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WORLD ENERGY RESOURCES AND NEW TECHNOLOGIES

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ABSTRACT: The development of civilisation is linked inextricably with growing demand for electricity. Thus, the still-rapid increase in the level of utilisation of natural resources, including fossil fuels, leaves it more and more urgent that conventional energy technologies and the potential of the renewable energy sources be made subject to re-evaluation. It is estimated that last 200 years have seen use made of more than 50% of the available natural resources. Equally, if economic forecasts prove accurate, for at least several more decades, oil, natural gas and coal will go on being the basic primary energy sources. The alternative solution represented by nuclear energy remains a cause of considerable public concern, while the potential for use to be made of renewable energy sources is seen to be very much dependent on local environmental conditions. For this reason, it is necessary to emphasise the impact of research that focuses on the further sharpening-up of energy efficiency, as well as actions aimed at increasing society's awareness of the relevant issues. The history of recent centuries has shown that rapid economic and social transformation followed on from the industrial and technological revolutions, which is to say revolutions made possible by the development of power-supply technologies. While the 19th century was "the age of steam" or of coal, and the 20th century the era of oil and gas, the question now concerns the name that will at some point come to be associated with the 21st century. In this paper, the subjects of discussion are primary energy consumption and energy resources, though three international projects on the global scale are also presented, i.e. ITER, Hydrates and DESERTEC. These projects demonstrate new scientific and technical possibilities, though it is unlikely that commercialisation would prove feasible before 2050. Research should thus be focused on raising energy efficiency. The development of high-efficiency technologies that reinforce energy security is presented, with it being assumed that these new high-efficiency technologies are capable of being applied globally in the near future.

KEY WORDS: primary energy consumption, efficiency, integrated coal gasification combined cycle; triple combined cycle.

INTRODUCTION

Current civilisational progress and development is inseparably and inextricably linked with increased demand for electricity. Analysis of historical change in the human population makes it clear that numbers of people increased very slowly for millennia. That all changed with the Industrial Revolution of the 18th and 19th centuries, which brought huge change, not only in the development of the sciences and technology, but also in demography. The present rate of demographic change remains high, though some impetus has certainly been lost (McFalls 1991).

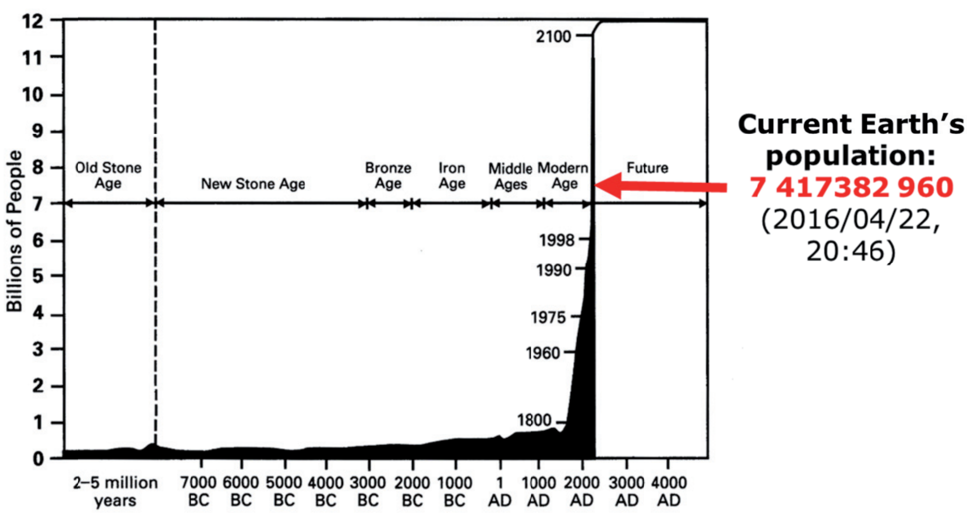

Figure 1. World population growth through history (sources: McFalls 1991)

The forecast world population as of January 1st 2016 stood at over 7.3 billion. The individual state with the largest population is China (with 1.367 bn people), as followed by India (1.252 bn), and then the USA, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, the Russian Federation and Japan. The last country, with its 126.5 million people, takes 10th place in the world ranking.

