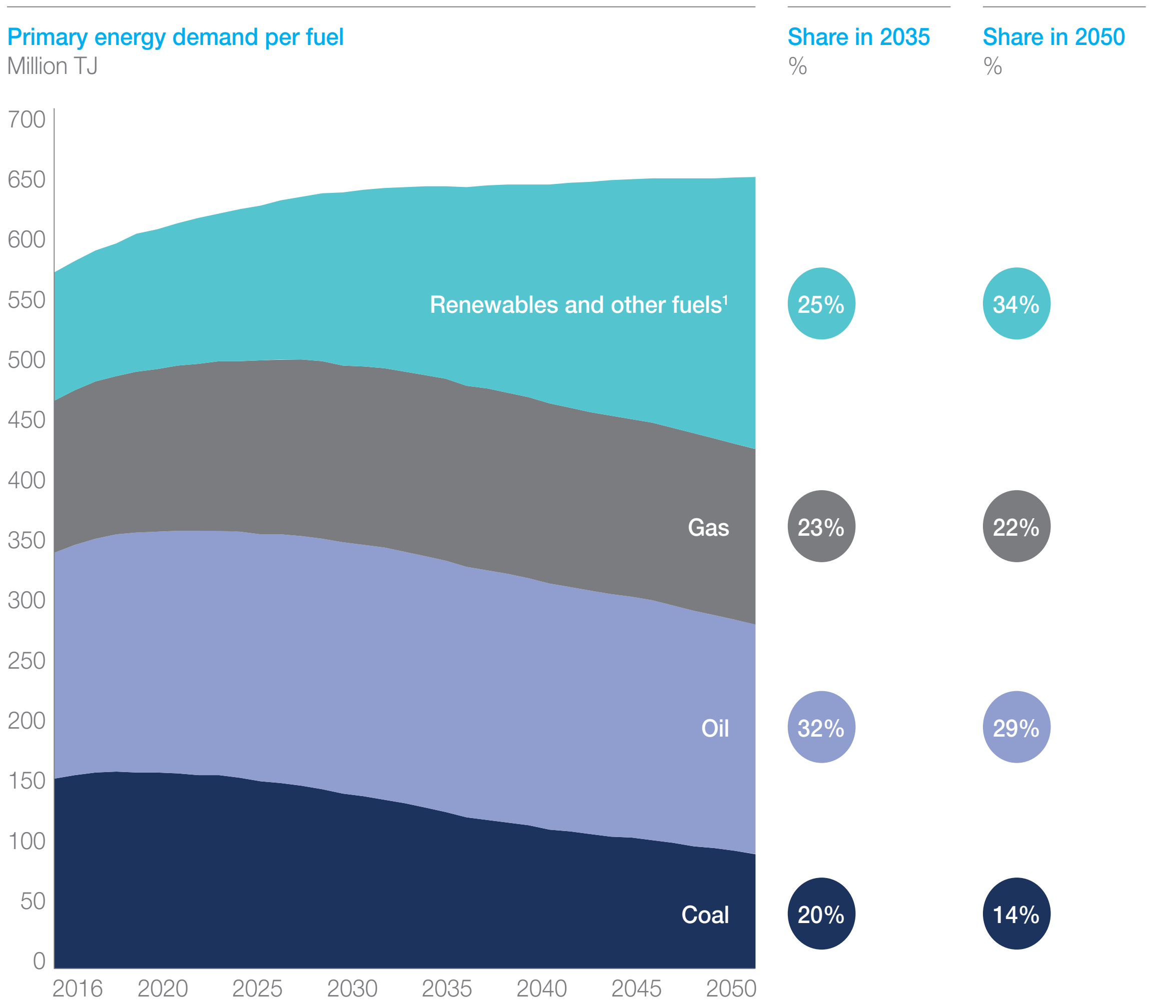
Insights in the following chapters:

2 **Electricity** consumption doubles until 2050, while renewables make up over 50% of generation by 2035

