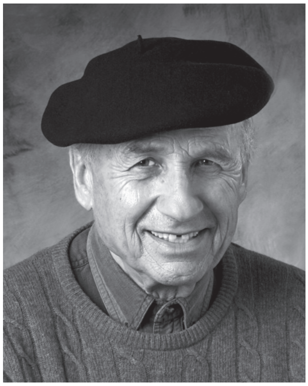
Chapter 22

A world powered predominantly by solar and wind energy

Walter Kohn



Walter Kohn, born in Vienna in 1923, majored in mathematics and physics at the University of Toronto and obtained his PhD at Harvard University. In 1957 he became a US citizen. Professor Kohn was awarded the Nobel Prize in Chemistry in 1998 'for his development of the density-functional theory'. His work revolutionized scientists' approach to the electronic structure of atoms, molecules and solid materials. As Emeritus and Research Professor at the University of California in Santa Barbara, Kohn is today collaborating with younger colleagues on research in this field. He was the executive producer of the documentary film The Power of the Sun, which dealt broadly with solar energy, was first shown in 2005, and was later shown internationally in 10 languages. The film presents the history, science and applications of solar energy, both in the developed and less developed world.

Note: An addendum to this chapter is available at http://www.nobel-cause.de/book/chapter22_addendum.pdf.

It is widely agreed that during this century humankind is facing two critical energy-related challenges:

1. Decline in oil and natural gas production. Total oil and natural gas production, currently providing about 60 % of global energy needs (see Fig. 1), is expected to peak in 10 to 30 years, with oil likely to peak first (IEA, 2004, p. 129).[1] Oil production in current oil fields is estimated to drop by about one half within a mere 20 or 30 years after passing its peak (see Fig. 2). Natural gas is expected to follow a similar pattern with a delay of two to three decades.

2. Increase in greenhouse gases. By the end of this century, accumulation of anthropogenic carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the Earth's atmosphere is expected to lead to a major increase of mean global surface temperature in a range from approximately 2 ºC to approximately 7 ºC above pre-industrial levels (see Rahmstorf *et al.,* this volume; IPCC, 2007), accompanied by significant acidification of ocean waters (WBGU, 2006; Hofmann and Schellnhuber, 2009) and a very substantial rise in the global ocean level (IPCC, 2007; Rahmstorf, 2007).

Both the exhaustion of oil and gas as well as global warming are due, in about equal measure, to two causes. First, the world's population is increasing rapidly, mostly in the less developed world (LDW) and in India, from 6.7 billion in 2009 to an estimated levelling off at 9 to 10 billion in about 2050 (see Fig. 3).

Second, per-capita consumption of fossil fuels has grown strongly since the Industrial Revolution in the developed world and is currently increasing rapidly in China, India (IEA, 2007) and the LDW. The governing simple mathematics for the global consumption of any commodity over a given period is:

(consumption) = (population) x (per-capita consumption)

At present, total consumption of energy is continuing to grow rapidly in China, India and in the LDW, but is fairly stable in the developed world.

The data shown in Figures 2 and 3 imply that, due to the continuing growth of world population, per-capita oil production will peak around 2015 (see Fig. 4), while the peak of total oil production, which (because much later) is harder to estimate, will occur some 15 or more years later.

The following are some broad principles for dealing with the global challenges of energy supply and climate change:

[1] The effects of the dramatic global economic downturn beginning in the summer of 2008 may not yet be fully reflected in data for the period after the middle of 2008.

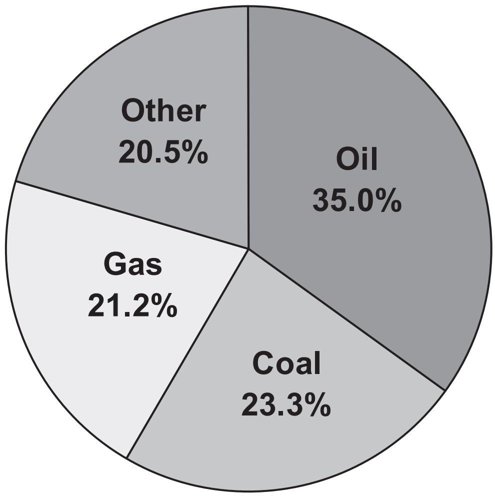


Fig. 1. Contribution of fuel types to global energy consumption in 2001. (*Source:* after Dell and Rand, 2004, p. 15)

