Is there Progress toward Sustainability?
Despite the inherent human resistance to change.

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Abstract

The theme of this paper is to briefly survey the status of current efforts to maintain our natural environment and then discuss prospects for achieving future sustainability. The author finds that while there has been general recognition of the need for environmental sensitivity and conservation of natural resources, progress toward achieving sustainability goals has been slow. A principal reason for this lack of action is found in the reactive nature of the human species. Situated by biological design in our environment we typically respond to environmental changes only after they have occurred. Accordingly, while a number of revolutionary proposals have been made in recent years that would ensure sustainability almost indefinitely they are unlikely to be implemented proactively. Instead they will be implemented piecemeal by necessity when it is almost too late to avert the near disaster situations that they were intended to prevent from occurring.

Keywords

agriculture, buildings, design, eco-efficiency, ecology, electricity, energy, environment, solar, sustainability, transportation, water, wind

Defining Sustainability

In a general sense *sustainability* is the overarching concept that acknowledges the need to protect the natural environment for future generations[1]. It proposes that anything that we manufacture or build today should be sustainable throughout its life span. Furthermore, at the end of its life span it should be amenable to deconstruction and the reuse of all of its materials in some form. This is indeed a paradigm shift when we consider that most recycling efforts are still in the earliest and most primitive stages. While the sorting of household, business and public waste into categories such as paper products, bottles and cans, landscaping material, and all other waste, is now reasonably well established in many parts of the world, comparable large scale recycling programs have yet to be initiated in the manufacturing and construction industries.

The concept of sustainability is closely associated with the term *eco-efficiency* that was coined by the World Business Council on Sustainable Development (WBCSD) in the early 1990s to

[1] The Bruntland Report (1987) defined *sustainable development* as "… meeting the needs of the present without compromising the ability of future generations to meet their needs" (UN 1987); 'Our Common Future'; United Nations, World Commission on Environment and Development, A/42/427 Supplement 25, 4 August, New York, New York).

describe competitive goods and services that reduce ecological impacts throughout their life-cycle in accordance with the ability of nature to support these impacts (WBCSD 1996). More specifically, WBCSD established the following eco-efficiency objectives: reduction of both the material and energy requirements of goods and services; maximization of the recyclability of materials and the sustainability of renewable resources; containment of toxic dispersions from materials and processes; and, the achievement of improvements in product durability and service intensity of goods and services. WBCSD believes that these objectives can be achieved through the judicious application of five strategies:

1. *Improved Processes:* The adoption of well designed manufacturing processes and service deliveries that avoid the generation of pollution in preference to the employment of end-of-process pollution clean-up procedures.
2. *Product Innovation:* The design of new products and re-design of existing products based on resource-efficiency principles.
3. *Virtual Organizations:* The exploitation of information technology to share resources in a networked environment and thereby increase the effective use of physical facilities.
4. *Business Strategies:* The exploration of alternative marketing models, such as the leasing of products as services rather than goods for sale and thereby refocusing the design emphasis on durability and serviceability.
5. *Waste Recycling:* The utilization of the by-products of one process as the ingredients of another process, with the objective of minimizing resource waste.

These principles are embodied in the notion of *ecological design* advanced by architects Van Der Ryn and Cowan. They defined *design* as "… the intentional shaping of matter, energy, and process to meet a perceived end or desire" and *ecological design* as the effective utilization of resources in synchrony with natural processes in the ecosystem (Van Der Ryn and Cowan 1996). These two definitions distinguish between a design process that is intent on meeting the objectives of the designer regardless of what those might be and one that demands synergy with the natural environment.

Converging Forces

Over the past 40 years we have seen the emergence of a new set of social concerns. These concerns are driven by a genuine fear that mankind has been recklessly ignoring repeated signs that the delicate balance in nature among plants, animals, and the physical environment is in danger of disruption with serious consequences. Contributing factors that are rapidly gaining widespread recognition include: an unevenly increasing world population; a fairly sudden change from inexpensive to much more expensive energy; a gradual realization that environmental pollution and lifestyle will have an impact on health and longevity; the detection of what appears to be a steady and irreversible global warming trend; and, the marked transition to an Information Age in which the interests and capabilities of the individual are greatly enabled.

