Energy in the Context of Sustainability

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Abstract: Today and in the coming decades, the world faces the challenge of meeting the needs of a still-growing human population, and of doing it sustainably – that is, without affecting the ability of future generations to meet their needs. Energy plays a pivotal role in this challenge, both because of its importance to economic development and because of the myriad interactions and influences it has on other critical sustainability issues. In this essay, we explore some of the direct interactions between energy and other things people need, such as food, water, fuel, and clean air, and also some of its indirect interactions with climate, ecosystems, and the habitability of the planet. We discuss some of the challenges and potential unintended consequences that are associated with a transition to clean, affordable energy as well as opportunities that make sense for energy and other sustainability goals. Pursuing such opportunities is critical not just to meeting the energy needs of nine billion people, but also to meeting their other critical needs and to maintaining a planet that supports human life in the near and long term.

The term *sustainability* – widely used today in corporate, academic, government, nongovernmental, and community settings – is defined in multiple ways. In the corporate sector, sustainability typically refers to the triple bottom line, or "three-legged stool," that incorporates concern for the economy, the environment, and social equity into industrial or economic activities. In development circles, the term often describes a pattern of development that "meets the needs of the present without compromising the ability of future generations to meet their own needs,"[1] or that promotes human well-being while protecting and conserving the life support systems of the planet.[2] Most biodiversity-conservation organizations embrace the strategy that the International Union for Conservation of Nature outlined in 1980 to integrate conservation and development objectives.[3] Despite differences in these and other definitions, all share a common concern: to maintain the planetary resources needed to meet today's needs as well as those of future generations.

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No resource is more fundamental to human development and well-being than energy. Energy is a key ingredient of almost all aspects of human existence, from producing food, to accessing and purifying water, to heating and lighting homes, to transporting materials and people, to creating the goods and technologies that humanity has come to rely on. Therefore, human well-being depends on sustainable, reliable, and enduring forms of energy. Yet for many, access to affordable energy remains an aspiration: there are still billions of people worldwide who do not have access to electricity and modern forms of energy, and as a result, energy is among the most frequently cited sustainability challenges.[4] As population growth combines with increased consumption patterns, demand for energy services will rise sharply.[5] Moreover, access to reliable sources of energy – even in areas that have had access in the recent past – is a growing concern. Significant technical, economic, and national security issues affect the availability of fossil fuels – namely, coal, oil, and natural gas – that currently supply 82 percent of global energy and 85 percent of U.S. energy.[6] The use of fossil fuels also has significant environmental impacts, including the production of pollutants that affect the health of people and ecosystems from local to global scales.

As a result of these burgeoning concerns, efforts are under way around the world to transform energy systems into something cleaner, more reliable, and affordable for all.[7] This transformation is urgently needed, as global demand for energy will likely triple over this century.[8] How that energy is supplied and distributed – and in what form – will determine whether the next generation inherits a sustainable planet.

This essay explores energy in the context of sustainability, focusing on some of the critical inter-linkages between energy use and other key issues, such as food, water, health, national security, and preservation of ecosystem services. It also examines what may be energy's largest long-term challenge to sustainability: namely, its impact on climate change. The rapidly evolving sustainability challenges on the planet – driven by the speed of change in population, consumption, infrastructure development, and climate change, among other factors – threaten to outpace the capacity of human and natural systems to adapt. Thus, transformation of global energy systems must be quick, and it must commence immediately. This essay discusses these factors and calls for enhanced public and private support of technology development worldwide, as well as for a workforce trained to solve interdisciplinary problems, in order to achieve revolutionary – not evolutionary – advances in energy and progress toward sustainability goals.

Among the many interconnections between energy and other resources, the nexus of energy and water is perhaps the most well studied and clearly documented.[9] Energy is used to collect and pump surface and groundwater; to transport and distribute water for multiple uses; to desalinate seawater; to transport and treat wastewater; and to heat and cool water for industrial, commercial, and residential end use.[10] Nearly one billion people do not have access to clean water, and nearly two billion do not have access to sanitation, so the demands for energy to help provide these essential services will only increase.[11]

Water is also essential to many elements of energy production. Among other uses, it is used to extract fuels and manage other aspects of mining and geologic production; for cooling in thermal electricity generation (using coal, gas, nuclear, and other fuel sources); for producing geothermal and hydrothermal energy; for scrubbing pollutants in coal-fired plants; and in the steam turbines of power plants. In turn, contamination of surface water and shallow groundwater from the production of energy resources is one of the most critical sources of water pollution.[12] Acid mine drainage from coal mines has a long history of environmental and health concerns, but newer technologies also raise concerns. Indeed, one of the most worrisome consequences of hydraulic fracturing of shale for natural gas production, which has recently skyrocketed in the United States and elsewhere, is related to the large amounts of water needed to carry out the fracturing process, as well as inadvertent contamination of surface water and shallow aquifer resources that can take place under poor drilling practices.[13]