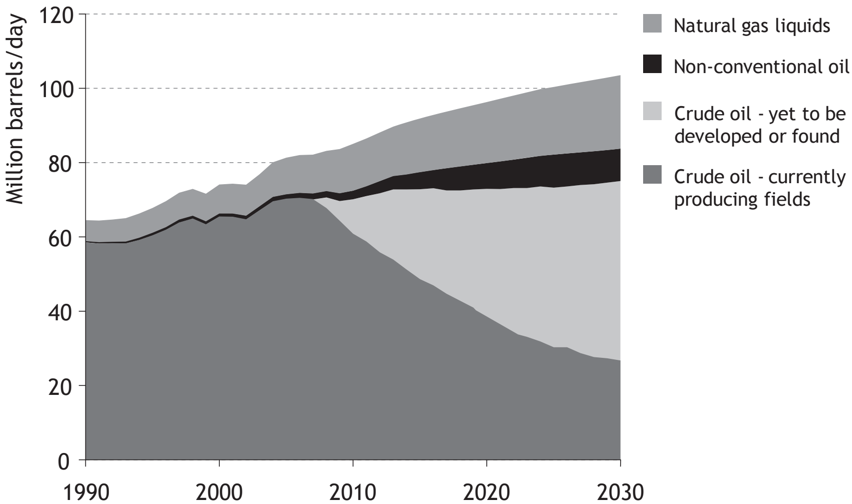


Fig. 2. World oil production by source. (*Source:* adapted from IEA, 2008)

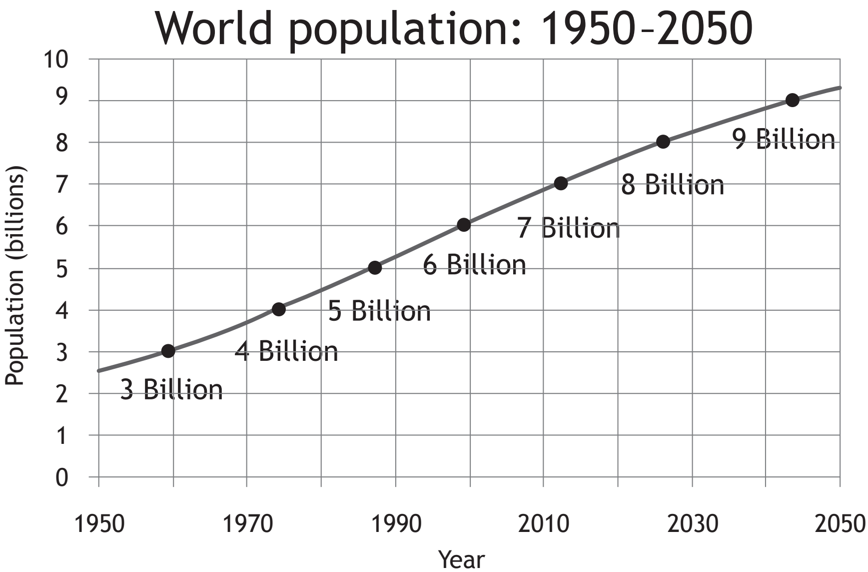


Fig. 3. World population growth. (*Source:* U.S. Census Bureau, 2009)

- They must be addressed without delay and with strong global cooperation.
- The growth of world population must be halted by about the middle of this century, or earlier, at no more than 9 billion, and gradually reversed.
- Energy conservation and efficiency in both consumption[2] and all forms of production must be substantially enhanced.
- Large-scale development of solar and wind power, and other established sustainable energy sources, must begin without delay.
- Four other major energy sources raise enormous problems that must be recognised. *Coal* generates pollution and is, without the costly capture and sequestration of CO_2, the greatest single cause of global warming. *Nuclear fission reactors,* with their as yet ineffective surveillance, are unacceptably easy stepping stones to nuclear weapons, as recent history has shown. Global-scale *bio-energy* production, which is CO_2-neutral in the steady state, strongly competes with food production for land and water. *Nuclear fusion,* while well established in the laboratory and in the hydrogen bomb, is still far from proven as a practical energy source.

[2] Examples include rapid replacement of SUVs and similar vehicles by much lighter, more fuel-efficient cars, and of incandescent by compact fluorescent lights; greatly expanded public transportation, especially in the USA and Canada; proper insulation of buildings; green architecture such as energy-neutral housing, and green city planning.

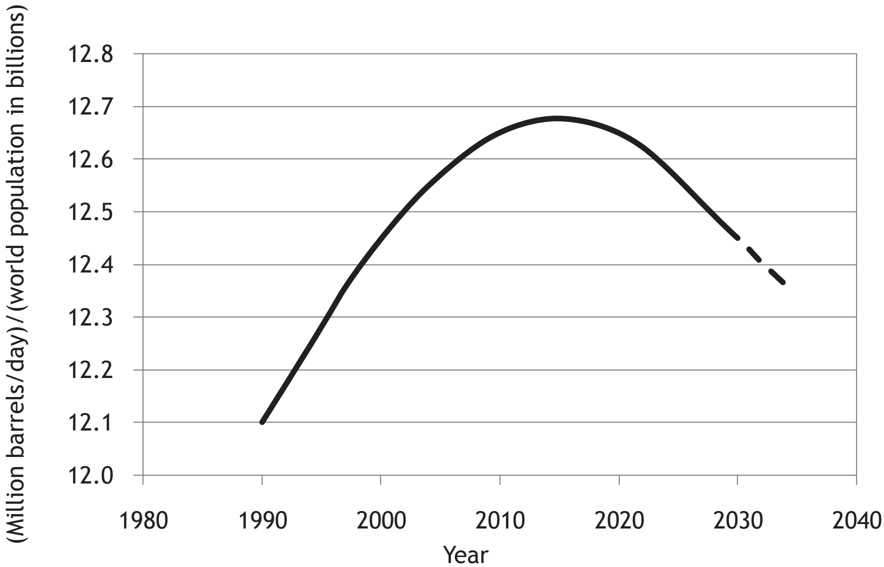


Fig. 4. Global oil production per person. Illustrative graph using data shown in Fig. 2 and Fig. 3. (*Source:* W. Kohn)

The revolution in energy production

In 2001, oil, coal, gas, biomass, nuclear, and other energy sources respectively accounted for approximately 35 %, 23 %, 21%, 11%, 7 %, and 3 % of global energy consumption (Dell and Rand, 2004; see Fig. 1). By the time oil and gas supplies are effectively exhausted in about the middle of this century, there probably will not yet be a safe and cost-effective technology available for carbon capture and storage, at least not on the required scale for burning of coal. This naturally shifts attention to solar and wind energy.

Solar energy is by far the most abundant source of energy (Sawin and Moomaw, 2008), but it is still substantially more costly than oil- or natural-gas-derived energy (U.S. Department of Energy, 2005). It currently accounts for less than 1% of total world energy production (Worldwatch Institute, 2007). However, its share is likely to increase greatly as projected growth rates of production are tremendous: a 30 % increase per year is a reasonable estimate (EPIA, 2008; BP, 2009).

Wind energy is currently much cheaper and more widely produced than solar energy. Its annual percentage increase is similar to that of solar energy (Global Wind Energy Council, 2008). The total average available wind energy up to the practical maximum height of about 80 metres above the ground (the typical hub height of large wind turbines) is much less than available solar energy. Nevertheless, according to current estimates, wind energy by itself could also supply the world's total energy needs several times over (Archer and Jacobson, 2005).

Given the limited amount of remaining fossil fuels and their dangerous impact on our climate, it is obvious that the infrastructure for acceptable alternative energies must be created rapidly, beginning immediately. Otherwise the world faces a frustrating choice between, on the one hand, a global economic meltdown and a violent scramble for dwindling oil and gas deposits, and, on the other, the dangerous use of coal and/or nuclear energy on a vast scale.