The confluence of these powerful environmental and societal forces is having a profound impact. With the increase in population, agriculture is gradually losing in its competition with residential development. As the cost of land increases, the need for denser habitation also increases the negative human impact on nature. An increasing demand for water, energy and materials is eroding the availability of natural resources on planet Earth. Moreover, the extraction and processing of the large amounts of raw materials to fulfill these needs not only damages the ecostructure, but also increases the pollution of the atmosphere to a level that has in some localized instances threatened the very existence of animal and human life. In particular, water has emerged as the most precious resource for habitation, agriculture, and the continuation of life itself.

The use of fossil fuel energy is increasing at a steady rate throughout the world, with developing nations in Asia beginning to outstrip even the US and Europe in terms of energy needs for their emerging industries. While there is some progress in the substitution of renewable energy sources, the technical and economic advantages of existing fossil fuel based energy production units are difficult to compete with. For example, in the US 41% of the electricity is still produced by coal plants. Even though this is down from nearly 49% in 2007, these electricity generating plants continue to be a major contributor (74%) to the generation of carbon dioxide in the atmosphere. While hydroelectric and other renewable electricity generating sources increased from 8.5% in 2017 to 13% in 2012 they still constitute a very small, even though not negligible portion of the entire electricity generation in the US (EIA 2014).

Water is critical for human survival and although four fifth of the Earth's surface is covered by water less than 3% of that enormous amount of water is freshwater. Almost 90% of freshwater is essentially unavailable in the form of ice and snow, as glaciers. In most parts of the world freshwater is being withdrawn at a much faster rate than it can be replenished. There are many examples of serious freshwater depletion, such as: reduction of the size of the Aral Sea in Russia by 75% in the 20-year period between 1960 and 1980, due to the Soviet collective farms program for the production of cotton; the annual withdrawal in some regions of the US (e.g., Arizona) of twice as much water as is being replaced by rainwater; and, the severe water shortage being experienced by 90% of the population in West Asia. In the US, even though the population is continuing to grow at a steady rate, the water consumption has leveled off since the mid-1980s. However, despite this per capita reduction there are clear signs that the annual withdrawal of around 400 billion gallons of water is not sustainable (USGS 2014).

More than 80% of the water consumption is for agricultural purposes. Therefore, the leveling off of the water consumption in the US is more than likely due to slight improvements in irrigation systems. However, it is estimated that more than 50% of irrigation water is still wasted due to evaporation, leaking canals, and mismanagement.

Water is also a major factor in respect to public health and hygiene. Waterborne diseases such as typhoid, cholera, and dysentery are responsible for the deaths of over 2 million persons each year (Gleick 2002, Hunter et al. 2000, Hunter et al. 1997). Much of this is due to a lack of water treatment plants in developing countries. Consequently, raw sewage is dumped into rivers at an alarming rate, For example, 300,000 gallons are dumped into the Ganges River in India every minute (Kibert 2005, 245). It is estimated that only 35% of wastewater is treated in Asia and less than 15% in Latin America. According to a 2000 survey by the World Health Organization more than 1.1 billion people around the world lack access to safe freshwater and more than 2.4 billion lack access to satisfactory sanitation (WHO 2000).

Clearly, while there has been some modest progress toward sustainability there has been no discernable paradigm shift despite the encouragingly wide-spread public recognition that we are on the path to an environmental crisis. Farmers have continued the wasteful practice of spraying crops instead of using drip irrigation. In this way some 70% of freshwater becomes contaminated with fertilizers, herbicides and pesticides. Food and water borne diseases account for more than two million deaths each year. The use of human waste as the only affordable fertilizer in Africa, Southeast Asia and South America is a cause of parasitic worm infections that afflict over two billion people.

