SUSTAINABLE INNOVATIONS: A SURVEY OF THE UNITED STATES

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1. Introduction

Those who are paying careful attention to global patterns of non-sustainability agree that a new path is desperately needed. We are edging closer to tipping points in a multitude of sectors: energy, fresh water resources, soil productivity, genetic and biological diversity and, importantly, global climate. While behavior and policy changes are crucial to turning around most non-sustainable trends of modern society, sustainable technology innovations must compliment behavioral and policy responses. Innovations in the arena of sustainable technologies and practices are accelerating in the United States with several novel approaches now seeking the venture capital necessary for commercial success.

Entrepreneurs, academicians, and government researchers are among those leading the effort to develop new technologies and practices that have the potential to transform the way in which non-renewable and often-hazardous products are utilized in daily global commerce. Substitution for, and ultimate elimination of, many non-sustainable products and services now appears not only possible but also likely.

2. Background

Innovations occur in every age. Some, like antibiotics, the printing press and rural electricity, quickly advance the betterment of large numbers of the human family. Other innovations achieve early success and dissemination, such as pesticide use, the carbon fuel economy, and industrial agriculture, only to be found increasingly non-sustainable to the very ecological life-support system of the planet. Many of the last century's innovations not only fail to address but actually now magnify our global challenges.

We have come to define and accept innovations as a series of measures often only a little "less bad" than what we began with. We too frequently find a way to innovate ourselves into deeper and more difficult circumstances relative to the prospects for a sustainable future. Our "less bad" innovations (substitution of one chemical for another, a less carbon-intensive fuel for another) merely delay the day of reckoning that awaits our inability to truly innovate in a sustainable fashion.

Stripped of the veneer of commercial and marketing glitz, many of our innovations are at best no more than linear responses to narrow, poorly articulated problem statements, often missing the real problem entirely. At best, they are ineffective; at worst, they create an even larger, more vexing problem set. Sustainable innovations require that we adopt a systems focus that allows more complex problems of non-sustainability to be addressed outside of a one-off approach to problem-solving that is destined to fail.

Thus, the greatest challenge we have before us today is to innovate on behalf of sustainability while we still have the opportunity. What follows is a broad sweep of six areas of non-sustainability in which hopeful and far-reaching innovations are being developed within the United States. When ultimately successful, these new developments promise their benefits to the world at large.

3. Innovations for Sustainability: A Brief Survey of the United States

Innovations which support sustainable development are occurring in dozens of sectors across the United States. I have selected six general areas of innovation which I believe will be crucial to helping turnaround a set of non-sustainable behaviors now commonplace not only in the U.S. but throughout the world. These non-sustainable behaviors are: 1) the legacy of contaminated soil and water stemming from the industrial revolution and the Cold War, 2) the proliferation in use of petroleum-based plastics with all of their end-of-life management issues, 3) the conventional pollutants and climate changing attributes from over a century of carbon fuels use, 4) the loss of topsoil and the decline in arable lands worldwide due to industrial agricultural practices, chemical use, and erosion, 5) the fresh water crisis throughout much of the developing world, and 6) the global spread of thousands of new and poorly-understood chemical pesticides.

The innovations that appear most promising to address these six urgent challenges are found in the science of mycoremediation, bioplastics, energy efficiency and renewable energy, natural systems agriculture, membrane and other water purification technologies, and the emerging promise of mycopesticides. Innovations in each of these areas are clearly not unique to the United States, but it is upon the American experiences and achievements of late that I wish to focus.

A. Mycoremediation

The science of mycology, particularly the science of mycorestoration, is easily a novelty to most biologists. Using macrofungal species to help remediate contaminated soils is beyond the proof of concept phase but remains in near-stillborn status compared to conventional physical and chemical treatment technologies in use around the world. However, at a small research facility in Washington State, the application of mycoremediation has taken form.

The company, Fungi Perfecti, led by mycologist and entrepreneur Paul Stamets, has developed strains of fungal mycelium that have proven effective in breaking down complex mixtures of hydrocarbons and other chemical and biological pollutants. In the most telling demonstration of this technology to date, Stamets treated diesel-contaminated soil with spores from oyster mushrooms in an effort to break down the pollutants. After eight weeks, the total petroleum hydrocarbons had been reduced from 10,000 parts per million to 200 parts per million, leaving the soil clean enough to use in highway landscaping.

In another innovative application of mycoremediation, Stamets designed a system to remove *Escherichia coli* bacteria from wastewater running off his farm near Olympia, Washington. The system channeled contaminated water through a series of organic barriers, inoculated with mycelium that served as filters before the water entered nearby surface water. Within a year, the mycofiltration system had all but eliminated *E. coli* from the effluent. No secondary waste streams were created in the process, leaving the process completely safe and cost-effective to implement.