The cautious good news is that efficiency of water use in traditional energy production has been on the rise and is expected to continue. In the United States, for example, the average amount of water withdrawn per kilowatt-hour of electricity production has decreased over the past several decades. But because absolute energy consumption has risen, the total amount of water consumed has also increased.[14] Some alternative energy sources, such as solar photovoltaics and wind, use relatively low amounts of water. Thus, diversifying the energy supply with these alternatives will help reduce the water demand for energy production.[15] Some bioenergy sources, on the other hand, use substantial amounts of water in the growth, conversion, maintenance, and harvesting of crops to produce fuels such as ethanol,[16] raising concerns about water shortages and the sustainability of biofuel energy production.[17]

Given that more than one billion people live in river basin areas where water use currently exceeds recharge levels, and because global water consumption doubled between 1960 and 2000 and continues to grow rapidly, the energy/water nexus will require more integrated and innovative planning to manage these systems in the coming decades.[18]

Energy and food production are likewise connected. Energy is critical to every step of the food supply chain,[19] and food-related energy use across the cycle – from production to use and disposal – is a major and growing fraction of national energy budgets. At the agricultural end of this chain, energy is used to produce and apply fertilizers; to pump and distribute irrigation water; to produce and apply pesticides; and to till the soil, harvest crops, and carry out other on-site management practices. Among these, irrigation is often the most significant consumer of energy. For example, a 2005 study estimated that pumping groundwater for agriculture represents one-third of annual energy use in India; as a result, high-energy costs can limit the use of irrigation pumping to maintain and expand agriculture.[20] Energy use per "unit" output is much higher for livestock systems than for cropping systems because there are inefficiencies at several steps in the process. In 2008, ecologist David Pimentel and colleagues calculated that the fossil energy required to produce animal products consumed in the American diet accounts for 50 percent of the nation's total food-related energy demand.[21]

Energy is used along the remainder of the food supply chain as well – from transportation, processing, and packaging to household food-related activities such as travel for purchasing food, refrigeration, freezer storage, and food preparation. Not surprisingly, given the close connection between energy and food, rising energy costs lead to higher average food costs, and spikes in oil prices are related to spikes in food prices.[22] Many opportunities exist for improving the efficiency of energy use (and other resource use) in food production, but as is the case with water, increases in efficiency can easily be offset by population growth and shifts to less-efficient consumption patterns. To meet the estimated 70 to 100 percent increase in food needed by 2050 to feed the growing global population, many analysts suggest that we must radically change the way food is produced, processed, stored, and distributed. In addition, methods for eliminating waste must be found; 30 to 40 percent of food is lost to waste in both developing and developed countries.[23] Such goals can have significant consequences for energy as well as food and water.[24]

Despite the clear influence of energy on the production, distribution, and cost of food, until recently the food/energy connection was not well understood. Modern biofuels have been heralded for their contributions to energy security and for reductions in environmental costs from fossil fuels; but many analysts suggest that, at least for first-generation biofuels like corn ethanol, the return on investment may not yield significant net energy benefits or greenhouse gas reductions. At the same time, the manufacture of corn ethanol competes for valuable land with activities such as food production and biodiversity conservation.[25] Moreover, some studies have found that food prices may rise as a result of increased competition for land between food and biofuels.[26]

There is a long litany of health impacts associated with energy use. More than five million premature deaths annually are attributable to air pollution and other energy-related effects.[27] In most developed countries, exposure to particulates – predominantly sulfates and soot from fossil fuel combustion – can reduce life expectancy. Air pollutants, especially volatile carbon and nitrogen oxides from stationary and mobile sources, drive tropospheric ozone pollution, with impacts on lung function as well as agricultural systems.[28] Although exposure to air pollution damages the health of everyone, numerous studies have shown that certain groups – for example, the elderly, children, and those with underlying disease – are at greater risk of being affected by air pollutants.[29]

About 40 percent of the global population – often the poorest – relies on dung, agricultural wastes, and wood fuels for cooking and heating.[30] Exposure to emissions from these fuels in the home extracts huge health care consequences.[31] Beyond the direct health concerns, the fact that poorer individuals expend proportionally more of their income on energy, despite using far less energy than the rich, leads to insecurity in critical areas such as health care, education, and food.[32] Moreover, because higher energy prices inflate the prices of almost all other goods and services (and can account for up to 15 percent of total prices of food, textiles, lumber, paper, and other necessities), the poor suffer not just in access to energy under rising prices, but in access to other essential needs.[33]