In the built environment the need to separate potable water from graywater and blackwater is well understood but rarely practiced. In the US alone the annual waste from the construction and demolition of buildings is almost half a metric ton per capita (145 million tons). Since buildings are not generally designed to be disassembled only a small percentage of demolition material can be recycled. To meet sustainability criteria buildings should be constructed of materials that have low embodied energy and are reusable, be designed to be as energy self-sufficient as possible, and incorporate a waste management system that at the very least is capable of dealing effectively with dry and wet waste, as well as the reuse of graywater. Despite some successes the recycling of dry waste is still in most cases a marginal business proposition.

In transportation the combustion engine still reigns supreme. Conventional hybrid automobiles that charge their batteries with a gasoline engine took 10 years to capture 2.5% of the US car market. In 2008 they were estimated to represent 10% of the market by 2015. Today (2014) the market share of conventional hybrid cars is only 3.3% and the estimate for 2015 has been reduced to 5% (Crowe 2012).

The question then arises: What is the reason for this apparent reluctance to fully embrace sustainability goals and objectives when the urgent need to implement the appropriate measures is recognized, the consequences for inaction are apparent on a daily basis, the required technology is mostly available, and the necessary management principles for large scale implementations have been successfully applied in multiple areas of human endeavor?

Human Resistance to Change

The recognition that we need to consider the impact that our actions have on the natural environment has come only gradually over the past several decades, mostly due to painful experience. Human beings have an aversion to change that is rooted in our biological evolution and deeply embedded in our cognitive facilities. To explore the source of the resistance to change and attendant tensions that inevitably accompany a paradigm shift it is necessary to understand that we human beings are very much influenced by our surroundings.

As shown in Figure 1, we are *situated* in our environment not only in terms of our physical existence but also in terms of our psychological needs and understanding of ourselves (Brooks 1990). We depend on our surroundings for both our mental and physical wellbeing and stability. Consequently, we view with a great deal of anxiety and discomfort anything that threatens to separate us from our environment, or comes between us and our familiar surroundings.

This extreme form of *situatedness* is a direct outcome of the evolutionary core of our existence. The notion of evolution presupposes an incremental development process within an environment that represents both the stimulation for evolution and the context within which that evolution takes place. It follows, first, that the stimulation must always precede the incremental evolution that invariably follows. In this respect we human beings are naturally reactive, rather than proactive. Second, while we voluntarily and involuntarily continuously adapt to our environment, through this evolutionary adaptation process we also influence and therefore change our environment. Third, our evolution is a rather slow process. We would certainly expect this to be the case in a biological sense. The agents of evolution such as mutation, imitation, exploration, and credit assignment, must work through countless steps of trial and error and depend on a multitude of events to achieve even the smallest biological change (Waldrop 1992, Kauffman 1992, Holland 1995, Pohl 1999).