A world powered predominantly by solar and wind energy

Of course, the real-world problems of coping with continuing population growth, disappearing oil and natural gas resources, and continuing global warming, are enormously complex and intricately connected. Global warming is fairly uniform across the globe. However, energy demands and availability vary enormously. Available solar and wind energy depends strongly on geography and local climate, and varies strongly with season, time of day, and weather. This creates additional, subsidiary challenges of cost-efficient energy *storage* and *transportation.*

I shall, of course, not even attempt to deal with all these issues within a few pages, but instead shall discuss a greatly simplified model for a world powered predominantly by solar and wind energy, which I shall call 'sol-wind energy', combining solar and wind energy into a single entity. The expression 'sol-wind energy' reflects the fact that these two energy sources are complementary, plentiful, clean, GHG-neutral, and are likely to decrease in cost to a similar value of under 10 US cent/kilowatt hour. I believe that this model provides a general perspective for acceptable and achievable future energy provision.

The relevance of this model for the real world derives from three facts:

- Solar energy incident per year on Planet Earth exceeds the total present human consumption of energy by a factor of about 10 000 (U.S. Department of Energy 2005); available wind energy alone, indirectly also derived from incident sunlight, is, of course, much smaller, but also greatly exceeds total present energy consumption (Archer and Jacobson, 2005).
- The required materials are effectively infinitely abundant: for photovoltaic energy the main material required is silicon; for photothermal energy various effective light-absorbers; and for the capture of wind energy the main material required is steel.
- Although the current contribution of sol-wind energy is still less than 1% of humankind's total energy consumption (REN21, 2008), in recent years production has been growing at the enormous rate of approximately 30 % per year (see

above). If extrapolated, this represents growth by a factor of about 200 in two decades and more than a factor of 2000 in three decades. According to this model, the production of sol-wind energy would substantially exceed the current annual production of total energy in a mere 20 to 30 years.

The assumption underlying this model – that sol-wind energy production will continue to grow by about 30 % annually for the next 20, or even 30, years – is, of course, extremely optimistic. Nevertheless, it is consistent with the data of the last several years, and also with the effectively unlimited availability of the required materials.

Is this growth also consistent with the availability of labour required to produce, maintain and operate the necessary sol-wind equipment in the short available timespan? I do not have a firm answer to this question; however I can offer the following argument: Today the effective cost of sol-wind power production is about three times higher than the average cost for all forms of energy, including indirect costs due to pollution and global warming. This implies about three times greater labour requirements. Assuming approximately constant future per-capita use of energy, and disregarding possible major scientific-technological advances in energy production, conservation, and efficiency, this suggests that the per-capita labour requirement to produce sol-wind energy would be also about three times greater than today. This substantial load would, of course, be very heavy, but not necessarily prohibitive. Unforeseeable future developments make this estimate very rough and, I believe, probably much too high.

Urgency

The clean and safe sol-wind model described above is emerging from the fossil fuel model of the last two centuries. This new model is the logical consequence of the rapid exhaustion of oil and natural gas over the next 10 to 30 years. Of course, the change of most of the world's energy infrastructure from fossil fuel to sol-wind during this very short time is a huge challenge. Every year waited means a year less before the dreaded global peak-oil year, when uncertainty will begin to morph into a new reality (peak oil happened as predicted in the USA in about 1970; predicted by Hubbert, 1956, and described by Hirsch *et al.,* 2005).

This transformation will be among the greatest challenges ever faced by humankind. We need to do everything in our power – and as rapidly as possible – to stop global warming, including, as previously stated, rapid stabilization, followed by reduction of world population, immediate major per-capita reduction of anthropogenic GHG emissions, dramatic energy conservation, and improved energy efficiency. The time to wait for absolute certainty is far behind us; it has become a time for urgent preventive action.

Energy supply and global warming are make-or-break twin challenges of our times. Unless we put our collective minds to it, the second half of the present century will be a disaster. On the other hand, if we put our minds to it now, I am convinced that we can look forward to a better future, in which solar and wind energy predominate.

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