Mycoremediation works because mycelia produce both enzymes and acids which break down carbon and hydrogen bonds. It matters not to the mycelia that these bonds are found in cellulose or petroleum products, pesticides, or other pollutants. The desire of mycelia to break these bonds make them predictable, effective and sustainable forms of hazardous waste remediation. Research continues on the effectiveness of mycelial strains in breaking down a variety of other toxic and hazardous compounds. Potential applications for these technologies include watershed protection, treatment of animal feedlot runoff, and even reducing the volumes of contaminated material that gets shipped to permanent disposal facilities.

B. Bioplastics

Early responses to the waste issue posed by conventional petroleum plastic products, predominantly containers, focused on recovery and recycling of the polymers into secondary products such as wood substitutes in fencing and furniture, toys, etc., in a practice known as down-cycling. This practice has been remarkable in its inability to dent the volumes of plastic still being landfilled or incinerated. Meanwhile, price volatility in petroleum feedstocks, coupled with technology advances in bioplastics and their initial niche marketing successes, now support a promising, sustainable alternative to the use of petroleum in an increasing number of commercial products.

Bioplastics constitute a new generation of plastics, made from cellulose, starch and oil derived from renewable plant resources. Bioplastics are both biodegradable and compostable, are neither hazardous in their production nor to the environment when disposed. Market research indicates that bioplastics have satisfactorily addressed the performance issue in comparison with synthetic plastics. While still more expensive than synthetics, bioplastics are now making inroads in a range of commercial, government and institutional food service outlets.

Within the United States, sustainable bioplastics center on the use and conversion of non-GMO biomass feedstocks. EarthWare is one U.S. company dedicated to the production of non-GMO wheat material for tableware and other food service industry products. BioCorp and EarthShell Corp. have formed alliances with DuPont and Eastman Chemical to manufacture lines of bioplastic products, also in the food service industry.

Metabolix, Inc. has recently won the Presidential Green Chemistry Challenge Award for its progress in commercializing a broad family of natural plastics produced from renewable resources such as corn sugar and vegetable oil. The company uses a proprietary fermentation process and has recently signed on with BP to develop the direct production of natural plastics from switchgrass.

Another exciting innovation in the filed of bioplastics is the use of biomass fractionation process to extract not only biomass products for plastics, but a variety of other value-added products. The U.S. company PureVision has developed a core fractionation technology to separate the major fractions of biomass: cellulose, hemicellulose, and lignin, into fiber, lignin and sugars to be then converted into value-added products such as resins, fuels, pharmaceuticals, and bioplastics.

C. Energy Efficiency and Renewable Energy

For almost three decades, the case has been made that energy efficiency is the cheapest source of new energy in the developed world. This remains the case today. The developing world, often without national electric grids, does not enjoy the opportunity to use efficiently what it does not have in excess to begin with. Technological innovations in both energy efficiency and renewable energy offer the promise of a sustainable energy future for both developed and developing worlds.

As in each of the six areas covered in this paper, innovations in energy efficiency and renewable energy are not the monopoly of any one country. There are powerful developments occurring in government and corporate laboratories worldwide. In the United States, some of the more commercially-ready innovations include super-efficient windows and lighting, a constantly more rigorous set of industry-led voluntary building standards under the Leadership in Energy and Environmental Design (LEED) program, solid state lighting, micro heat pumps, portable fuel cells, biodiesel applications, several photovoltaic improvements, and an exciting new effort to reduce the vulnerability of central electric grids through the use of an internet-modeled "Energy Web," being developed by the Bonneville Power Administration.

One example in the area of super-efficient lighting is the work being done at the Pacific Northwest National Laboratory (PNNL) to improve the performance of reflector-type compact fluorescent light bulbs and also redesign fixtures now currently hardwired for these energy-efficient lamps. The goal here is to reduce the build up of waste heat in the fixtures that make ballast failure more possible and repairs both difficult and dangerous to make – both impediments to increased use of energy efficient lamps.

On the photovoltaic front, advances are being announced weekly. One innovation developed by the American firm HelioVolt is in the production of inexpensive solar cells that can be incorporated into skylights, roofing, and building materials. Meanwhile, Energy Innovations has developed a rooftop solar system that combines crystalline solar panels with motorized mirrors. The mirrors move to track the sun and focus energy onto the cells, reducing the number of cells needed for a given amount of output. The lower cost of the mirrors plus the reduced system installation costs make this a promising new technology.