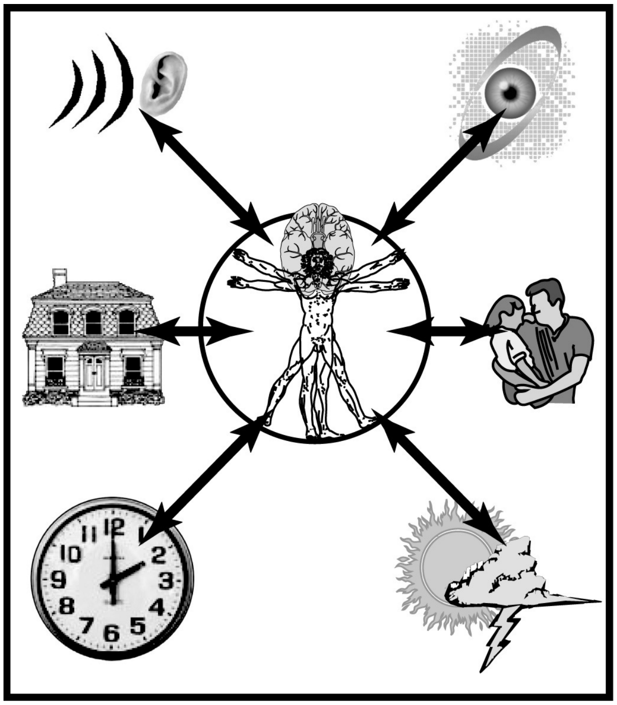

Figure 1: Situated in our environment

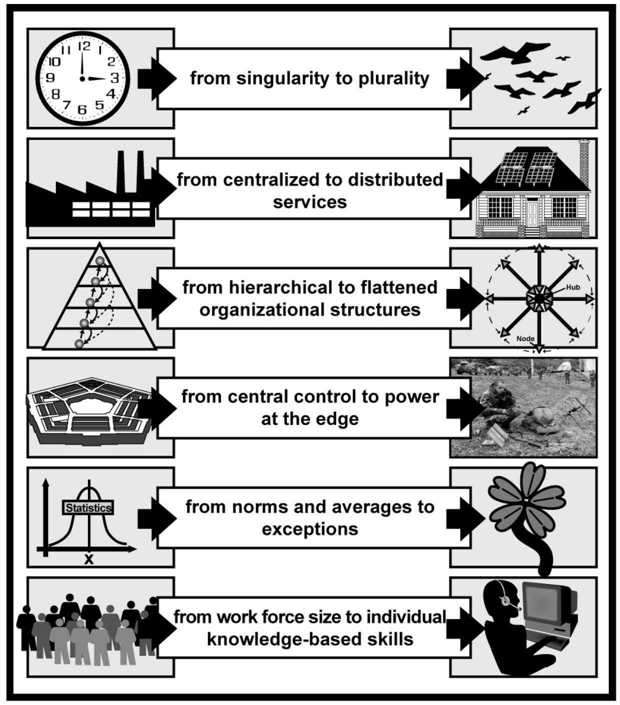

Figure 2: Many fundamental changes

In comparison to biological evolution our brain and cognitive system appears to be capable of adapting to change at a somewhat faster rate. Whereas biological evolution proceeds over time periods measured in millenniums, the evolution of our perception and understanding of the environment in which we exist tends to extend over generational time periods. However, while our cognitive evolution is of orders faster than our biological evolution it is still quite slow in comparison with the actual rate of change that can occur in our environment.

Over the past hundred years there have been many fundamental changes in our human values and the way we perceive our environment (Figure 2). The Industrial Age placed great value on physical products and devised ingenious ways to maximize the manual contributions of the human work force in a subservient role to a highly automated mass production process. In the Information Age the focus has moved from the physical capabilities of the human work force to the intellectual capabilities and potential of its individual members. The attendant symptoms of this profound shift are the replacement of mass production with computer controlled mass customization, virtual products as opposed to physical products, and the creation and exploitation of knowledge.

In respect to the forces that are driving our increased concern for maintaining a sustainable natural environment, the rate of change has not been constant. For example, while there have been much earlier warnings about the need to conserve energy from forward thinking individuals, it was not until the energy crisis of the 1970s due to an Arab-Israeli conflict that a larger cross-section of the US population was persuaded to adopt energy conservation measures. Even then it was the pain of increased fuel costs rather than an appreciation of environmental concerns that prompted action. As soon as the fuel prices fell the consumers again purchased large sports utility vehicles[2] with low fuel efficiency ratings.

It is therefore very much the foresight and persistence with which the advocates of sustainable development have pursued this important subject that has resulted in public awareness and a general sense of necessary action. Unfortunately, this awareness has resulted in only gingerly steps in the right direction rather than the necessary paradigm shift. As we will see in the next section of this paper there are several decisive steps that could be taken. However, by virtue of our human nature the necessary willingness to take those steps is likely to come as a reactive consequence of mounting hardship and pain rather than proactive actions.

Proactive Opportunities

While opportunities for the implementation of proactive measures to more decisively and effectively move toward sustainability exist in many areas, only the following four are briefly addressed here: transportation; building design and construction; agriculture; and, electricity generation.

> ***Transportation:*** As far as automobiles are concerned it will be difficult to replace the combustion engine in the near term. The foundational economics on which the automobile support network is built, in terms of gasoline availability and distribution, is simply too ingrained and convenient for the individual car owner to be replaced overnight. This is why progress in this area of transportation has been disappointingly slow. The most popular alternatives to gasoline in automobiles continue to be liquid fuels. US data based on 2.9 million vehicles indicate ethanol to be the dominant alternative (83%) with hybrid gasoline vehicles being a distant second (14%). Of the remaining 3% or 94,000 vehicles 84% are pure electric vehicles, 12% use compressed natural gas, and the remaining 4% are split among a variety of fuels including liquefied petroleum gas (2%), diesel-electric hybrid (1.3%), liquefied natural gas (0.3%) and hydrogen (0.1%).
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> High-speed railways offer an attractive alternative for mass transportation over longer distances. In respect to energy consumption and carbon dioxide production normal speed rail travel consumes about 33% less energy and produces 70% less carbon dioxide than car travel, on a per person basis. When comparing high-speed rail transportation with road (car) and air travel it outperforms both of these decisively. For example based on 2010 data, for the 512 km trip from Tokyo to Osaka in Japan the time taken is 6 hours 45 minutes by car and 4 hours 15 minutes by air, while the high-speed train takes only 2 hours 25 minutes. On this same trip the car produced 209 pounds, the plane 178 pounds and the train only 50 pounds of carbon dioxide (CRS 2013). The deterrents to high-speed rail transportation are of course unavailability and the presumed convenience of travel by car. As shown in Table 1, the construction costs of high-speed rail are appreciable and

[2] A sports utility vehicle (SUV) is an automobile, similar to a station wagon, mostly equipped with four-wheel drive for occasional off-road driving. SUVs are considered light trucks and have in the past been regulated less stringently than passenger cars under the US Energy Policy and Conservation Act for fuel economy standards, and the US Clean Air Act for emissions standards.

depend on the terrain, population density and applicable labor rates rather than the particular technology selected.

Table 1: Construction costs of high-speed rail networks (based on 2010 (US)$)

Route	$ million/km	Status	Distance	Technology
Yatsushiro to Kagoshima	$51	2004	126 km	Wheels on rail
Barcelona to Madrid	$24	2008	749 km	Wheels on rail
Los Angeles to San Francisco	$39	Proposed	832 km	Wheels on rail
Las Vegas to Victorville	$14	Proposed	293 km	Wheels on rail
Las Vegas to Anaheim	$30	Proposed	430 km	Maglev
Baltimore to Washington (DC)	$83	Proposed	64 km	Maglev

If it were available, high-speed rail travel could easily be preferred to air travel for longer distances due to greater comfort, lower cost, and the fact that at the destination the local transportation options are the same.

Buildings: There is much scope for the effective introduction of sustainability principles in the design, construction, life cycle occupancy, and demolition of buildings. Buildings based on current construction and occupancy practices are all at least in some measure destructive to the natural environment. Typically: the site is graded to provide convenient vehicular access and suit the layout of the building and its immediate surroundings; the construction materials and components are produced from raw materials that are extracted from nature and consume a great deal of energy during their production; the materials and components are transported to the site consuming more energy in transit; on-site construction generates waste in terms of packaging material and the fabrication of footings, walls, floors, and roof; during the life span of the building, energy is continuously consumed to maintain the internal spaces at a comfortable level and power the multiple appliances (e.g., lights, communication and entertainment devices, food preservation and preparation facilities, and security systems); despite some concerted recycling efforts, much of the liquid and solid waste that is produced during the occupancy of the building is normally collected and either treated before discharge into nature or directly buried in landfills; and finally, at the end of the life span when the building is demolished most if not all of the construction materials and finishes are again buried in landfill sites.

Let us consider the other extreme, a building that has been designed on sustainability principles and is operated as a largely self-sufficient micro-environment. As defined in broad terms by Van Der Ryn and Cowan (1996) such an ecological design aims to be in symbiotic harmony with nature. This means that the building should integrate with nature in a manner that is compatible with the characteristics of natural ecosystems. In particular, it should be harmless to nature in its construction, utilization, and eventual demolition. For example:

- Without the use of excavation equipment the footings of the building will need to adjust to the site topography, rather than the converse. Under these circumstances careful site selection will be a necessary prerequisite to any successful construction project. Also, to accommodate changes in topography that could occur due to environmental influences, the footings will need to be adjustable at least in height. Any significant reshaping of the site topography and certainly larger areas covered by building footings or paving should be avoided.

- The adoption of minimum weight structural principles would be a desirable ecological design criterion. It would serve to minimize the size of footings, reduce the consumption of energy required for transporting materials and components to the site, and require fewer raw materials to be mined from the Earth's surface.
- The building will need to be largely self-sufficient in terms of the energy required to sustain its occupants. This includes environmental control (i.e., temperature, humidity, air quality, and air composition), food preservation and preparation equipment, water and other waste recycling systems, communication and computer hardware devices, and any other electronic monitoring and control facilities.
- The occupants of the building should depend on the treatment and reuse of graywater and the recycling of solid waste. In both cases water emerges as one of the most precious and essential resources for the sustainment of human life.
- Apart from the treatment and reuse of graywater, the building will need to incorporate a waste management system that is capable of sorting dry waste as a precursor to recycling and processing wet waste in an anaerobic or similar treatment facility for composting purposes.
- The building materials and component products will need to be reusable in some form at the end of that life span. To satisfy this ecological design requirement the building must be deconstructable, the materials must be recyclable, the products must be able to be disassembled, and the materials dissipated from recycling must be harmless (Kibert 2005, 279). The concept of a *closed-loop* building material strategy is central to ecological design and *green building* principles.

The traditional approach to the design of the building envelope has been to reduce the flow of heat out of the building by embedding thermal insulation in the envelope and to control the heat flow into the building by means of sunshading devices or by treating the building envelope as a heat sink that will shield the desirable constant comfort conditions of the interior building spaces from the diurnal temperature swings of an external arid climate. Roof overhangs and other sunshading devices are used to shield the envelope and the building interior from direct solar radiation or in colder climates to control the amount of solar radiation that is permitted to penetrate into the building interior as a natural source of heat. While manually movable and automatically controlled sunshading devices have been commercially available for many years, their use in buildings is only gradually becoming prevalent. For various reasons, including cost and maintainability, fixed sunshading devices are still prevalent. Manually openable windows and internal blinds are still by far the most common and preferred form of natural thermal and daylighting control in low to mid-rise buildings.

This leaves considerable scope for the implementation of far superior thermal control strategies that could be applied to the design of energy-neutral and net energy export buildings. First, thermal insulation could be considered as a dynamic rather than static approach for achieving energy efficiency. It should be possible to automatically generate thermal insulation on a near real-time basis as external climatic conditions change[3]. This will require the development of new *thermal insulation on demand* technologies that are tightly coupled with external electronic monitoring devices. Second, the level of fine tuning required to achieve very high degrees of energy efficiency mandates the continuous monitoring of internal and external environmental conditions. The necessary technology to support the precise monitoring of temperature, humidity, air movement, radiation, precipitation, and air quality, has been commercially available at relatively low cost for more than a decade. Third, the same level of monitoring and precision will need to be applied to the control of sunshading devices. Much headway can be made in this area by simply taking advantage of existing electronically controlled devices before considering more elaborate technologies, such as the ability of a building or portion of a building to change its configuration in unison with the movement of the sun (Fisher 2009).

Water is such a precious commodity that even though buildings account for only about 12% of the total use of water there is increasing pressure to reduce this amount through recycling. In fact it is generally suggested that it should be possible to reduce the freshwater draw of buildings by as much as 90% in *high-performance* buildings (Kibert 2005, 408). It has been found that water conservation in buildings is as much a human behavioral problem as it is a mechanical solution. For example, whether or not the building occupants abide by guidelines that suggest soaping of hands before turning on the water during hand-washing, is a behavioral issue. However, how the waste water from the hand-washing operation is captured, treated, and reused as graywater, is a mechanical issue. These issues require different solution approaches.

The solution of the behavioral problem relies mostly on education and motivation. Much can be achieved in this regard by making the building occupants aware of the amount of freshwater that they are using, at the time of usage. The near real-time measurement of the amount of water that has just been used by a building occupant and the concurrent display of this measurement as immediate feedback to the occupant is likely to be more effective in the longer term than automatically stopping the water flow as soon as the recommended freshwater draw has been exceeded. At the same time, communication on a continuous basis of the cumulative water usage to each individual building occupant, in comparison to all other occupants, can motivate occupants to use less water on a competitive basis. Again, inexpensive electronic measurement and alerting devices are already available to meet these objectives.

The capture, treatment and reuse of graywater are amenable to a range of mechanical solutions that are largely independent of user control. While all of the solutions that are currently available and even those that may become available in the foreseeable future will result in an increase in capital costs, this increase will be a relatively small percentage[4] of the total cost of the building.

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[3] In 1967 Laing proposed an approach for generating *thermal insulation on demand* through multi-layered membranes in which the width of interstitial air cavities is controlled by either electrostatic or pneumatic forces (Feder D. (ed.) (1967), Proceedings of the 1st International Colloquium on Pneumatic Structures, IASS, University of Stuttgart, Stuttgart, Germany, (pp. 163-179)).

[4] If the plumbing costs (including fixtures) of a typical home are currently about 5% of the total cost of the building then even a 40% increase in plumbing costs is only a 2% increase in the capital cost of the building.

Agriculture: Prior to the 1980s technology and management advances allowed agriculture to greatly increase food production through: mechanization with farming machinery; improved fertilizers and pesticides that reduced spoilage; artificially bred plants that increased disease resistance; and, vaccination and drugs that reduced livestock losses. However, these advances that allowed agriculture to barely feed an increasing world population severely stressed the land beyond its capacity in the post-1980s. With agrochemicals destroying the natural cycles of nutrient renewal, agriculture has been increasingly interfering with the delicate balances of the Earth's ecosystems.

There are certainly ways in which these adverse effects of agriculture can be curtailed without necessarily impacting the need for greater food production. First, the wide-spread practice of spraying crops wastes massive quantities of precious water. The implementation of drip irrigation systems and the application of soilless technologies under controlled indoor conditions are promising directions. Growing food indoors under controlled conditions has become economical through three technologies: drip irrigation; hydroponics; and, aeroponics. Plants are typically rooted in lightweight, inert material such as vermiculite that can be reused for years. Small tubes drip nutrient-laden water precisely at each plant's root. The advantages of these soilless technologies are manifold. Crops can be grown year-round without concern for droughts and floods. Harvesting yields are maximized due to ideal growing and there are no crop losses due to insects, beetles, worms, and birds.

More revolutionary is the concept of vertical farming in multi-story food production buildings located in urban areas, so that the food will be consumed close to where it is grown (Despommier 2009, 2010). The potential advantages are enticing and include: multiple harvests per year; ability to utilize recycled city graywater; considerable savings in transportation costs; local reuse of waste as a source of energy; and, reduced risk of infectious disease. An automated conveyor would move seedlings through areas that are optimized to particular stages of plant growth with tailored water, lighting, temperature, and nutrients. For example, a 20-story vertical farm could exploit appropriate technologies at different levels, such as: photovoltaic panels integrated in the external wall to generate electricity; incoming seeds could be tested in a laboratory and germinate in a nursery; and, retail groceries in proximity would sell fresh food directly to consumers without the need for transportation.

The question then arises: Can vertical farms in cities be economical with the high cost of real estate in urban areas? In fact, every larger city has many less desirable areas that could be utilized. In terms of availability of usable crop growing area a 1 hectare city block would provide 20 hectare of floor area in a 20-story building. If we allow for two growing layers per floor and four harvests per year then 1 hectare of building footprint area would be equivalent to 80 hectare[5] of horizontal indoor greenhouses. The principal current roadblocks to vertical farming are established farming and business practices, and the need for abundant daylight.

Electricity Generation: In 2009 professors Mark Jacobson of Stanford University and Mark Delucchi of the University of California at Davis proposed a plan for how 100% of

[5] Allowing for the fact that a greenhouse would have two harvests per year (i.e., compared with one harvest per year on normal farmland) the multiplication factor would be 160 rather than 80.

the world's energy for all purposes could be provided by non-fossil fuel sources within 20 years (Jacobson and Delucchi 2009). Their proposal is essentially a hybrid approach based on wind, water and solar (WWS) energy sources that calls for millions of wind turbines, water machines and solar installations; - paramount to a political and societal transformation that would require a paradigm shift. They argued that since electricity is a more efficient energy source, the total global conversion to non-fossil fuel would actually result in a 32% reduction in energy demand[6]. Based on this assumption and the maximum global energy consumption in 2009 of approximately 12.5 trillion watts, they projected the equivalent global energy consumption in 2030 under WWS conditions to be 68% of 16.9 trillion watts[7] or 11.5 trillion watts.

Considering only technologies that were known to work in 2009 and of these only those technologies that have near-zero emissions of greenhouse gases and air pollutants over their entire life cycle, they made two assumptions: (a) that virtually all fossil fuel heating can be replaced by electric systems; and, (b) that most fossil fuel powered transportation can be replaced by battery and fuel-cell vehicles. Making allowances for mountains and oceans, they made the following approximate projections for the availability and demand of WWS energy:

- ***Wind:*** 40-85 trillion watts available (only 20,000 MW[8] used in 2009), with a projected demand of 3,800,000 of 5 MW wind turbines and 720,000 of 0.75 MW wave converters.
- ***Water:*** 2 trillion watts available (negligible use in 2009), with a projected demand of 490,000 of 1 MW tidal turbines, 5,350 of 100 MW geothermal plants and 900 of 1300 MW hydroelectric plants.
- ***Solar:*** 580 trillion watts available (only 0.0008 trillion watts used in 2009), with 1,700,000,000 of 0.003 MW roof top photo-voltaic systems, 49,000 of 300 MW concentrated solar plants and 40,000 of 300 MW photo-voltaic power plants.

They pointed out that not only did sufficient concrete and steel exist for the projected 3.8 million wind turbines, but both of these materials are recyclable. However, they conceded that certain specialist materials such as lithium[9], silver, tellurium, indium, platinum, and neodymium, would be in short supply. Jacobson and Delucchi estimated the overall global construction cost of the total WWS solution to be in the order of (US)$100 trillion plus the cost of transmission facilities.

Conclusion

To be proactive rather than reactive is not in our human nature. Situated as we are in our environment we are biologically engineered to incrementally adapt to the changes in our

[6] Only about 20% of the energy in gasoline is used to move a vehicle, while 80% is wasted as heat. Up to 80% of the electricity delivered in an electric vehicle is used to move the vehicle.

[7] The projected increase in global energy consumption in 2030 is due to increases in population and rise in living standard.

[8] Million Watts (MW).

[9] The world's largest known lithium supply lies below salt flats some 4,200 m above sea level in the Bolivian Andes.

environment after they have occurred. While some of us are capable of the conception of revolutionary ideas such as vertical farming and the WWS solution, society as a whole is not willing to implement the required paradigm shift until the hardship or threat to status quo have become unacceptable. In this way we set our own limits that are typically not governed by any lack of intelligence or creativity, but rather by our inherently reactive human nature. Therefore, although we are willing to logical deduce from our understanding of the physical world that the principles of sustainability, eco-efficiency and ecological design are sound and that their implementation is necessary for our very survival we will implement them only reluctantly when we are in dire straights.

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