Energy also plays a significant role in national security. All the issues discussed thus far (energy and water, energy and food, and energy and health), in addition to issues such as population migration, energy acquisition, and energy diversification, are key determinants of both national and global security.[34] The energy transition can either reduce or enhance the potential for conflict. In particular, the diversification of energy supplies and the transition to alternative sources of energy is critical – as suggested by the staggering official estimates that the Pentagon has paid $40 to $400 per gallon of fuel (including the cost to transport the fuel) to power a combat vehicle or aircraft in Afghanistan.[35] Ensuring that energy is readily available, sustainable, and resilient will continue to be a key component of national and global security concerns.[36]

The preceding sections illustrate some of the most direct ways that energy choices affect our ability to meet other critical human needs. Our energy choices also have an impact on the life support capacity of the planet, including on our atmosphere and ecosystems (and the services they provide), and, perhaps most important, on climate – specifically, through the emissions of greenhouse gases, principally carbon dioxide, methane, nitrous oxide and particulates from combusting carbon-based fossil fuels. Climate change in turn affects all components of human and natural systems, adding both complexity and urgency to the search for sustainable energy solutions. A substantial body of evidence, accumulated through several decades of multidisciplinary research, indicates that Earth's global climate has already warmed 1.4 degrees Fahrenheit. Most of the warming can be attributed to greenhouse gas emissions from the burning of fossil fuels for energy as well as, to a lesser extent, emissions from land use and agriculture.[37] The pace and magnitude of current changes are challenging the historic tolerances of species and infrastructure; planning based on the climate of the past is no longer an option.

Climate change is associated with a broad spectrum of other changes, including increases in extreme precipitation events, more frequent hot spells, rising sea levels, and shifts in ranges of crops, forests, and pests. The future severity of these and other impacts will depend on how much the climate changes, and that will depend on what humanity does both to reduce greenhouse gas emissions and to increase resilience to climate impacts. Climate change poses great risks for a wide range of resources and environmental systems, including freshwater resources, agriculture and fisheries, coastal environments, and ocean and land ecosystems.[38] For example, as the climate changes, dry places on the planet are expected to become drier and subject to more severe drought, while wet places may experience increasing intensity of rainfall and associated damages. Agricultural systems will face higher temperatures, which could push certain crops out of historical production zones; increased demand for water; and new disease vectors that could disrupt production. Most models suggest dramatic increases in the frequency of very hot temperatures,[39] which could lead to greater public health impacts from heat stress, increased demand for energy to cool built environments, and greater risks of food shortages.[40]

The impact of climate change on the frequency and intensity of extreme weather events is of particular concern.[41] During the past several decades, the United States has been subjected to a greater frequency of extreme weather.[42] We have too often seen how floods and droughts can affect global production of goods and services, thereby disrupting energy, water, and food systems as well as global trade. Hurricanes Katrina and Rita, for example, shut down or suspended three-quarters of the more than four thousand offshore oil and gas platforms overseen by the U.S. Department of the Interior.[43] Moreover, recent droughts and floods in Pakistan and Thailand have killed thousands, displaced millions, and disrupted supply chains for commodities as diverse as clothing, food, and computer hard disks.[44]

While strategies for achieving the sustainable production and supply of energy must seek to reduce greenhouse gas emissions and climate change, they will also need to consider the energy system's resilience to climate-related impacts. Such efforts will be critically important across temporal and spatial scales; indeed, extreme events as well as slow-onset events, such as sea level rise, can pose serious challenges to the ability to meet global energy demand.

International, national, and regional institutions are, in many ways, ill-prepared to cope with current weather-related disasters, let alone potential problems such as a growing number of refugees fleeing environmental damages spawned by climate change.[45] Concomitant with an energy transition, society must improve natural resource management and preparedness/response strategies to deal with future climatic conditions that will be fundamentally different from those experienced in the last hundred years.

Pursuing the energy transition in the context of sustainable development raises special challenges and opportunities. Among these, equity among the more and less developed countries of the world and trends in urbanization deserve special attention. Energy access across the planet is deeply uneven; the poorest on the planet use about 5 percent of the energy consumed by the average U.S. citizen. According to the World Bank's Data Catalog, the United States used 7,000 kg of oil equivalent per capita in 2009. By comparison, India, China, South Africa, Ethiopia, and Bangladesh used 560, 1,700, 3,000, 400, and 200 kg of oil equivalent per capita, respectively.[46] However, many of the easiest and cheapest opportunities to reduce energy use, produce clean energy, and reduce climate and other environmental changes can be found in developing countries, where infrastructure has yet to be built, where there is potential to greatly improve efficiency of energy use, and where land-use practices can decrease greenhouse gas emissions. A clean-energy transformation can go hand in hand with other forms of sustainable development in developing countries.[47]

Whether developing countries embark on a more sustainable development path will be heavily influenced by transition costs; higher-income countries must provide financial and technical support. Global cooperation will require more than financial contributions, however. Developing countries harbor the concern that integrating climate concerns with development decisions could erode existing development assistance or shift responsibility for mitigation onto the developing world. Enshrining a principle of equity in regional or global deals would do much to dispel such concerns and generate trust.[48] Moreover, high-income countries must bring their own indefensible energy footprints down to sustainable levels.