3 **Gas** continues to grow its share of global energy demand—the only fossil fuel to do so—and then plateaus after 2035

4 **Oil** demand growth slows down substantially, with a projected peak in the early 2030s

5 **Carbon emissions** are projected to decline due to decreasing **coal** demand, yet a 2-degree pathway by 2050 remains far away



1 Includes biomass, hydro, and nuclear
Source: McKinsey Energy Insights' Global Energy Perspective, January 2019

Energy mix:

The range of energy sources (Portfolio like) of a region, either renewable or non-renewable.
The energy mix is the group of different primary energy sources from which secondary energy for direct use - usually electricity - is produced. Primary energy in the form of fossil fuels is nowadays still mostly used directly for motor-driven vehicles, i.e. transport. Further energy conversion of the co-produced waste heat after burning is not possible.

Energy issues are an increasingly pressing priority in national and global policies alike. Regular access to and reasonable prices for raw energy materials are factors essential to economic and social development, as witnessed by the continuous increase in global energy demand (which should go up by one-third within 2035 according to official estimates, spurred by development in China and other emerging economies and brisk global demographic growth). This rise in world energy consumption is associated with increased challenges in terms of energy supply security, competition, energy efficiency, sustainable growth and containment of environmental impact.

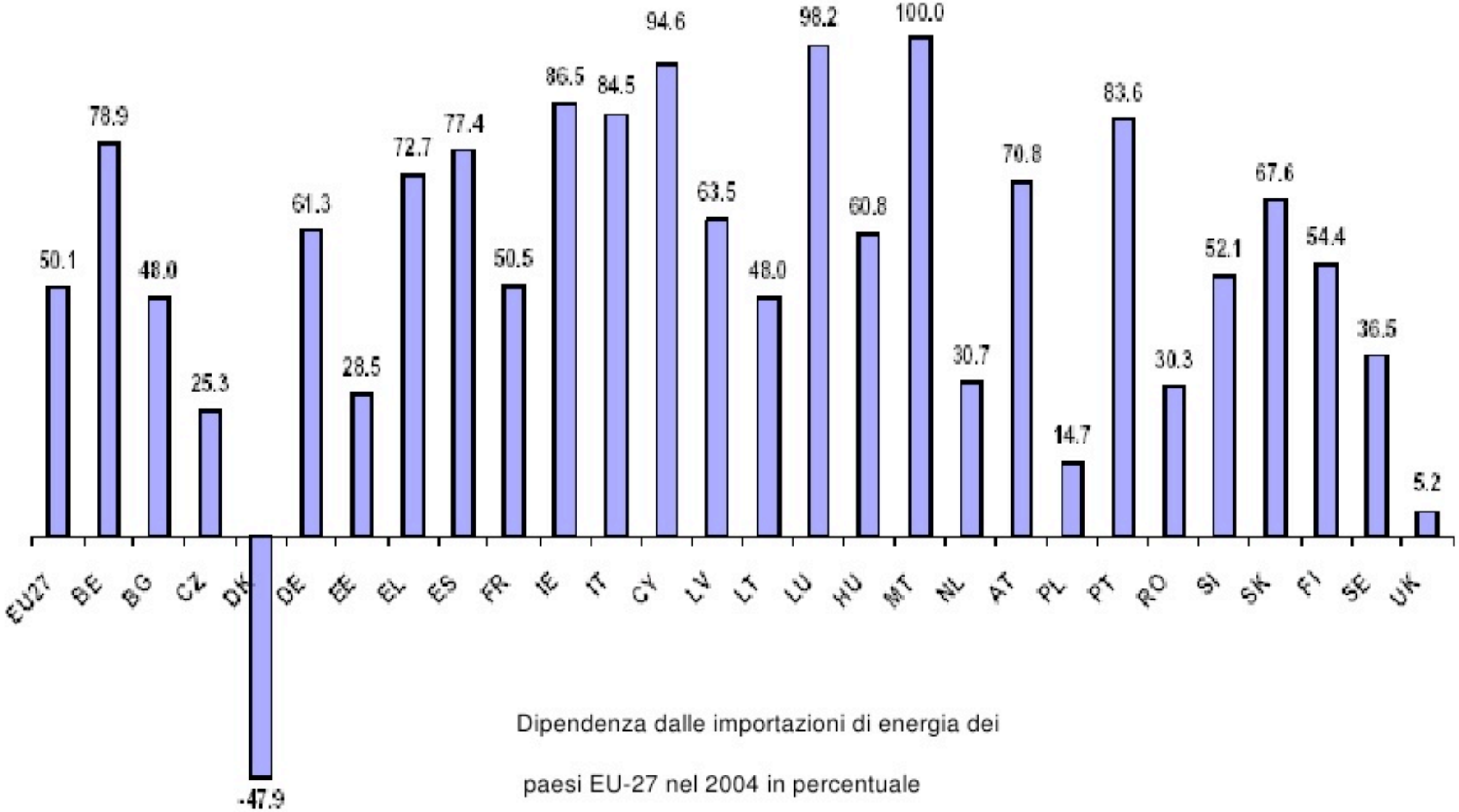
SURENESS. One of the main goals of X-nation's **energy security strategy** is *to ensure the certainty and regularity of supply by means of concerted national and international level efforts that have consumers and producers in mind*. Italy makes it a priority to differentiate supply countries, routes and directions, as well as the energy mix itself (fossil, renewable), with a view to strengthening its role as an "energy hub" connecting Africa, central and eastern Europe and Asia.
Overall primary energy consumption ***in the U.S.*** in 2015 relied most on petroleum , natural gas and coal . Renewables contributed and nuclear power . In the same year, about 4 million GWh of electricity were generated in the U.S., 67% of which was generated from fossil fuels (coal, natural gas, and < 1% petroleum), 20% from nuclear power, 6% hydropower and 7% other renewables.
While the rise of global energy consumption with the global population growth cannot immediately be counteracted, the sustainability of growth can partially be improved by changing the energy mix towards renewables.