Table 1. Prediction of world's population in 2050 (sources UN; The Economist)

Range	1950		2015		2050 forecast	
	Country	Population [bn]	Country	Population [bn]	Country	Population [bn]
1	China	0.544	China	1.386	India	1.620
2	India	0.376	India	1.252	China	1.385
3	United States	0.158	United States	0.320	Nigeria	0.440
4	Russia*	0.103	Indonesia	0.250	United States	0.401
5	Japan	0.082	Brazil	0.200	Indonesia	0.321
6	Indonesia	0.073	Pakistan	0.182	Pakistan	0.271
7	Germany	0.070	Nigeria	0.174	Brazil	0.231
8	Brazil	0.054	Bangladesh	0.157	Bangladesh	0.202
9	United Kingdom	0.051	Russia	0.143	Ethiopia	0.188
10	Italy	0.046	Japan	0.127	Philippines	0.157

* USSR Union of Soviet Socialist Republics

Estimates suggest that the number of people worldwide will be some 9.7 bn by 2050. The increase leading to this total will be far from even around the world, however. The largest percentage increase in population for 2016–2050 will be the +109% anticipated for Africa, as followed by Oceania on +44%, North America and the Caribbean on +24%, South America +21%, Asia +20%, and Europe –4%. The natural increase in Africa is of a rapid nature and, if the predictions prove correct, it will by the end of the century have a greater population than Asia.

Today's greatest concentration of population characterises China and India, which are – taken together – inhabited by some one-third of the entire world population. Favourable conditions for the development of agriculture on the Chinese Lowland and Ganges Plain respectively were factors that encouraged settlement, and the second half of the 20th century saw the population of these regions skyrocket.

Areas that are densely populated in relation to indices of wellbeing and are the best-developed from the economic point of view are Europe, Japan, South Korea, the east and west coasts of the USA and the east coast of Australia.

In contrast, some 1.3 billion people have no access to electricity, most especially in the developing countries of Asia (622 million people with no access) and Africa (623 million).

PRIMARY ENERGY CONSUMPTION AND ENERGY RESOURCES

Development of the economy and of civilisation itself is irrevocably linked with a growing consumption of fuel, and – as a consequence of the huge demand for fossil fuels exerted – some deposits have come to be worked out entirely – in the second half of the 20th century in particular.

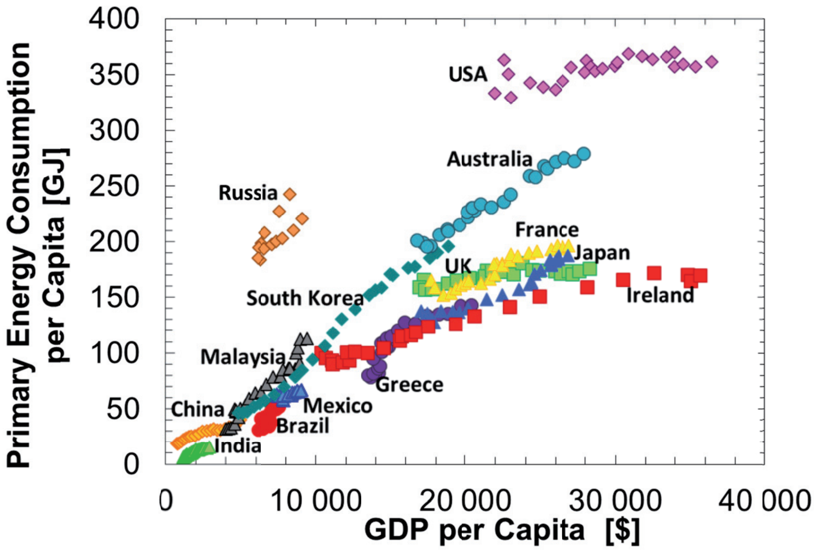

Figure 2. Energy use grows with economic development, energy demand and GDP per capita (1980–2004); Source: UN and DOE EIA

Though there remain considerable reserves of coal in the world, they are very often now present in difficult geological and mining conditions. A similar situation applies to oil and gas. New deposits of oil and gas are still even being discovered, but the conditions underpinning their exploitation would be very capital-intensive indeed (given, for example, locations in deeper ocean basins or areas afflicted by extreme climates). Non-conventional deposits are also being (or could also be) utilised, for example in rocks of very limited permeability that are at the same time parent rocks or porous rock-reservoirs; but again the exploitation possibilities are limited and very costly.

Table 2. World's documented reserves of conventional fuels and their sufficiency in 2005 (Mokrzycki *et al.* 2008)

Fuels	Reserves [Mtoe]	Reserves share [%]	Reserves consumption [Mtoe]	Consumption share [%]	Sufficiency of reserves (Reserves/Production) [years]
Coal	469 298	59.6	2 957.0	31.7	158
Petroleum	159 644	20.3	3 861.3	41.4	41
Natural gas	158 815	20.1	2 515.2	26.9	63
Total	787 757	100.0	9 330.5	100.0	84

Analysis of the data presented in Table 2 supports the contention that documented reserves of oil might last 41 years, and those of natural gas 63 years. In contrast, the reserves of (hard and brown) coal are sufficient to allow this resource to be exploited for a further 158 years. These estimates are all based on assumptions regarding current levels of exploitation, and should thus be treated as approximations. It is clear that demand for energy sources are set to increase, rather than decrease, given the inexorable rise in the human population. Further key factors are those of ongoing economic growth (i.e. "progress") in many or most countries – on the one hand, as well as the possibility for use to be made of non-conventional deposits of oil and gas (e.g. in tar sands, bituminous shales and so on), on the other (Mokrzycki *et al.* 2008).

However, crude oil is the dominant raw material where primary energy structure is concerned. The distribution of documented reserves of oil in the world is very uneven, with 60% in the Middle East, 8.9% in South America, 6.3% in Russia, 5.5% in North Africa, 5.2% in central Africa, 4.9% in North America and 3.9% in the Caspian Sea Basin. Just three states – Saudi Arabia, Iran and Iraq – have 42% of documented reserves globally; while the top 10 countries from this point of view (Saudi Arabia, Iran, Iraq, Kuwait, the UAE, Venezuela, Russia, Libya, Kazakhstan and Nigeria) have more than 81%. It is not a favourable circumstance for the world economy that some of these areas are unstable from the political and economic points of view (Mokrzycki *et al.* 2008).

Natural gas consists mainly of methane (CH_4), with small amounts of heavier hydrocarbons. Gas is found in pure deposits, but also together with oil. It is a fuel, but can also serve as a (precious) raw material in the chemical industry, and is a resource whose world distribution coincides markedly with that of crude oil. Thus the largest document reserves of natural gas (more than 40% of the known total) are in the Middle East, as followed by Russia with 27%. Asia in general has 6.6%, the Caspian Sea Basin 5.2%, North America 4.8% and North Africa 4.5%. Overall, in excess of 77% of the documented reserves are associated with the territories of just ten countries, while Russia, Iran and Qatar alone have more than 57% of the total (Mokrzycki *et al.* 2008).

According to the reports of the International Gas Union, reserves of natural gas from non-conventional deposits do exceed those discovered and confirmed in conventional deposits – a fact that may permit some raising of the margins where global energy security is concerned.

Reserves of hard coal and brown coal are present in 71 countries. Their advantage is the fact that resources are stull considerable, and remain accessible on world markets. This helps explain why the role of coal in power generation worldwide has remained steady at around 30% of the total. Different analyses do not point to consumption of coal being further limited in upcoming years, notwithstanding any pollution implications, given the way that this fuel is uniquely able to ensure energy security.

Three continents lead in terms of industrial reserves of coal, i.e. North America (29.3%), Asia (27.4%) and Europe (25.5%). The remaining continents are Australia and Oceania (8.2%) and Africa (7.2%). Ten states have 93.6% of the world's coal reserves, i.e. the USA (28.5%), Russia (17.5%), China (13.8%), Australia (8.1%), India (8.0%), South Africa (7.1%), Kazakhstan (4.4%), Ukraine (4.0%), Colombia (1.0%) and Poland (0.9%) – see Mokrzycki *et al.* 2008.

In the second half of the 20^{th} century, nuclear power came to be regarded as offering huge prospects for civilisation's further development. Equally, accidents of various levels of seriousness culminating in the Chernobyl disaster led to this form of power supply being seen as a threat to health and the environment. The image was improved somewhat by new technical solutions that did indeed ensure safer reactor construction; but this real and image-related gain was set back by the tsunami-induced Fukushima disaster of 2011, which again reminded the public of their justifiable apprehensions regarding the harnessed power of the atom.

As of 2015, there were 348 nuclear reactors in 30 countries, together producing about 11% of the world's electricity. What is more, the recognised reserves of uranium are enormous. The existing nuclear power stations could readily work for another 200–300 years, even if no new sources of uranium beyond those already known are discovered. 31% of known resources of uranium are in Australia, as followed by Kazakhstan (on 12%), Russia (9%), Canada (9%), Niger (8%), South Africa (5%), Brazil (5%), Namibia (5%), the USA (4%) and China (3%).

Conventional power sources plus nuclear fission together account for almost 78% of the world's electricity output, with the remaining 22% therefore being generated using renewables. Beyond that, it should be stressed that the role of renewables in generating power is mainly a reflection of hydropower, which accounts for 16.4% (within the 22%) of world output. That leaves all the remaining sources accounting for just 5.6% of the electricity generated around the world, with that 5.6% comprising wind power on 2.9%, bio-power systems on 1.7%, and solar PV energy on 0.7%, with geothermal systems and wave power together accounting for just another 0.3%.

Hydropower remains the dominant renewable source of electricity. The greatest potential for the further development of hydroelectric power exists in Asia, South America and Africa.

INTERNATIONAL GLOBAL PROJECTS

At present levels of energy consumption worldwide, the documented industrial-scale resources of fossil fuels will last for less than a further 100 years. Is the international community then striving to resolve the problem of civilisational development irrevocably linked with a growing demand for electricity?

The answer is in the affirmative, as efforts are being made to achieve energy security in a global sense. Examples might be projects that bring together governmental and academic institutions, as well as businesses. Specifically, the discussion here were focus on the ITER, hydrates and DESERTEC projects.

THE ITER PROJECT

ITER, meaning "the way" in Latin. ITER is a major international experiment aiming to demonstrate the scientific and technical feasibility of fusion as an energy source. It will be 30 times more powerful than the Joint European Torus (JET) which is currently the largest comparable experiment operating in the world. Europe has a major track record in fusion. Europe's JET (Joint European Torus) located at Culham (UK) is the world's largest fusion facility, and the only one currently capable of working with a deuterium-tritium fuel mixture. JET has achieved all its originally-planned objectives and in some cases has even surpassed them. In 1997, it achieved a world record fusion power production of 16 MW and a Q = 0.65.

ITER aims to produce a large amount of fusion power (500MW) for about 7 minutes or 300MW for 50 minutes. ITER will allow scientists and engineers to develop the knowledge and technologies needed to proceed to a next phase of electricity production through fusion power stations (https://www.iter.org/proj/inafewlines).

Under ITER, the fusion reaction will be achieved in a tokamak device that uses magnetic fields to contain and control the hot plasma. The fusion between deuterium and tritium (D-T) will produce one helium nucleus, one neutron, and energy. In a tokamak, the plasma is held in a doughnut-shaped vessel. Using special coils, a magnetic field is generated, which causes the plasma particles to run around in spirals, without touching the wall of the chamber. The helium nucleus carries an electric charge which will respond to the magnetic fields of the tokamak and remain confined within the plasma. However, some 80 percent of the energy produced is carried away from the plasma by the neutron, which has no electrical charge and is therefore unaffected by magnetic fields. The neutrons will be absorbed by the surrounding walls of the tokamak, transferring their energy to the walls as heat. The Q formula symbolizes the ratio of fusion power to input power. $Q \geq 10$ represents the scientific goal of the ITER project, which is to say the delivery of ten times as much power as is consumed (https://www.iter.org/proj/inafewlines).

At the Geneva Superpower Summit in November 1985, following discussions with President Mitterand of France and Prime Minister Thatcher of the United Kingdom, General Secretary Gorbachev of the former Soviet Union proposed to U.S. President Reagan an international project aimed at developing fusion energy for peaceful purposes. The initial signatories: the former Soviet Union, the USA, the European Union (via EURATOM) and Japan, were joined by the People's Republic of China and the Republic of Korea in 2003, and by India in 2005. Together, these six states plus Europe represent over half the world's population. The ITER Agreement was officially signed at the Elysée Palace in Paris on 21 November 2006 by Ministers from the seven ITER Members. In a ceremony hosted by French President Jacques Chirac and the President of the European Commission M. José Manuel Durao Barroso, this Agreement established a legal international entity to be responsible for construction, operation, and decommissioning of ITER. There were 20 years of discussion and preparation preceding the launch of the ITER project (https://www.iter.org/proj/inafewlines).

ITER is being constructed at Cadarache in southern France. Europe, as the host party, and France, as the host state, has special responsibilities for the success of the project. In particular, Europe is paying 45% of the construction costs and 34% of the costs of operation, deactivation and decommissioning of the facility, as well as preparing the site. Europe's contribution to ITER is managed by F4E.

The ITER project will entail heat being dispersed via cooling towers. In the subsequent fusion plant prototype DEMO, and in future industrial fusion installations, the heat in question will be used to generate steam and – by way of turbines and alternators – electricity. The next step after ITER will be a demonstration-scale power plant or DEMO, which will demonstrate the viability of electricity being produced from fusion on the large scale (https://www.iter.org/proj/inafewlines).

The latest situation as regards project implementation can be followed at https://www.iter.org/.

HYDRATES PROJECTS

Hydrates (clathrates) are crystalline substances consisting of frozen water and trapped molecules of gas – in this context, methane, first and foremost. Hydrates are present in pockets at great depths beneath marine sediments, as well as in land areas with permafrost. There are extremely disparate estimates regarding the size of the hydrate resources, but they are considered to exceed those of natural gas quite markedly. However, given the technological difficulties, hydrates are not yet being exploited on the large scale.

Japan is pursuing research into possible technologies by which hydrate deposits can be exploited in areas around that country's various islands (http://www.mh21japan.gr.jp/english/). Similar work to obtain energy from marine sediments is being carried out by the USA, South Korea, India and China (http://woodshole.er.usgs.gov/project-pages/hydrates; http://worldoceanreview.com/en/wor-3-overview/methane-hydrate/extraction/).

An international consortium comprising governmental and commercial entities from Canada, the USA, Japan, Germany and India has pursued research in Canada's permafrost zone (specifically near Mallik), while the USA is seeking to achieve commercial feasibility with its efforts to exploit hydrate deposits in Alaska (http://woodshole.er.usgs.gov/project-pages/hydrates/).

ELECTRICITY FROM THE DESERTS FOR THE EUROPEAN MARKET: THE DESERTEC PROJECT

The DESERTEC Project assumed the construction in the Sahara of a network of solar-powered plants that could supply electricity to both Europe and North Africa (in fact an anticipated 15% of the EU's entire demand) – http://www.desertec.org/.

Electricity from the plants was to be channelled and transmitted via submarine cables to which the EU countries would have access via Sicily. It had been assumed that DESERTEC would be in a position to generate 100 GW by 2050. Furthermore, the 2009 assumptions were for a project cost in excess of EUR 400 bn, with 50 large European businesses (like E.On, RWE, Siemens and Deutsche Bank) coming together within the project consortium. However, 2014 brought the resignation of 47 consortium participants, on the basis of a scale and prohibitive costs of the project that were coming to look utopian. This was all the more the case given the unstable political and economic situation in the North African and Saharan region.

ENERGY SECURITY AND NEW TECHNOLOGIES

At present rates of energy consumption, the globally-documented industrial-scale reserves of fossil fuels will suffice for another 100 years or so. Meanwhile, the ITER and ”hydrates” international projects may be in a position to supply answers concerning the feasibility of using these energy resources within about 50 years. Equally, access to energy in general can be said to be constrained by the wealth of a given country, as well as the political situation in the world as a whole. In these circumstances, a key problem for the all revolves around the steps that need to be taken for energy security to be assured. Economic forecasts make it clear that oil, natural gas, hard coal and brown coal will be the main energy carriers for several decades yet, in the cases of both Poland and the wider world. Meanwhile, alternative solutions, be these based on nuclear or renewable energy, tend to provoke public disquiet and/or are very much dependent on local environmental and climatic conditions. This makes it imperative for research to be directed at raising energy efficiency, as well as the awareness of society where issues of energy and power supply are concerned.

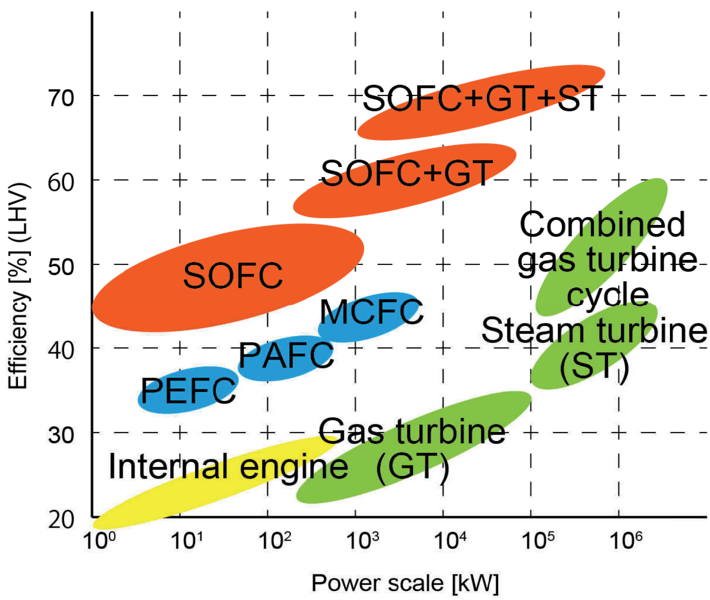

Figure 3. Efficiency of total energy utilization
(GT – Gas Turbine, ST – Steam Turbine, SOFC – Solid Oxide Fuel Cell, PEFC – Polymer Electrolyte Fuel Cell, PAFC – Phosphoric Acid Fuel Cell, MCFC – Molten Carbonate Fuel Cell).

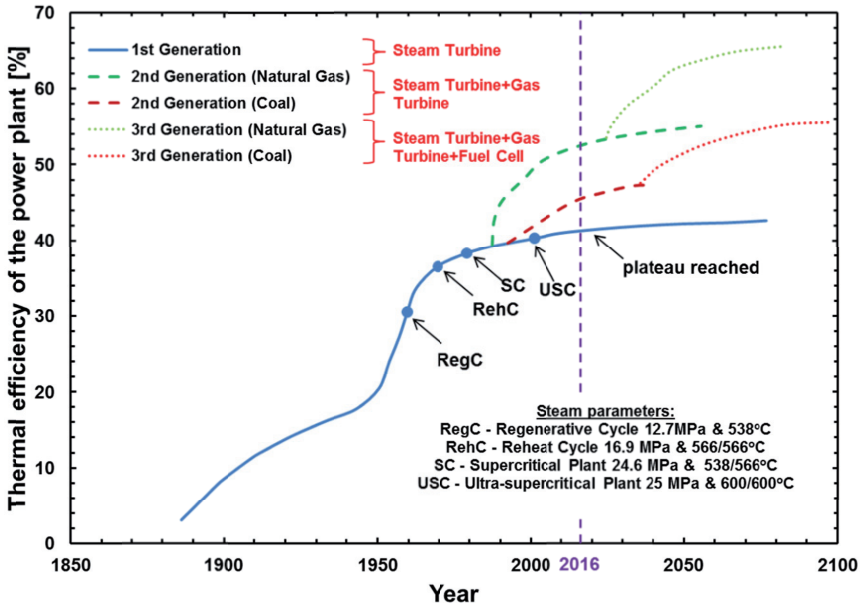

Figure 4. History of thermal efficiencies (sources: Kaneko 2015)

Figure 3 makes clear the possibilities for new technologies to raise levels of energy efficiency. An example might be the development of distributed power generation, whereby the place of gas-fired furnaces producing warm water may be taken by solid oxide fuel cells (SOFCs), which produce electricity and warm water in configurations that can achieve electric efficiencies in excess of 40% and efficiency of co-generation 80% – see Table 3.

Table 3. Small scale SOFC "ENE-FARM" Type S

Type	SOFC
Size	0.6 m x 0.935 m x 0.335 m
Power output	700 W
Efficiency	46.5% (LHV), 42% (HHV)
Efficiency of co-generation	90% (LHV), 81.2% (HHV)
Weight	94 kg

Type	Co-generation unit
Size	0.74 m x 1.7 m 0.31 m
Tank	90 L
Water temperature	70°C
Weight	94 kg
Hot water	41.9 kW
Room heating	17.4 kW

Figure 5. Small scale SOFC 700 W *"ENE-FARM" Type S*
(ENE-FARM installed 120 000 residential fuel cell units in Japan)

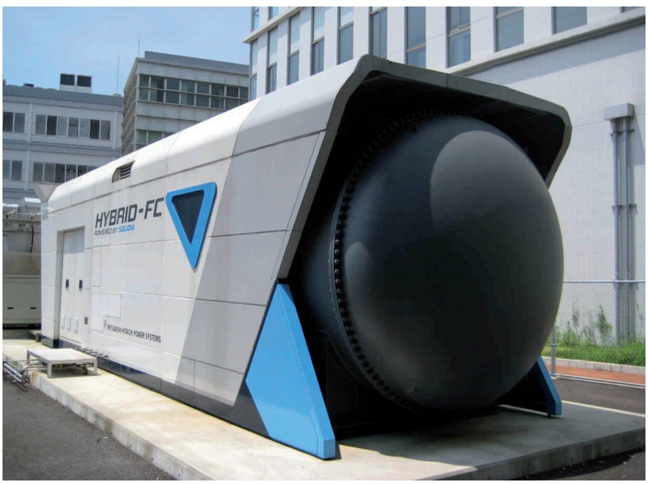

Figure 6. 250 kW SOFC- MGT hybrid system

Small 250–1000kW hybrid systems (SOFC + a micro gas turbine) achieve efficiencies of over 52% and are subject to testing at several research-and-development centres.

Conventional power supply based on a "first-generation" system should give way to systems of the "second" and "third generations".

First-generation power supply is based on the Rankin cycle. Efficiency of a power plant unit working on ultra-supercritical parameters reaches about 42%. The steam heated in these units is at a pressure of 250 [at] and a temperature of 600°C.

Analysis of Figure 4 shows that increasing the pressure and temperature of steam heated in the units operating on ultra-supercritical parameters does not increase their efficiency in a significant way. Additional material and economic problems also appear. Chrome steel should be replaced by nickel steel, and there is also a lack of data relating to the durability of the latter (as a new material), where work takes place at around 700°C and under a pressure of 250 atmospheres, and as the power-generation unit is operated over a period of several decades.

Systems based on the coupling of a gas turbine with a steam turbine are of greater thermal efficiency, because they bring together the Brayton and Rankine Cycles. Gas turbines operating at higher temperature ranges allow for greater efficiency to be achieved with a Brayton and Rankine configuration (Kaneko 2015). Currently, there are gas turbines that operate at a temperature of 1600°C. And work is being done on new types of gas turbine that will be able to operate at 1700°C.

Second-generation systems use natural gas as fuel and are again based on a coupling of a gas turbine with a steam turbine.

Recently given over for successful commercial use was a second-generation installation using coal as fuel, in the shape of the 250 MW Integrated Gasification Combined Cycle (IGCC) at Nakoso (Japan) – see Nunokawa (2013), Nunokawa and Asano (2014).

In turn, at present under construction are two IGCC units of 540 MW each located at Nakoso and Hirono (Japan). The development work there is to be completed by 2020, and the efficiency of the 540 MW IGCC is a planned 48%. (Kaneko 2015).

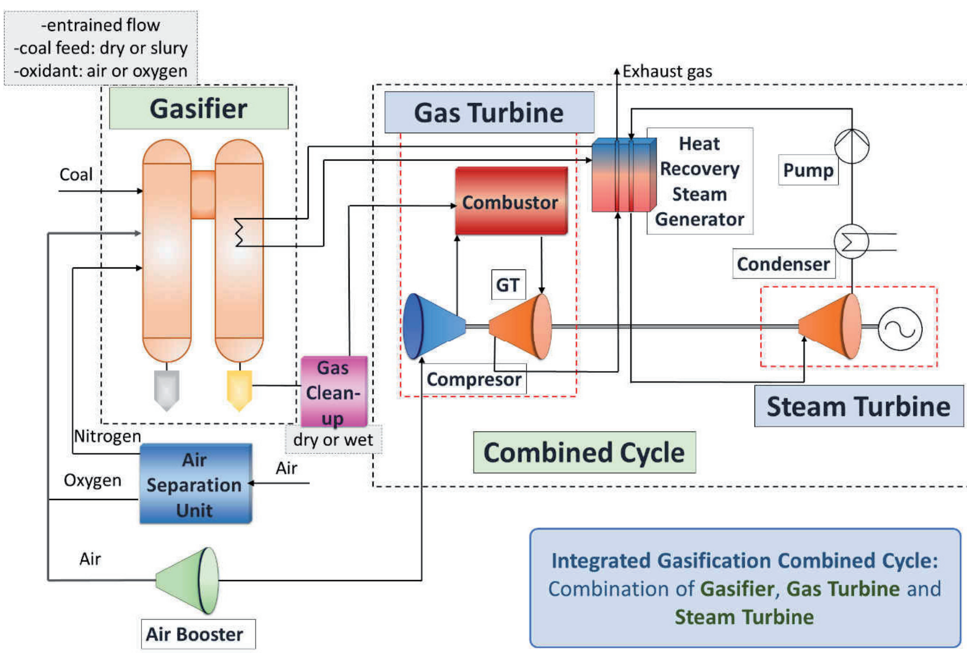

Figure 7. System configuration of the Integrated Gasification Combined Cycle (IGCC)

In contrast, third-generation systems are to integrate solid oxide fuel cell (SOFC) technology with gas and steam turbines. Efficiency in the case of these systems may reach 65% in the case of methane and 55% as regards coal (Kaneko 2015, Kobayashi *et al.* 2011, Kobayashi *et al.* 2013a, Kobayashi *et al.* 2013b, Osaki CoolGen Corporation 2013).

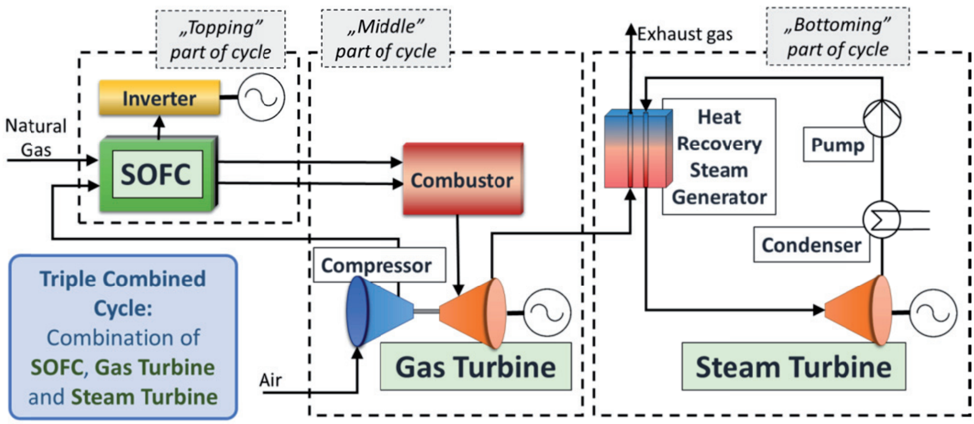

Figure 8. Triple Combined Cycle for LNG
(Triple Combined Cycle: Combination of SOFC, Gas Turbine and Steam Turbine)

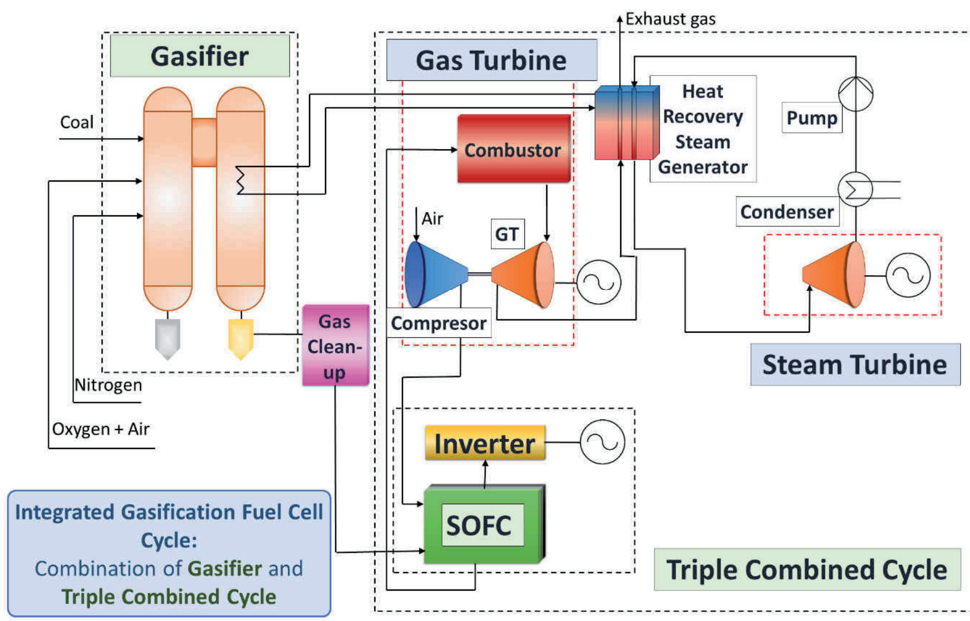

Figure 9. Triple Combined Cycle for Integrated Coal-Gasification Fuel Cell Combined Cycle (IGFC)

SUMMARY

The story of recent centuries is that dramatic economic and social change came in the wake of revolutionary industrial changes made possible by new developments in the power-generation sphere. If the 19th century was the age of coal and steam, the 20th century was that which saw the development of motorisation, and was hence the era of oil and gas. The question to be asked now concerns the name of this kind likely to be given to the 21st century.

At the current level of energy consumption, the industrial-scale reserves of fossil fuels around the globe are sufficient for around 100 years more.

The international projects involving fusion (ITER) or the exploitation of hydrates may yield answers allowing for practical, applicable solutions within 50 years, with actual implementation then following by the end of the 21st century.

In the meantime, if global energy security is to be assured and levels of pollution reduced, it will be advisable to bring "third-generation" power-supply technologies into full(er) use in the upcoming years.

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