In the Pacific Northwest, an important innovation is underway to remake the very design of that Region's electric utility grid. Vulnerable to disruption and outages due to weather and other extreme events, including a recent region-wide blackout, management at the Bonneville Power Authority are embarking on a remake of the current electrical grid system. A system now centralized into a few large generating facilities connected by long stretches of transmission line will be transformed into a web-like array of small, decentralized, and (importantly) renewable energy generation sources such as wind energy, fuel cells, and photovoltaic. Added to the conventional mix of hydroelectric, combined cycle gas turbines and other central stations, the Energy Web promises a robust energy network that depends for its vitality and economic value on the contribution of renewable sources to the supply mix.

D. Natural Systems Agriculture

The ability to feed current and future generations is a prime objective in any nation's policy for sustainable development. Within the United States, food surpluses have become a significant export commodity above and beyond the satisfaction of domestic needs. However, an industrial agriculture that features monoculture in crops, heavy inputs of chemicals and energy, and an emphasis on short term productivity, has resulted in growing soil erosion across the nation's prime agricultural regions, particularly the Midwest. A quarter to a third of the topsoil present at the beginning of intensive agriculture 200 years ago has been eroded. The frequent absence of a winter soil cover leaves remaining top soil subject to wind or snow/rain erosion or both.

At The Land Institute in Salina Kansas an innovative effort has been underway for several years to develop a new paradigm for food production where nature's patterns are mimicked rather than subdued with high-input energy and chemicals. Called "Natural Systems Agriculture," this innovative approach aims to establish a perennial polyculture that can both preserve soil during the winter while producing high crop yields during the growing season.

Agronomists are working to breed wild species of crops like wheat with traditional wheat to make a grain crop that re-grows each year, saving soil, planting expenses, and the costly inputs now needed to extract steady yields from increasingly impoverished soils. Natural Systems Agriculture is a sustainable innovation, one that uses the natural prairie as the model for grain crops. It aims for an agriculture that is resilient, productive over the long term, economical, and ecologically responsible.

Another sustainable innovation that will compliment Natural Systems Agriculture is the work being done in crop science known as "Smart Breeding." In this significant and immensely sustainable approach, scientists are working with plant species to identify dormant characteristics such as drought resistance, durability, and increased nutritional value, and then cross breeding and hybridizing these traits into traditional strains of crops. Rather than genetically manipulating a crop to try and achieve a desired characteristic, scientists are now able to simply turn on a plant's innate ability to produce that same trait.

Smart Breeding has the promise to revolutionize agriculture via an open system method that allows farmers anywhere to take advantage of the new strains. Because it is essentially an open system, Smart Breeding and its resulting, ever-variable strains, cannot be locked up in patents by a single company. Advances in genomics and data management make it possible to identify and catalog the multitude of traits contained and expressed in individual varieties of crops and then activate them in crop production with the result of increased yields, more nutritious foods, and lower costs – all without the need to employ genetic engineering or become dependent on a few international seed companies.

Couple Natural Systems Agriculture and Smart Breeding with crop management techniques such as perimeter crop trapping, biodynamic faming, and advanced methods of permaculture, and a truly innovative and sustainable agriculture becomes available.

E. Water Purification

The Millennium Development Goals are but one sign of the international urgency behind improving access to safe drinking water across most of the developing world. Unique challenges are faced in this effort as the growth of dozens of the world's ex-urban centers has been unplanned leaving hundreds millions of people in sprawling conditions without traditional water infrastructure. Sustainable innovations in water purification may well need to be small, decentralized, point of use systems given the huge costs of overlaying traditional-scale drinking water delivery systems where none now exist. What technologies can help with this?

The list includes self-cleaning membranes, solar distillation, low-cost arsenic filters, and UV-Tube devices. Researchers at the University of California at Berkeley have developed an affordable, simple, and easy-to-use household water disinfection device that uses ultraviolet light to inactivate pathogens. It can be built with using materials commonly found in developing countries and, importantly, it does not require water pressure to operate. Field testing is now underway.

Elsewhere, Proctor and Gamble has developed an electrolytic cell technology that uses the naturally occurring salts in water to produce a dilute solution of mixed oxidants that disinfects water. It works either in-line with a distribution system or can be used to disinfect individual tanks or containers of water. The power requirements are as minimal as a pair of AA batteries or solar cells.

Membrane technologies are not new, but as innovations help drop their price and increase their reliability, they will become a greater part of the response to substandard drinking water quality. The four major types of membrane filtration – reverse osmosis, microfiltration, ultrafiltration, and nanofiltration – are now being used for the removal of bacteria and other microorganisms, particulate material, and natural organic material. The American Water Works Authority is a leading advocate for the development of membrane technology as an economic and effective water treatment method. Advances in automation and in lowering the input energy required to drive water through the membranes continue to brighten the prospects for membrane use.