Challenges facing the ***EU*** *in the field of energy include issues such as* ***increasing import dependency****, limited diversification,* ***high and volatile energy prices****,* ***growing global energy demand****, security risks affecting producing and transit countries, the growing threats of climate change, slow progress in energy efficiency, challenges posed by the increasing share of renewables, and the need for increased transparency, further integration and interconnection in energy markets. A variety of measures aiming to achieve an integrated energy market, security of energy supply and a sustainable energy sector are at the core of the EU's energy policy.*

One of the agreed priorities of the May 2013 European Council was to intensify the diversification of the EU's energy supply and to develop local energy resources **in order to ensure security** of supply and **reduce external energy dependency**. With regard to renewable energy sources, Directive 2009/28/EC of 23 April 2009 introduced a 20% target to be reached by 2020, and the Commission proposed a target of at least 27% by 2030 in a revised Renewable Energy Directive (COM(2016)0382).
In the light of the crucial importance of gas and oil for the security of the EU's energy supply, the EU adopted ***several measures to ensure that risk assessments are carried out and that adequate preventive action plans and emergency plans are developed***. Regulation (EU) No 994/2010 concerning measures to safeguard security of gas supply was adopted on 20 October 2010 with the aim of strengthening prevention and crisis response mechanisms. Directive 2009/119/EC requires **Member States to maintain minimum oil stocks**, corresponding to 90 days of average daily net imports or 61 days of average daily inland consumption, whichever of the two quantities is greater. The Commission has proposed extending the scope of application of Directive 2009/73/EC (the Gas Directive) to pipelines to and from third countries, including existing and future pipelines (COM(2017)0660).

