Nuclear Fusion Energy—Mankind's Giant Step Forward

Sing Lee & Sor Heoh Saw

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ORIGINAL RESEARCH

Nuclear Fusion Energy—Mankind's Giant Step Forward

Sing Lee · Sor Heoh Saw

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Abstract Estimates of energy supply versus consumption indicate the middle of this century as the critical point when world energy supply will no longer keep pace with the demand. The demand grows inexorably because of both the world population growth as well as the growth of average per capita energy consumption. Technological and economic progress are closely correlated with per capita energy consumption. Hence the inadequacy of energy supplies will limit the progress of human civilization, stifling its soaring spirit. Conservationism, making incremental improvements in this situation, is completely inadequate. What is needed is a giant step—the development of a new, limitless, clean source of energy—nuclear fusion energy. Nuclear fusion technology, when perfected to fusion-burn only deuterium, will have a fuel supply lasting millions of year, even with continuing energy consumption growth as in the past. Intensive efforts in five decades of Tokamak research has advanced the fusion product up by 10^7 times, to the point when breakeven is only a step away. The next step necessarily involves international collaboration on an unprecedented scale in ITER—the International Thermonuclear Experimental Reactor, on which work has started in Cadarache France. ITER and later Demo are envisioned to bring online the first commercial nuclear fusion energy reactor by 2050. Using this as the starting point and the history of the uptake of nuclear fission reactors as a guide, a scenario is described here which depicts a not unreasonable rapid take up of nuclear fusion energy starting after the middle of this century. Just into the next century fusion energy should be able to take up the slack and allow Mankind to continue its progress and growth. Because the development of fusion energy is such a complex technological task it is probable that there will be several decades when the constraints of energy shortage will be severely felt as shown by the flattening of the energy consumption from around 2040 to 2100. Such a period of stagnation seems unavoidable even with the envisaged development and rapid adoption of fusion energy. On the other hand without nuclear fusion energy the scenario depicts a severe downturn unavoidably in the fortunes of Mankind with world population shrinking below 5 billion and eventually even lower.

Keywords Nuclear fusion energy · World energy consumption · World energy supplies · World population

S. Lee · S. H. Saw
Institute for Plasma Focus Studies, 32 Oakpark Drive, Chadstone, VIC 3148, Australia
e-mail: sorheoh.saw@newinti.edu.my

S. Lee · S. H. Saw
INTI International University, 71800 Nilai, Malaysia

S. Lee (✉)
Nanyang Technology University, National Institute of Education, Nanyang, Singapore 637616
e-mail: leesing@optusnet.com.au

Introduction

When Christopher Columbus sailed into the Americas in 1492, world population was 450 million (7% of today's population) and world energy consumption was less than 1% of present day consumption. The world was sparsely populated. There were ample energy resources waiting to be developed to support a larger and more progressive human civilization.

The invention of the first reliable steam engine in 1775 started the Industrial Revolution, replacing manual labour with a variety of machines. Then the scientific discoveries of the early 1900s, led by Einstein, enabled Man to control the processes within the atom leading to electronics, lasers, computers, global communications, aerospace transportation, new materials, nanotechnology, biotechnology and nuclear energy. Thus continues the era of human prosperity on a greater scale than ever before with corresponding increase in energy consumption and population increase.

World population grew from the 450 million in Columbus' time to 1.6 billion [1] at the start of Einstein's career around 1900–6.8 billion towards end 2009. In the past 100 years world population grew 4 times, whilst energy consumption grew 10 times. Thus energy consumption grew faster than population growth; in other words energy consumption per head also grew more than 2 times. This trend of per capita energy consumption growth is bound to continue as the rest of the world marches relentlessly in an attempt to catch up with the best standard of living in the world. As is well known, per capita consumption of energy is closely correlated with standard of living [2].

In the past 100 years the doubling time of world population was about 50 years whilst the doubling time of energy consumption was 30 years. If this trend were to continue, world population would reach 27 billion in another 100 years whilst energy consumption would increase another 10 times. This is of course unsustainable as the world is already near the critical point when supply of energy barely meets the demand. Energy resources are limited and supply trends are estimated to peak in a few short decades from now. This is the reason underlying the demographers' projections that world population growth must slow down in the near future. The current debate on the unsustainability of population growth, energy consumption trends and the degradation of the environment, whilst important in raising public awareness, does not address the fundamental problem.

What is needed to safeguard Mankind's unimpeded progress is not incremental moves; but one giant bold step—the development of a new limitless source of energy, clean non-polluting energy which will not further aggravate the environment. This is not a pipe-dream. The technology is already nearly proven. Fifty two years of scientific and technological work have already shown that the technology is feasible. Moreover the last final push is set to begin with an international consortium comprising the major economic and scientific communities of the world. The project is ITER—the International Thermonuclear Experimental Reactor which is currently being built in France at Cadarache. The process involves nuclear fusion which is the same process occurring in the stars causing their glow and powering all the energetics of the universe, including all life on earth. In the stanza below the dream (any dream), the river, the glamour and the night of the first two lines are all dependant on the process mentioned in the last two lines:

And a dream lies on the river
And a glamour veils the night
Whilst above the white stars quiver
With nuclear fusion—bright.

Nature is thus showing the way, powering the whole universe with nuclear fusion. Man is in the process of emulating nature.

In 50–100 years time, with human control of this limitless clean non-polluting energy, Man's scientific and technological progress can continue to accelerate, human population can continue to grow. With limitless energy, materials can be created or mined in extra-terrestrial territories like our Moon or further afield from the planets. Living space can be extended by extra-terrestrial colonization which will also serve as energy production bases to avoid overheating the earth. Man's will to explore, up the mountains, down to the sea floors, to the heart of the atom, to the very fabric of space–time; to colonize, like the Americas, Australia in days gone by, and to grow, should not be stifled by a limit to energy or a limit to population. Man's spirit must, will remain indomitable. As Columbus reached for the Americas in the not too distant past 500 years ago, in the not too distant future, Man will reach for the stars.

Einstein's $E = mc^2$ enabled Man to understand the energy source of the universe. Man's control of $E = mc^2$ is demonstrated in the awesome power of his Hydrogen bomb. Man will liberate his destiny with $E = mc^2$ in nuclear fusion reactors—the Dawning of the Fusion Age.

This subject of nuclear fusion is a key subject which will grow in world-wide importance as the ITER project progresses towards maturity. An international conference such as this* is the ideal platform to present the basic science and issues of nuclear fusion in such a way as to interest and educate the world-wide community.

World Population, Energy Consumption and Supplies

Correlation of Standard of Living to Energy Consumption

There is a close fundamental correlation between the stage of development of a country and its energy consumption. Developed countries have the highest per capita consumption of energy. Poorest, least developed countries have the lowest per capita consumption**.** This can be seen from Fig. 1 which plots GDP per capita against energy consumption per capita. There is generally good correlation between GDP per capita and energy consumption per capita.

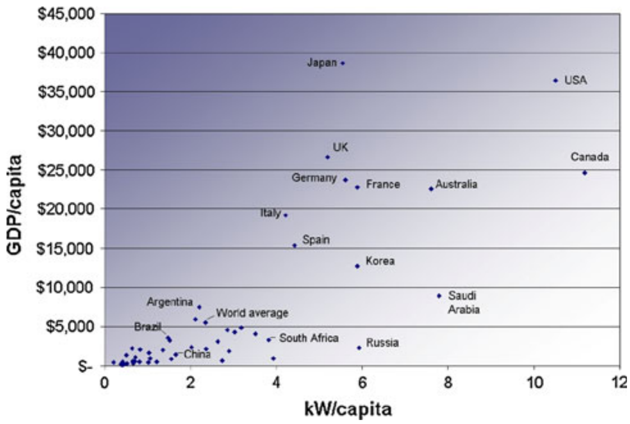

Fig. 1 Showing the close correlation between economic wealth and energy consumption [expressed as equivalent power] per capita-2006 [2]

Thus as less developed countries move up in their development, energy consumption per capita rises. The world energy consumption per capita will continue to rise in the foreseeable future, driven by the rapid development of China, India, Latin America [2].

Energy Supplies

Energy used by today's industrial societies is derived from utilization of finite earth resources. These resources are an inheritance and their consumption involves the expenditure of materials accumulated by the earth over aeons of time [3].

The quantity of fossil fuels available to man has been the subject of intense interest and numerous estimates. A good review has been made recently [4]. In the context of this paper we are not attempting to present the most precise figures or the most reliable projections into the future. Since all projection scenarios point to the need for Mankind to take a giant step to solve its energy needs, a projection scenario not in wild variance with the consensus would be adequate for our purposes. Hence we present Fig. 2 [3] which shows world energy production from 1850 with projection into the next century. Included in this figure are the fossil fuels coal, petroleum and natural gas. Also included are renewables such as hydro, wind, photovoltaic and biomass and nuclear fission energy production. In the same figure is included the world population and its projection into the next century (top line). The close correlation between the world population scenario with the total energy production scenario in all such estimates is no mere coincidence. We venture to say that it reflects the acceptance of the demographers to the fate that humanity is expected to endure—the limitation of growth and progress due to the shortage of energy resources. Pushing the projection further, one probable scenario would be the severe retardation of human civilization, even to the point of extinction.

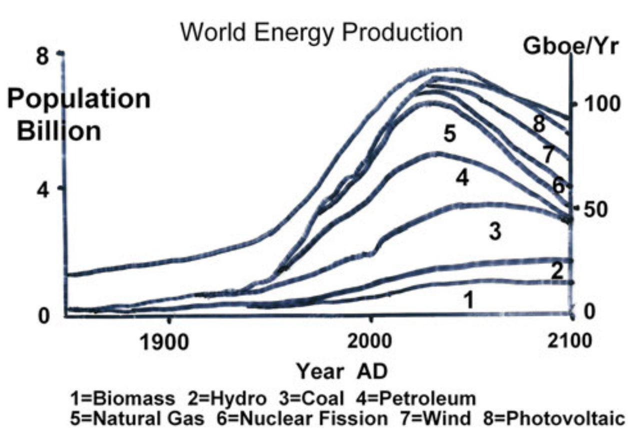

Fig. 2 Estimates of world energy production projected into the future in a scenario [3]. Starting from the bottom, the shaded layers are respectively: Biomass, Hydro, Coal, Petroleum, Natural Gas, Nuclear Fission, Wind, and Photovoltaic. The topmost line is the projected world population

World Population Growth

World population is growing; food, water, housing, education, medical care must grow correspondingly, in fact faster as less developed countries becomes more developed. Rate of population growth is about 1.5% per year and population is projected to grow to 10 billion by 2030 (see top line in the Fig. 3) and can be expected to continue growing beyond that time given no drastic limitations. If the needs of the growing population cannot be met, there will be economic, political and environmental upheavals. The key is the availability of energy. If energy supplies prove inadequate, then world population will stagnate and even drop as shown in the middle and bottom lines depicting scenarios of lower growth.

The most popular demographic projections nowadays appear to follow the middle line or a line somewhere between the top and middle line, projecting the world population to stabilize in the region of 10 billion.

It is likely that these popular projections are all based on the underlying assumptions of the inability of resources, principally the underlying resource, that is energy resources, to keep up with the growing demand. Thus as already mentioned in the previous section, the growth of the human race is assumed by the demographers to have reached a critical point at which the population will be limited, even start to seriously decline, dictated by the limitations of energy resources.

Energy Consumption Scenario

Even if world population growth slows down to zero: world energy consumption will continue to rise due to the

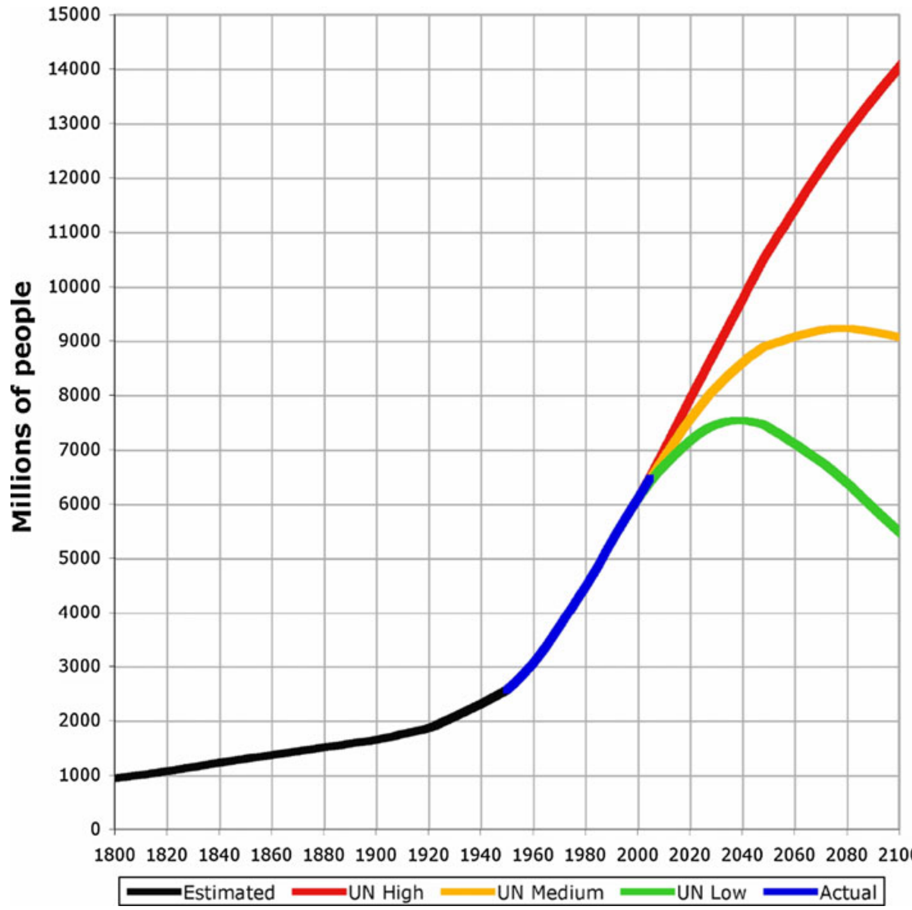

Fig. 3 World population and projection [5]

continuing development of the less developed nations and the corresponding need for a higher energy per capita consumption. Consider the following popular scenario: The world population growth slows down to zero and world population stabilizes at 10 billion at around 2030. However due to continued improvement in the standard of living of the world on average, the demand of energy continues to rise, until world consumption exceeds the supply of conventional energy sources. Then for energy consumption per head to rise on average to ¾ of US 1985 per head consumption (which was equivalent to 10 kW per head of power consumption, a comfortable level by any reckoning), alternative sources of energy have to make up the shortfall.

This is depicted in Fig. 4. If the shortfall is not made up then obviously the less developed country will unfortunately continue to remain less developed and the average per head consumption will not rise to ¾ US 1985 consumption.

The Dawning of the Fusion Age

Nuclear fusion technology, when perfected to fusion-burn only deuterium, will have a fuel supply lasting millions of year, even with continuing energy consumption growth as in the past. In nature, nuclear fusion energy powers all the stars and consequently all life in the Universe. Fusion energy has been demonstrated on earth in the hydrogen

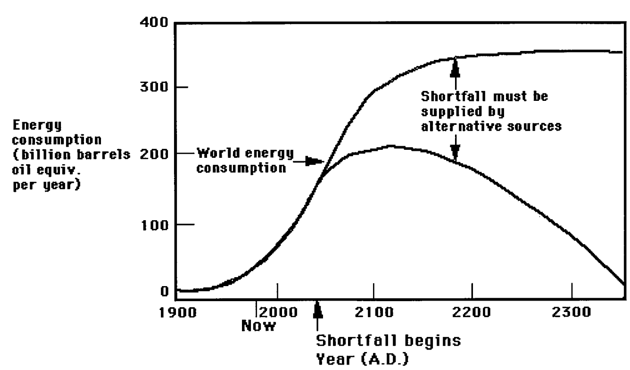

Fig. 4 Energy consumption versus energy supply based on a stabilized population of 10 billion with average energy consumption per head taken as ¾ of 1985 US per head consumption. The energy supply curve matches the demand curve until just before 2050 when the supply curve becomes unable to meet the demand curve. The increasing shortfall is indicated by the widening gap between the demand (upper) curve and the supply (lower) curve

bomb. Intensive efforts have been made to harness fusion as an energy source. Fifty two years of Tokamak research has identified a fusion product (density-confinement time–temperature $n\tau T$) of 10^{22} m^{-3}-s-keV as a minimum requirement for breakeven. In these 52 years, the research has pushed the fusion product up by 10^{7} times, to the point when breakeven is only a step away [6, 7]. Immense efforts in science and technology have already been expended. A glimpse of the scientific basis and technological achievements is provided by the Joint European Torus JET, the biggest fusion experiment yet, which reached $Q = 0.6$ in 2000 [8] (In this context $Q = 1$ is breakeven and $Q = 10$ is a good target). The next step necessarily involves international collaboration on an unprecedented scale, to solve the greatest technological challenge we have yet faced. This takes the form of the International Thermonuclear Experimental Reactor, on which work has started in Cadarache France [9]. ITER aims to reach $Q = 10$ by the 2020s, to demonstrate feasibility of nuclear fusion as an energy source. Beyond that lies DEMO which will deliver power into the grid by 2040 [6, 7, 9, 10]. The scientific and engineering plans are well laid and with the support of the best scientific, engineering and political will of all the major world powers and the stakes being the very survival of human civilization, success must be guaranteed.

If energy supplies were to become unlimited then there is no need to restrict the growth of energy consumption, a better standard of living or the growth of population. This is depicted in the Fig. 5 of energy consumption well into the twenty-second century. Such unlimited growth (curve 4 of Fig. 5) need not imply unbridled wasteful consumption. The best practice of environmental conservatism could, should be incorporated into growth, so that efficient and 'green' habits become part of the sustained culture of the human race.

From Fig. 5, it is seen that the development of nuclear fusion energy is coming not a moment too soon. The critical point when total available energy starts to decline is seen to be reached just before the middle of this century; thereafter the consumption curve has to drop (light blue curve 1, available energy, without fusion energy) and Man will have to cope with a decreasing supply unless the increasing shortfall is made up by nuclear fusion energy (brown dot-dash curve 2, available energy, with fusion energy).

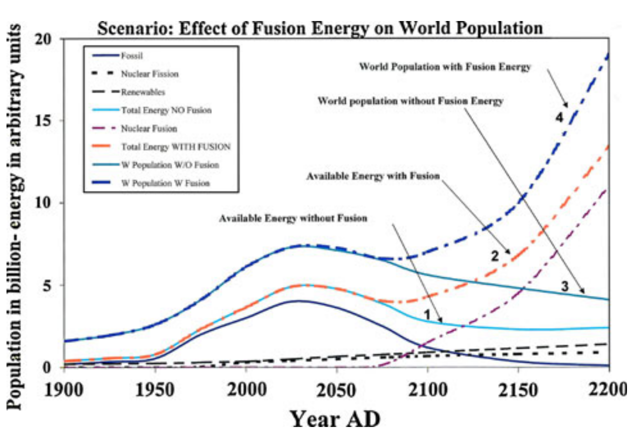

Fig. 5 Energy consumption based on continuing population growth; provided no limit to energy supply

How fast can we expect the take-up of nuclear fusion energy? To set a reasonable scenario we look at the history of the uptake of nuclear fission energy. The first commercial nuclear fission power station was installed at Calder Hall in the UK in 1956 with 50 MW. By 1960 1 GW was installed. By the late 1970s the installed nuclear fission power world-wide had reached 100 GW. Then in the 1970s and 1980s rising costs of fission reactors due to regulatory changes and pressure-group litigation [11, 12] together with falling fossil fuel prices made fission plants less attractive and the industry slowed down so that by the late 1980s installed fission power had only grown to 300 GW and by 2005 only to 370 GW, supplying some 15% of the world's electricity consumption and 2.1% of total power consumption. From looking at the history of the development of nuclear fission power plants we learn that given the perceived necessity, in less than 20 years the installed capacity could grow 100 fold from a base of 1 GW (tenfold every 9 years for 18 years). The scenario of Fig. 5 assumes an installed 1 GW of commercial nuclear fusion power plant in 2050 growing 1,000-fold to 1,000 GW by 2077 (tenfold every 9 years for 27 years) and then with a slower growth to 10,000 GW by 2100 (tenfold in 23 years); thereafter tripling every 50 years. The initial rate of 1–1,000 GW from 2050 to 2077 starts at the same base and is about the same rate as achieved by the nuclear fission industry from 1960 to the late 1970s. This is not unreasonable as by 2050 the world would know with a certainty the desperation of its energy position.

The scenario of Fig. 5 thus depicts a not unreasonable rapid take up of nuclear fusion energy starting just after the middle of this century. Just into the next century fusion energy should be able to take up the slack and allow Mankind to continue its progress and growth (brown dot-dash curve 2, available energy, with fusion energy). Because the development of fusion energy is such a complex technological task it is probable that there will be several decades when the constraints of energy shortage will be severely felt as shown by the flattening of the energy consumption from around 2040 to 2100 as depicted in the scenario of Fig. 5 (brown dot-dash curve 2, available energy, with fusion energy). Such a period of stagnation in energy and corresponding stagnation in world population (dark blue dot-dash curve 4 showing world population scenario, with fusion energy) seems unavoidable even with the development and rapid adoption of fusion energy. Without nuclear fusion energy the scenario is as shown by the light blue curve 1, depicting a severe downturn in the fortunes of Mankind with world population dropping below 5 billion (green curve 3, world population scenario, without fusion energy).

Conclusion

The human spirit, its will to explore, to always seek new frontiers, the next Everest, deeper ocean floors, the inner secrets of the atom: these are iconised into human consciousness by the deeds of Christopher Columbus, Edmund Hillary, Jacques Costeau, and Albert Einstein. In the background of the ever-expanding universe, this boundless spirit will be curbed by a requirement to limit growth. That was never meant to be. That should never be so.

Man should have an unlimited destiny. To reach for the moon, as he already has; then to colonize it for its resources. Likewise to reach for the planets. Ultimately-the stars. Man's spirit must and will remain indomitable.

Conservationism is essential but probably not enough for the survival of the human race within the stunted limits which are popularly accepted in the present as depicted by the light blue line 1 of Fig. 5. Conservationism is important but certainly not enough to secure the continued soaring of the human spirit. That requires a new limitless clean supply of energy—one giant step for Mankind—the Dawning of the Fusion Age.

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