At Lawrence Berkeley Laboratory, an innovative arsenic filter has been created using coal ash contained in small tea-bag-sized packets. The ash is coated with ferric hydroxide that reacts with the arsenic and forces the element to precipitate onto the ash particles. Tests with water containing 2,400 parts per billion saw the filter lower the arsenic content to 10 ppb. For those areas of the world facing high levels of arsenic, whether naturally-occurring or human-caused, in drinking water sources, this emergent technology holds great hope.

The challenge of providing clean drinking water to everyone on the planet remains daunting. As the developed world comes up against the replacement costs for deteriorating water infrastructure while at the same time struggling to meet its own pledges to developing nations under the Millennium Development Goals, small-scale, distributive, affordable and effective innovations will be needed. The exciting work underway in the U.S. and elsewhere gives hope that this is an area where progress can not only continue but grow in magnitude.

F. Mycopesticides

The global challenge posed by the continued use of chemical pesticides is well-known. The application of mycological science to the control of pest insects is one more significant and sustainable innovation for the 21st century. As with the advances in mycoremediation discussed above, the development of mycopesticide technology is emerging from the laboratories of Fungi Perfecti, in Washington State. There, mycologist Paul Stamets has achieved an important breakthrough in the use of naturally occurring fungal life to control social pest insects such as fire ants, termites, and carpenter ants.

Stamets' technology, reflected in a far-ranging patent awarded last year, uses the pre-sporulating stage of a fungus to kill targeted groups of social insects. This is a naturally-occurring insect-specific alternative to chemical pesticides that does not harm other plants or animals. The innovation rests in the distinction between this approach and previous attempts to use the *Metarhyzium* fungus spores as a pest killing agent. While spores are toxic to insects also, the insects know to avoid them. The mycelial strains developed by Stamets not only avoid this difficulty but act as an attractant, a food, and a recruitment agent for other insects.

Presently, this technology is being matched with investors in readiness for registration as an approved pesticide in the United States to be followed by widespread commercialization.

<u>4. Sustainable Information Sources</u>

Innovation for sustainability is occurring not only in new methods of energy, water, agriculture, and toxics elimination, but in mechanisms to disseminate sustainable innovations faster and more effectively to places where they are needed most. Several emerging programs within the U.S. Environmental Protection Agency (USEPA) are gaining attention and use.

The International Innovation and Best Practices Program has been developed by EPA's National Center for Environmental Innovation (NCEI). It is a resource for government, business, and non-governmental organizations in their search for best sustainable practices across a range of environmental fields, including water infrastructure, waste remediation, toxics avoidance, land use and reducing air emissions from energy production. The NCEI itself contains a massive data base of environmental best practices, while the International Innovation and Best Practices Program features a gateway to information and resources on innovative environmental projects and programs around the world.

The international gateway for innovation provides resources such as a compendium of resource in environmental learning, international innovations by topical area (air, climate change, chemicals, waste, water), innovations in multi-media approaches (environmental management systems, industrial ecology, cleaner production, sustainable transport, urban management), examples of U.S.-international partnerships with a focus on innovations in environmental policies and methods, international exchange opportunities, and techniques for evaluating innovation programs.

There are at least two other US EPA activities of note supporting the development of innovative and sustainable technologies. These emerge from EPA's Office of Research and Development and feature both research activities as well as contributions to a growing data base of innovation success stories within the United States.

The first is EPA's Collaborative Science and Technology Network for Sustainability. This initiative features a grant program aimed at collaborative approaches to systems-oriented, forward-looking and preventative approaches to environmental protection. The initial program supports twelve projects, with another round of funding planned. A companion initiative from EPA's Office and Research and Development is the National Student Design Competition for Sustainability. The initial year of this program led to over sixty interdisciplinary student design projects addressing scientific and technical challenges to sustainability in both the developed and developing world.

In the private sector, an exciting new information source for sustainable environmental innovations (though its scope is focused on innovation across all technologies) is that provided by the firm Yet2.Com. Its website provides a Technology Marketplace Report collection of innovative technologies that is updated weekly. It seeks to match potential sources of venture capital with the scientists and innovation entrepreneurs behind each innovation. The data base contains thousands of innovative technologies for sale or license as well as a listing of technology needs open to prospective inventors and innovators.

5. Summary

In summary, the progression towards innovations that are both effective and lasting over the long term will determine how successful the world will be towards achieving sustainable development. The lens through which all innovations must be viewed is one of sustainability, where systems-focused and nature-mimicking solutions are both sought and implemented. This paper has identified a few of those exciting innovations occurring in the United States while emphasizing that sustainable innovations know no national borders. The challenge in the years ahead is to ensure that we innovative towards rather than away from sustainability. Our challenges are too great for us to be adding to them rather than moving, as we must, along the path to more lasting solutions.

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