A major concern of developing countries is technology access. Innovation in energy-related technologies remains concentrated in high-income countries, although developing countries are increasing their presence. (For example, China is seventh in overall renewable energy patents, and an Indian firm is now the leader in on-road electric cars.) In addition, developing countries – at least the smaller or poorer ones – may need assistance to produce new technology or tailor it to their unique local circumstances. International transfers of clean technologies have so far been modest. They have occurred in, at best, one-third of the projects funded through the Clean Development Mechanism, the main channel for financing investments in low-carbon technologies in developing countries.[49]

Meeting clean-energy objectives without detracting from other sustainability goals will require careful processes, tools, and approaches for selecting among options and recognizing competing demands for land, water, energy, and a variety of ecosystem services in the face of a growing population.[50] Over the course of the last few decades, progressive degradation of the environment by human activities has been increasingly well documented. Loss of biodiversity and overuse of natural resources have already reduced or rendered less reliable some ecosystem services, with significant adverse impacts on society.[51] The energy sources that we choose, where those sources are located, and the amount of water and land consumed to access the sources will affect sustainability goals.

Certain types of biomass (ethanol, for example) currently compete with traditional agriculture for access to limited land and water.[52] This competition is projected to intensify as global demand for biofuels rises; looking ahead, a fourfold increase in biofuel production, primarily in North America and Europe, is expected by 2030.[53] Pressure to expand land for biofuels could lead to a massive conversion of managed and unmanaged forests and preserved areas, further jeopardizing indigenous cultures and biodiversity. Placing a value on the carbon held in forests and soils could lessen this impact significantly.[54]

Large wind and solar developments also pose challenges.[55] They consume large tracks of land, raise potential noise concerns associated with energy generation, and rely on a manufacturing process that could produce toxic waste if new generation techniques are not created.[56] Additionally, wind and solar both face pressure from NIMBY (“Not In My Backyard”) syndrome, whereby local residents want to have access to these technologies but, for aesthetic reasons, do not want new developments in their communities. Carbon capture and storage and nuclear energy can also affect local landscapes and carry risks associated with accidents and storage of waste material.[57]

We must also carefully consider how future energy choices affect our ability both to mitigate and adapt to climate change. As noted above, the range of clean-energy choices could reduce or mitigate climate change but could also negatively affect the preservation of biodiversity, natural resources, and ecosystem services. At the same time, the effects of climate change on food and water resources and ecosystem services could impede the use of these resources in the development of clean-energy alternatives. Moreover, efforts to meet human needs through adaptation to climate change – for example, greater use of electricity for air conditioning or water and energy resources for irrigation – could have unintended impacts on energy use, increasing greenhouse gas emissions. A sensible strategy should, on the one hand, seek to rapidly mitigate the pace and ultimate magnitude of climate change and other environmental degradation and, on the other hand, adapt to unavoidable climate changes already under way as well as those that are yet to come.[58]

Growing urbanization poses both opportunities and challenges for the energy transition as well as for broader climate and sustainable development goals. Cities are major consumers of resources; they are also centers for job creation and economic growth. Cities are responsible for two-thirds of global energy consumption, and this proportion will continue to grow.[59] By 2050, eight billion of the nine billion people in the world will live in cities (with five billion in the developing world). Today, one million people are added to the urban population each week. Such rapid urbanization is compatible with sustainability goals only if green infrastructure becomes a criterion for new buildings and retrofits, and if negative consequences on food access and human health are avoided.[60]

Given the need to transform energy in the near term in order to reduce the most critical challenges of climate change, inertia in the built environment poses a particular challenge. Infrastructure investments are long-lived; existing factories, power plants, roads, and power distribution networks will remain in place for decades. Decisions made today concerning land use and urban form (the structure and density of cities) will have impacts lasting more than a century. And long-lived infrastructure triggers investments in associated capital (such as cars for low-density municipalities, or gas-fired heat and power generation capacity where there are gas pipelines), locking economies into lifestyles and energy consumption patterns.

Because of their density, efficiency, and ability to incorporate innovations and new technologies (in addition to the infrastructural opportunities noted above), cities are ideal environments for enhancing quality of life, using land and water more efficiently, and reducing greenhouse gas emissions. Particularly for underserved communities, there are many opportunities in cities to modernize delivery of energy services while also prioritizing more efficient infrastructure and protecting and restoring green spaces. Coordination of place-based policies can simultaneously enhance transportation choices, improve air and water quality, reduce waste, maintain a reliable water and energy supply, advance public health and awareness, enhance disaster preparedness and response, increase climate resilience, use public resources more efficiently, help mobilize private investment, and strengthen local decision-making. