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The Challenge of Greening Energy Systems[1]

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Abstract

Human economic activities and social structures are heavily dependant on the complex energy systems which span our globe. The current global energy system relies on international agreements and free-market activity to balance the various factors of energy supply and demand, resource discovery and extraction, transportation logistics, and political considerations. This type of energy system has functioned reasonably well since the time of the Industrial Revolution, and has grown continuously since that time.

Modern society's high energy-demands are beginning to strain the planet's finite fossil-energy supplies, and the energy sector is now subject to increasingly frequent disruptions and price shocks. Future growth from emerging economies will demand even greater quantities of energy and resources. This is occurring under the shadow of rising world energy prices and the potential 'peaking' of liquid and gaseous fossil-fuel supplies.

Presently, energy from renewable sources accounts for less than twenty percent of world primary energy supply. The relative share of 'green' sources of energy has not increased substantially in the past thirty years, and despite many technological advances, there continue to be significant barriers in the implementation of biomass, wind, and solar energy. Price and implementation challenges in the renewables sector often do not compare favourably to other energy sources. In many nations, hydro-electric power has been fully developed, and increasingly, large hydro projects are not viewed as green. Integrating green energy into existing energy systems is problematic for these reasons and others, such as regulatory restrictions and the technical challenges associated with power intermittency and non-dispatchability.

We have every reason to believe that energy demand will continue to grow. Other authors have suggested that supplies for future demand will be met by nuclear fission and fossil-fuel energy sources. There are serious challenges to this vision. Nuclear generation facilities require enormous capital investment and many years to plan and construct. Projections of fossil-energy growth in natural gas must be tempered by the knowledge that gas is increasingly subject to supply limitations, high prices, and transportation problems. This suggests that coal, among the most polluting of energy sources, may continue as the backbone of energy supply in many areas of the world, but at a high environmental cost.

This paper examines the current state of world energy supply and demand, and attempts to evaluate future challenges by considering key energy-system leverage-points capable of influencing global energy trends. Important factors include: population growth, economic growth, energy-demand growth, fossil energy supply, technology improvements, renewable energy solutions, and conservation measures. Understanding the nature of global energy systems is an important step towards the implementation of cleaner and greener energy technology.

1 Defining Green Energy

What is green energy? We often associate being 'green' with environmental awareness and a compatibility with the biological systems that support life on earth. Advocates of a

green ideology often argue for the related concept of sustainability, another term that is difficult to define. Both of these words are widely used in popular language, leading to some confusion about their meaning.

In this paper we will consider being 'green' to indicate environmental compatibility, with little or no negative environmental impact. This differs from the concept of sustainability, which we will define as an action that can be repeated continuously without depleting or diminishing resources.

Sustainability and greenness are related, but differ in important ways. Many physical and chemical processes can be continued over time, regardless of compatibility with the natural environment. Nuclear energy, solar energy, and hydro power are examples of energy sources which may be sustainable over human timescales of hundreds or thousands of years, but these may or may not be environmentally compatible. Conversely, some natural processes are short-lived, and can not be repeated indefinitely, thus, by definition, they are not sustainable. Heat generated from the anaerobic breakdown of carbonaceous material is a green process (composting), but it cannot be sustained indefinitely without additional feedstocks. The distinction is crucial to how we view and make decisions about human energy sources.

Like all colours, green exists in a spectrum of shades and tones. The greenest of energy sources will be both environmentally compatible and sustainable for long periods of time. Many of the energy technologies currently viewed as green have important incompatibilities with regard to environmental systems. Indeed, many of the technologies considered to be sustainable cannot be maintained over long time scales.

2 Green beginnings

Before industrialization, virtually all energy was derived from natural sources. Burned biomass from wood, plant debris, dung, and animal fat met energy needs by producing heat and light (Wright 2004, Sims 2003). As the human enterprise became more sophisticated, so did our energy sources. Mechanical power for industry was provided by river hydro and windmills, and energy for transportation was found in wind for sailing ships, and horses and oxen provided power for transportation and agriculture (Diamond 2005).

These energy sources are ultimately solar in origin, with radiated heat energy from the sun driving hydrological cycles, differential heating producing wind currents, and photosynthesis in plants converting solar energy into stored chemical energy. The green chlorophyll pigments crucial to photosynthesis are the ultimate origins of a 'green' thinking, and biomass energy was the principle green energy source for hundreds of millennia.

Despite the seemingly endless quantity of such natural energy sources, for most of recent human history, our use of energy has not been environmentally compatible. Our constant harvest of fuelwood resulted in the destruction of forests wherever populations were concentrated, leaving Europe devoid of trees, and the unfortunate but legendary residents of Easter Island doomed to extinction (Wright 2004). Using natural sources of energy does not guarantee environmentally compatibility or sustainability.

3 Modern energy use

The gradual introduction of coal as a fuel, accelerated by the invention of the steam engine, and the discovery of large petroleum reserves eventually led to a world dominated by fossil energy sources. Our reliance on petroleum has increased from nearly zero in the1860's to roughly 35% in the present day. Overall reliance on fossil energy currently measures 80% (IEA 2005). In the late 1950s the power of the atom was harnessed as nuclear energy, an energy source which currently represents 6.5% of global primary supply. Hydropower continues to be a significant energy source, providing 2.2 %, while renewable energy from geothermal, wind, and solar energy represent only 0.4%, 0.05%, and 0.04%, and respectively (IEA 2005).

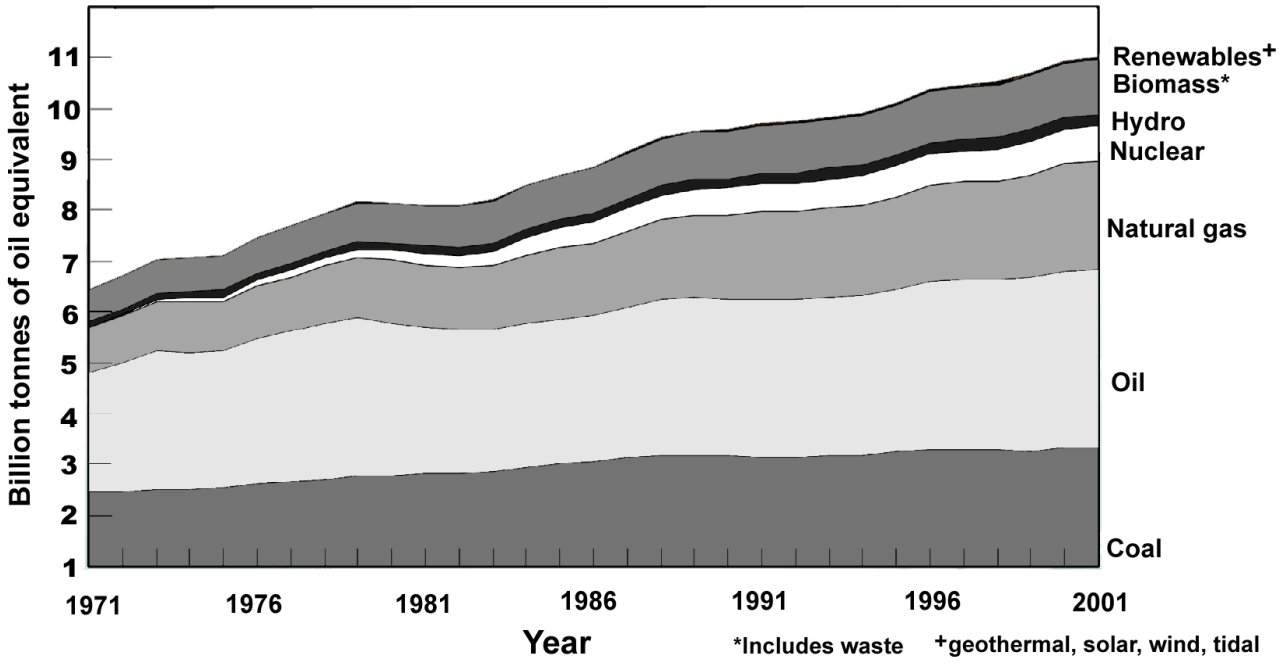


Figure 1. Trends in modern energy use over 30 years from 1971 to 2001 (IEA 2003).

Overall, energy supply has been growing at a rate of 2.1% per annum (IEA 2003), but it can be considered to have become modestly greener over the past 30 years. The share of fossil energy has decreased from 86% in 1971 to 80% in 2001, with the difference largely made up through an increase in nuclear energy. Biomass energy has remained relatively constant at 11% (IEA 2003).

Demand for energy is projected to grow at a rate of roughly 2% per year to 2050 (OECD 1999). This will require a large increase in the supply of energy from conventional sources such as coal, oil, and natural gas. Unfortunately, there are concerns that supply will be restricted. High demand and limited supply creates the conditions for price volatility and market increases such as we are seeing in the current world price of oil.

The current global energy system relies on a balancing-act of international agreements, market activity, and the trade and transport of large quantities of energy resources to maintain continuous energy to support human economic and social systems. A failure of any component in the complex energy system can have serious implications for the way we live.

4 The energy problem

The first step in solving a problem is recognizing it exists: humanity has an energy problem. In recent years, two major concerns have emerged from the high reliance on fossil energy: first, we recognize that fossil energy resources are finite and being consumed at a rapid rate, suggesting we will run out of inexpensive fossil energy sources in the near future, and secondly, emissions from fossil fuel burning have been linked to climate change effects in the earth atmosphere.

The problem of fossil energy depletion has been discussed by a number of authors (Hubbert 1971, Holdren 1991, Simmons 2005), and the problem of carbon dioxide emissions and climate change has been studied in depth by the United Nations Intergovernmental Panel on Climate Change, or IPCC. There have been numerous calls for change from national leaders, and through multinational agreements such as the Kyoto accord. Despite the widespread recognition of energy related problems, we have done very little to green our global energy systems.

The combination of fossil energy supply limitations and the accumulation of climate changing waste gases in the atmosphere have combined to form a serious energy problem. It is not that we are running out of energy, but more so that we may be running out of cheap energy, and we may also be reaching or surpassing important thresholds in environmental tolerance.

The energy problem is currently being attacked from a number of angles and disciplines, but what is generally lacking is a coherent energy policy. There are problems of both hierarchy and scale in addressing energy issues; decision-makers are often working on a local or regional scale, but energy supplies, energy prices, and CO2 pollution are global. In many cases, disputes about energy resources extend beyond international borders. The role of government, industry, and the general public in resolving these issues is poorly understood. Each group appears to be waiting for the other to provide solutions. The current energy problem involves a complex matrix of problems and opportunities, technologies, and political, economic, social and environmental factors. Some of these factors are presented in Figure 2.

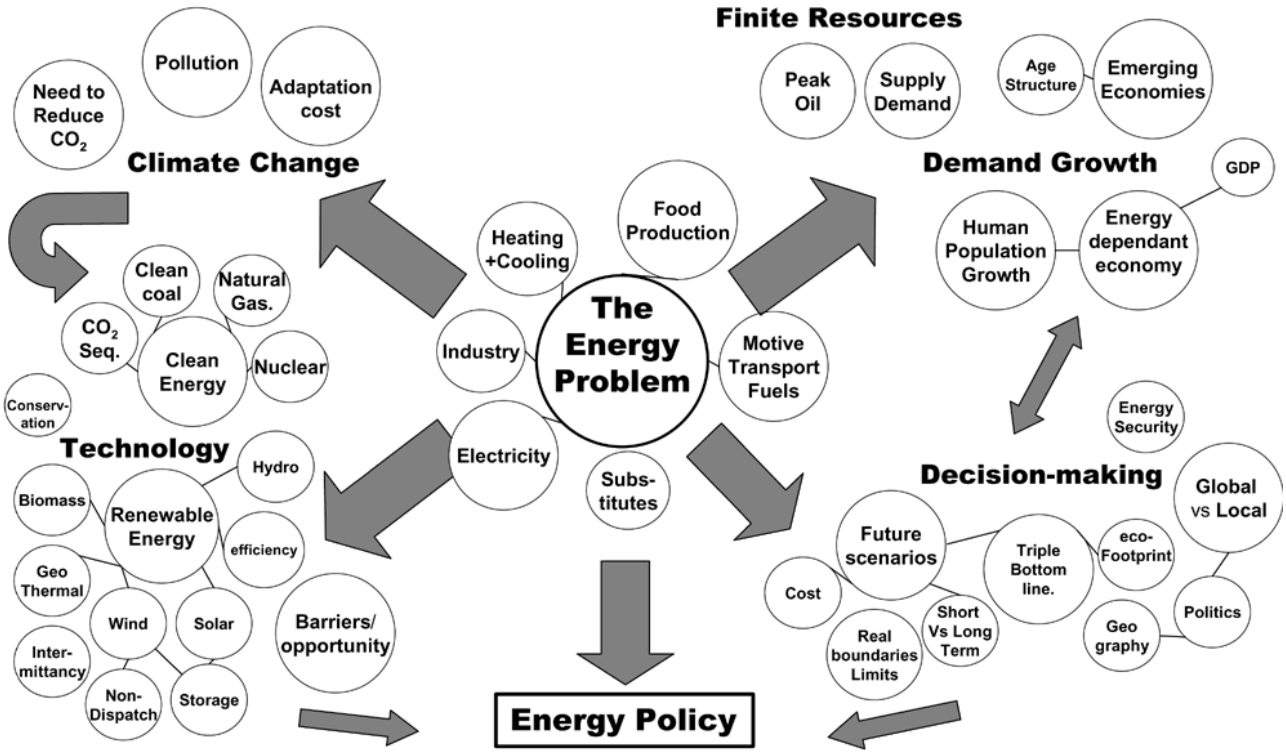


Figure 2. Example of interacting factors in the current energy problem.

The source of the energy problem can be attributed largely to a tremendous growth in energy demand over the past 150 years combined with our dependence on finite, non-renewable, fossil energy sources. Energy demand is closely related to population size. The human population has doubled since 1961, and tripled since 1927 (UN 1999). In addition to greater numbers of people, increases in economic activity and a higher standard of living have contributed to a need for greater and greater quantities of inexpensive energy.

The inability to meet future demand is seen by some as the greatest problem facing humanity in this century (Simmons 2005). Others argue that the by-products of energy utilization will result in a slower, but potentially more dangerous and irreversible problem of environmental degradation (MA 2005).

A range of technological options for clearer energy have emerged over time, and some may offer important contributions to solving the current energy problem. However, because energy infrastructure is expensive and slow to build/implement, important decisions must be made well in advance of the time when energy resources will be

required. Ideally these decisions will be based on clear information and a well-reasoned, carefully debated energy policy.

5 Population, Affluence, and Technology

Ehrlich and Holdren (1971) investigated the effects of population on resource use and environmental impact and proposed a simple relationship to describe the effect. Environmental impact can be seen as a function of population-size, multiplied by the affluence of the population in relationship with the technology utilized by that population (Holdren 1991). In equation form this is represented as:

$$I = P \times A \times T \quad (1)$$

A decrease in population or affluence can reduce environmental impact, or, better technology can moderate the effects of growth in either of population or affluence. The use of inappropriate technologies can exacerbate the problem.

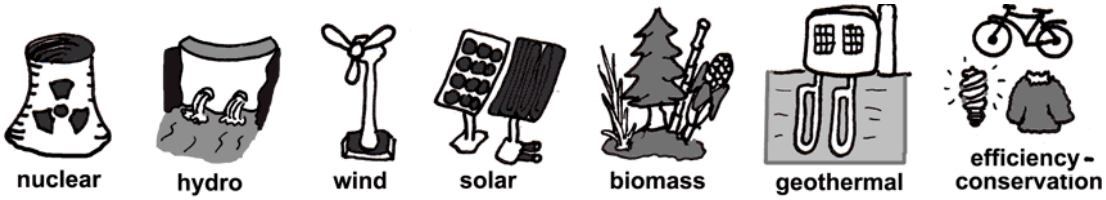
Reducing or eliminating demand growth is a potential solution to our energy problems, but this argument challenges the current notions of economic progress, human population growth, and technological development. Population growth is difficult to slow, and still a politically sensitive subject. Affluence can be considered in many ways a key human goal. Affluent societies often have a higher quality of life. The development of emerging economies and the spread of western affluence are seen as an important modern achievement, though it may prove to be one with serious ramifications. The consequence of accepting population and affluence as largely unchangeable factors is that we must rely almost exclusively on technology to offer solutions to the energy problem.

6 The call for greener forms of energy

Energy technology is already an important focus in resolving the energy problem, but can technology sufficiently green our energy systems to prevent problems for future generations? The answer is likely yes, but only if we are able to properly implement green technologies in a short period of time, and on a very large scale. We face a serious challenge in finding energy supplies that meet the criteria of being available on a sustainable basis, with no negative effects on the earth environment, at low-cost, widespread availability, and in large quantities.

6.1 Green energy options

There are numerous technological options which are considered to have green attributes. Generally speaking, most technologies that do not involve fossil fuels are considered green, but there is important and ongoing debate over nuclear energy and hydro power, which are often considered to have problematic attributes. We can consider there to be a spectrum of shades of green with some options being low-impact and cleaner, and others having high environmental impacts and being 'meaner' (Figure 3).



	nuclear	hydro	wind	solar	biomass	geothermal	efficiency - conservation
¢/kWh*	2 - 9	3 - 8	5 - 13	25 - 125	5 -15	2 - 10	-
Env. impact	high	high	mid	mid	mid	mid-low	negligible
potential	limited	limited	good	limited	good	limited	excellent
comments	radioactive waste	few sites remain	site-specific birds	expensive materials	low energy return	site-specific	Simple, cost-effective

*(Turkenburg 2001)

Figure 3. Characteristics of potential green energy sources.

The cost of energy is a strong limiting factor in the advancement of certain energy technologies, particularly in the case of solar photovoltaics which produce energy in the range of US 20¢/Kwh. Other technologies offer cheaper energy output but may be limited by their tremendous scale and large capital requirements. Nuclear energy and hydro power are two common examples.

Not all green energy options equally suited to solving energy problems. Many have limited potential implementation due to restrictions on how they function. The simplest and most cost effective measures, efficiency and conservation, are sometimes not pursued because they are not properly understood or are unprofitable for industry. Hydro power and geothermal energy have very specific physical requirements which are relatively rare. Wind and Solar energy are dependant on the availability of a passing energy flows, and are intermittent sources of energy supply. Biomass energy requires highly productive

ecosystems with excess capacity, and even then, the energy return on investment is quite low (Pimmentel and Patzek 2005).

Despite strong support from some authors (Hoffert et al. 2002), nuclear energy has serious challenges in becoming a green energy source. Nuclear energy is limited by finite fuel supplies, regulatory restrictions, and security concerns. Nuclear energy also has problems associated with the disposal of radioactive waste, uranium mining, water use, and thermal pollution (Makhijani and Saleska 1999).

We have few quantitative measures for the green qualities of our energy supply. The relative advantages and disadvantages of each technology remain actively debated, and it is likely that readers will view the spectrum of green energy supply in different ways. Unfortunately, this shifting debate is yet another cause of delay in green energy implementation. As Holdren (1991) points out, every option has an impact; our goal is to reduce that impact and be as environmentally compatible as possible. Our ability to be purely green vanished as soon as human societies moved past hunting and gathering, and we are now charged with the responsibility of protecting the earth environment as best we can for future generations, while simultaneously offering opportunities for improved quality of life for as many as possible.

7 There is no green, only 'greener'…

In summary, there are no perfectly green solutions to providing energy for human needs. We face important challenges with the likelihood of decreased fossil energy supplies, and ironically a CO2 "hangover" which threatens to alter the global climate. We have a reasonable understanding of the problems, but we have yet to implement the decision making, policies, and investments that are needed to make a green energy future possible. Technological innovation is the basis for almost all visions of a green future, but conservation and efficiency are perhaps the most promising starting points. There is a very real danger that if not managed properly, the scale of this problem will exceed our efforts to correct it. It is a great, green, challenge.

'Black gold' and brown coal have fueled much of the growth in human civilization to our present 6.5 billion individuals. We have in the past been guilty of colour blindness in our view of energy choices, but hopefully the sheen of new technology and green of

improved environmental awareness will allow us to change our current energy path and continue towards a bright and vibrant future.

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