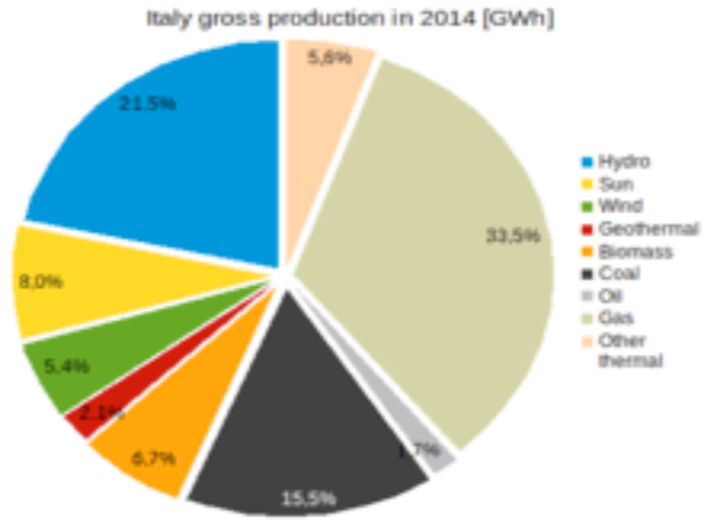
According to the Energy Union (2015), ***the five main aims of the EU's energy policy are to****:*
1.Ensure the functioning of the ***internal energy market*** *and the* ***interconnection of energy networks****;*
2.Ensure ***security*** *of energy supply in the EU;*
3.Promote energy ***efficiency*** *and energy saving;*
4.Decarbonise *the economy and move towards a low-carbon economy in line with the Paris Agreement;*
5.Promote the development of new and renewable forms of energy to better align and ***integrate climate change goals*** *into the new market design;*
6.Promote research, innovation and **competitiveness**.

La sicurezza energetica

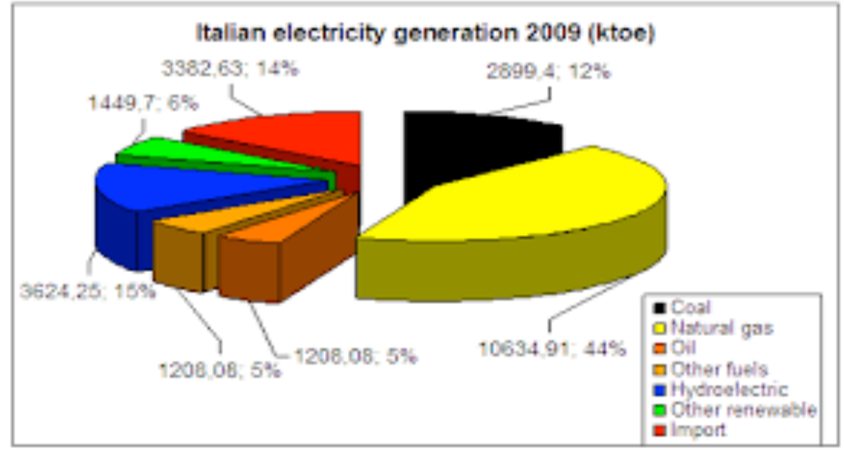


Dipendenza dalle importazioni di energia dei

paesi EU-27 nel 2004 in percentuale

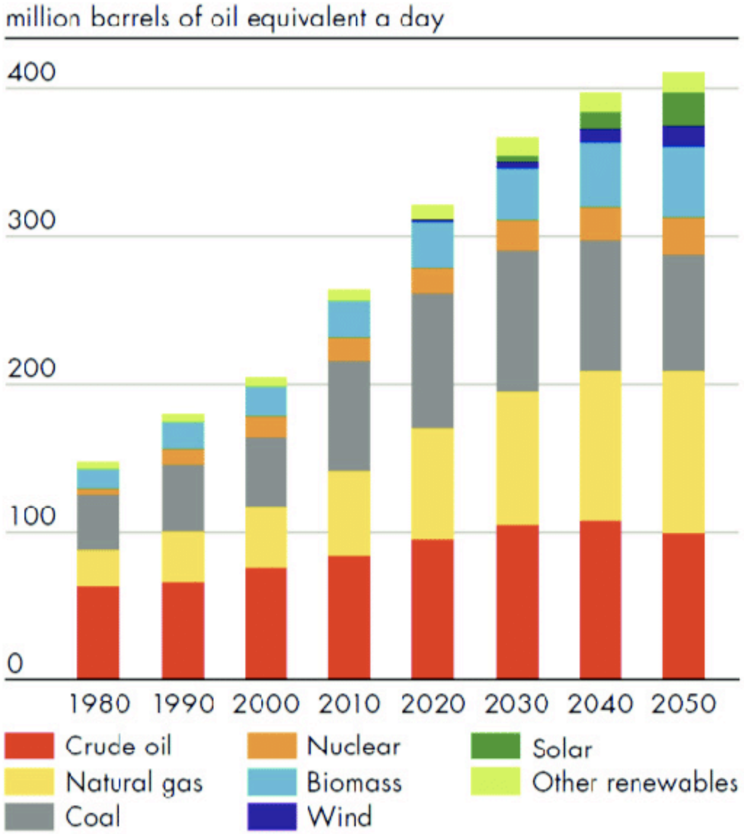


Italy gross production in 2014 [GWh]
5,6%
21,5%
33,5%
8,0%
5,4%
2,1%
6,7%
15,5%
1,7%
Hydro
Sun
Wind
Geothermal
Biomass
Coal
Oil
Gas
Other thermal

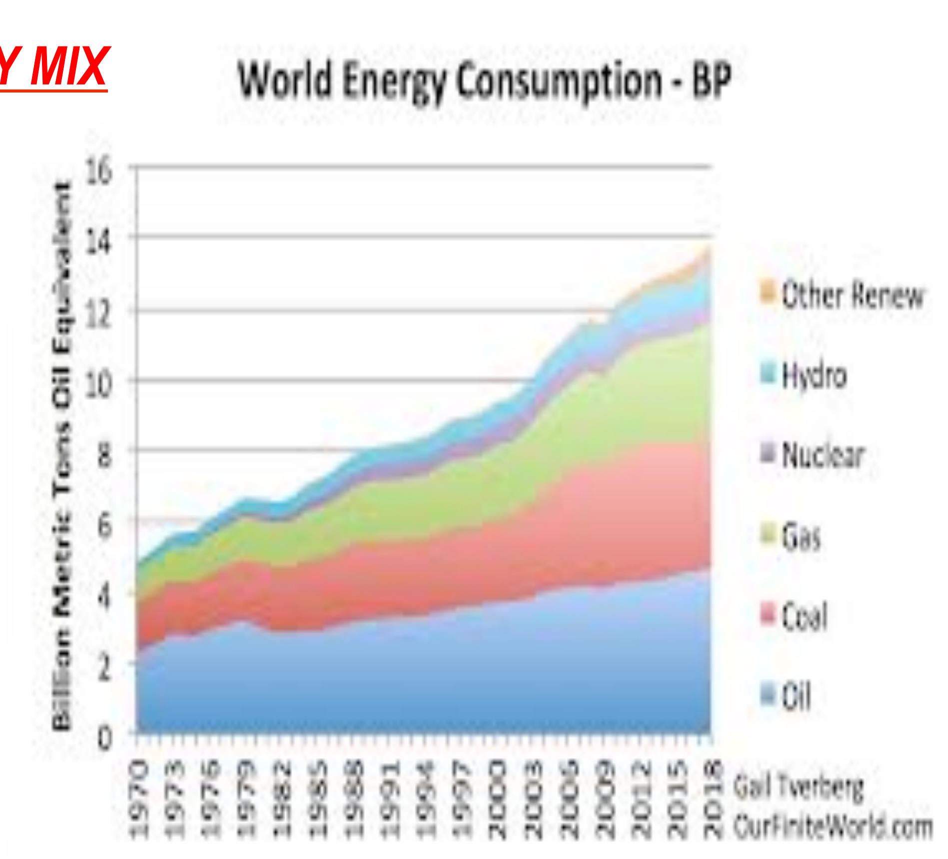


Italian electricity generation 2009 (ktoe)
3382,63; 14%
2899,4; 12%
1449,7; 6%
3624,25; 15%
1208,08; 5%
1208,08; 5%
10634,91; 44%
Coal
Natural gas
Oil
Other fuels
Hydroelectric
Other renewable
Import

ENERGY MIX



million barrels of oil equivalent a day
400
300
200
100
0
1980
1990
2000
2010
2020
2030
2040
2050
Crude oil
Natural gas
Coal
Nuclear
Biomass
Wind
Solar
Other renewables

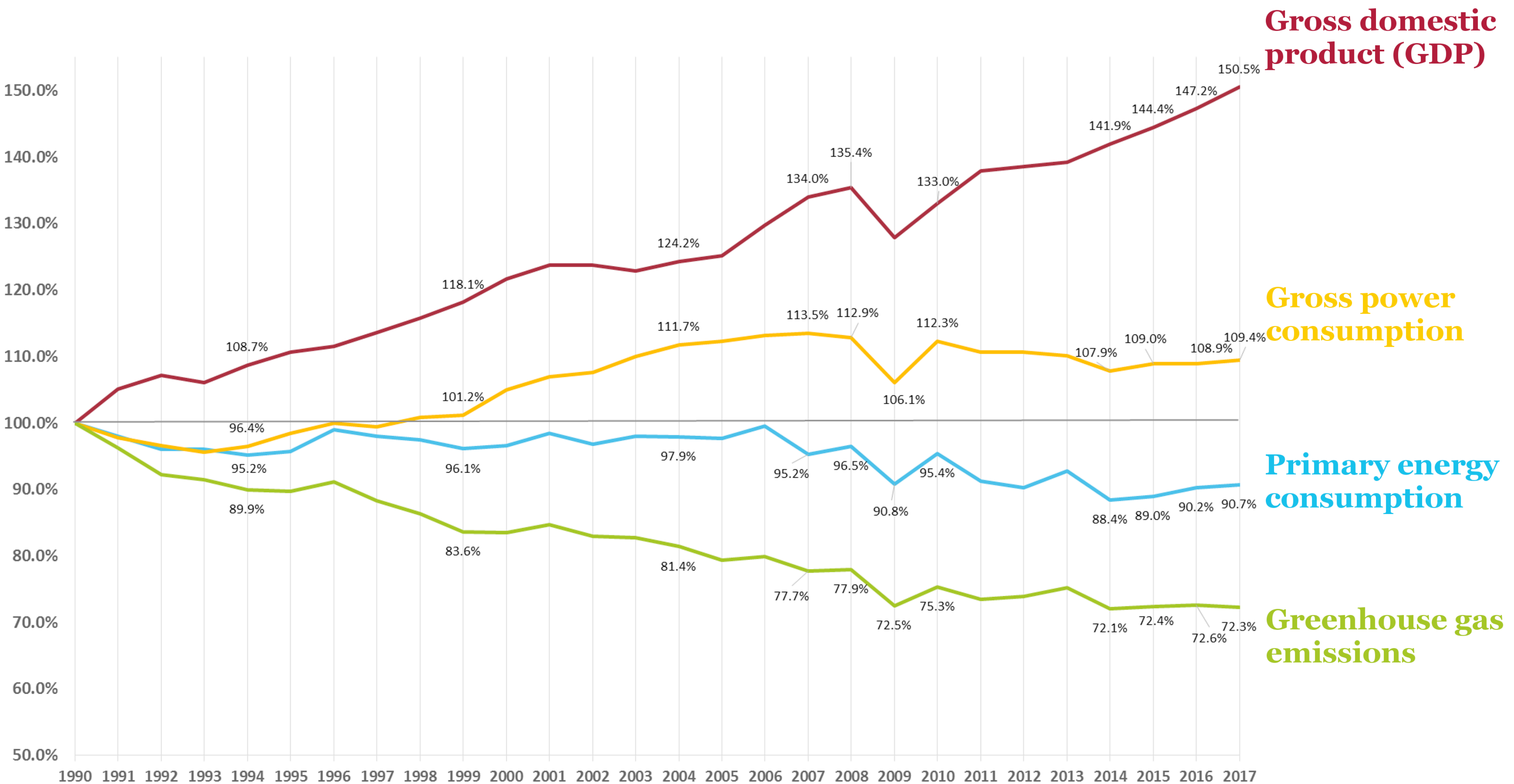


World Energy Consumption - BP
Billion Metric Tons Oil Equivalent
16
14
12
10
8
6
4
2
0
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
2015
2018
Other Renew
Hydro
Nuclear
Gas
Coal
Oil
Gail Tverberg
OurFiniteWorld.com

Economic growth, power & energy consumption, GHG emissions 1990 - 2017.

Data: BMWi 2018, UBA 2018.

CLEAN ENERGY WIRE

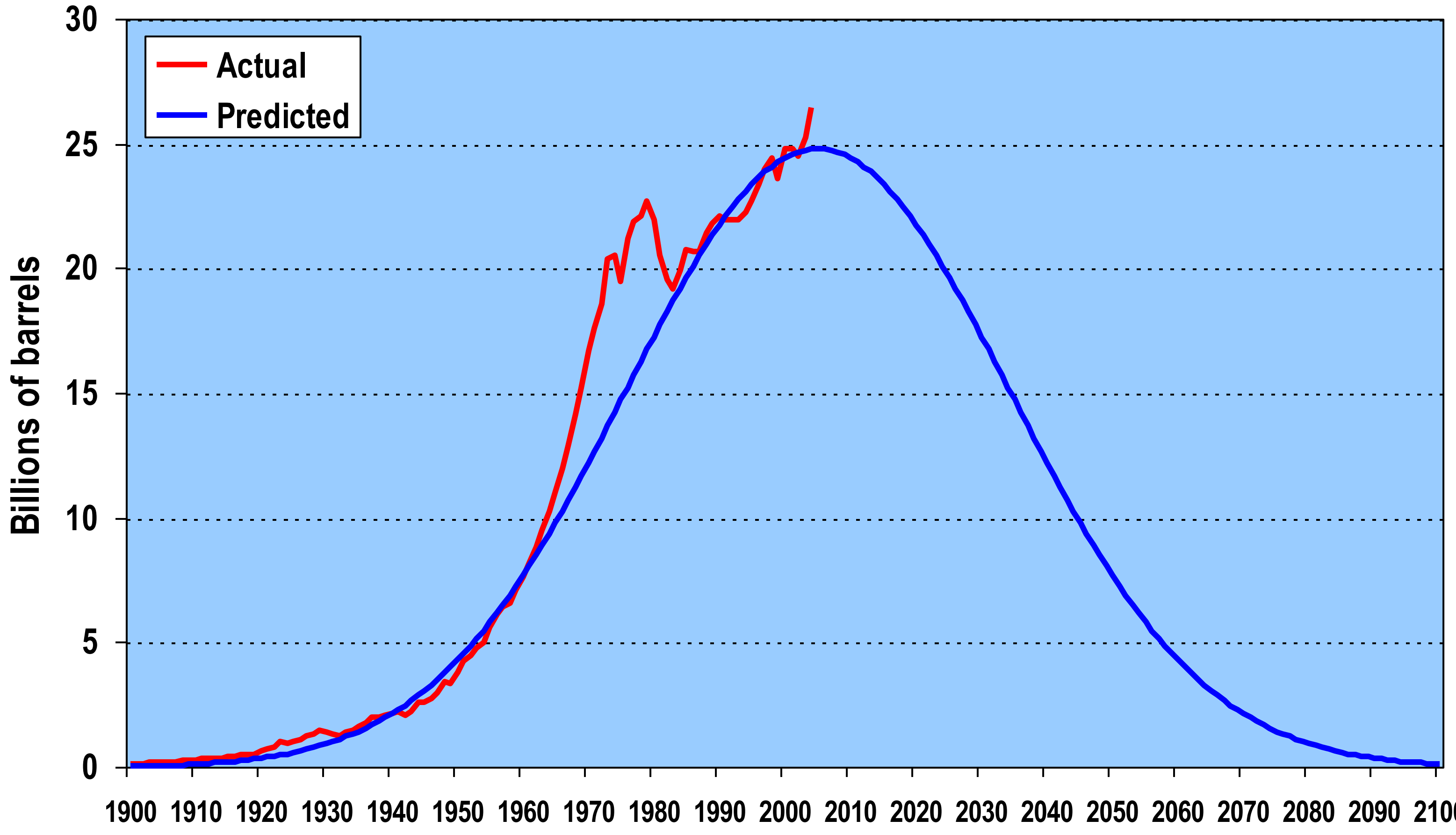


Note: As a general rule, emissions data for the last year shown can expected to be preliminary.

Energy Sources & Reservoires

- 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)



Proven reserves

DEFINITION of Proven Reserves

Proven reserves is the quantity of natural resources that a company reasonably expects to extract from a given formation. Proven reserves are established using geological and engineering data gathered through seismic testing and exploratory drilling. In oil and gas extraction, once the physical shape of a formation is understood, the reservoir is estimated by fluid contacts. Fluid contacts refer to the natural layering of gas, oil and water in a formation. An accurate picture of the formation shape and known levels of fluid contact provide the data for a volume estimate with a high degree of confidence. Proven reserves are classified as having a 90% or greater likelihood of being present and economically viable for extraction in current conditions. Proven reserves are also referred to as proved reserves. Within the oil industry, proven reserves are also referred to as P1 or P90. Proven reserves also take into account the current technology being used for extraction, regional regulations and market conditions as part of the estimation process. For this reason, proven reserves can seemingly take unexpected leaps and drops. Depending on the regional disclosure regulations, extraction companies might only disclose proven reserves even though they will have estimates for probable and possible reserves.

Rapid Changes in Proven Reserves

Understanding the natural resource extraction industry can be challenging because **proven reserves are just one of three classifications**. Most people assume proven oil and gas reserves should only go up when new exploratory wells are drilled, resulting in new reservoirs being discovered. In reality, there is often more significant gains and losses resulting from shifts between classifications than there are increases in proven reserves from truly new discoveries. For this reason, it is useful for investors to know a company's **proven, probable and possible reserves** rather than just the proven reserves. If an investor doesn't have the data on probable reserves, proven reserves can suddenly change in a number of different situations. For example, if a company has a large amount of probable reserves and a relevant extraction techno. If an investor doesn't have the data on probable reserves, proven reserves can suddenly change in a number of different situations. For example, if a company has a large amount of probable reserves and a relevant extraction technology improves, then those probable reserves are added to the proven reserves. Additionally, if the price of oil goes up, oil and gas companies have a wider range of more expensive extraction methods that can be deployed while still turning a profit, again moving probable reserves into proven. Sometimes it is a matter of regulations, where a technology cannot be deployed until approved. In this case, the approval can positively impact the proven reserves for the entire industry operating in the region, as has occurred with hydraulic fracturing. Of course, proven reserves can also decline. They do so naturally as reservoirs are depleted through production, but they can also see sharp drops when regulations take a particular extraction or operational method off the table. So, even when the probable and possible reserves are disclosed, it can still be difficult to predict changes in proven reserves.

Proven Reserves in Oil, Gas and Mining

For the oil and gas sector, the Society of Petroleum Engineers has set the international standards for petroleum reserve definitions. In the mineral and mining sector, the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) works to standardize reserve definitions. The mining industry prefers inferred, indicated and measured to represent the growing knowledge and confidence in a formation, but analysts still apply probable and proven to the mining industry. Proven reserves in mining are the economically viable and minable portion of the measured mineral resource. Loosely speaking, the mining industry definition of proven reserves has been adopted from, and adheres to, the oil and gas sector definition. In the U.S. both industries are ultimately answerable to the Securities and Exchange Commission for their definitions, as these public disclosure have a material impact of extraction companies' stock.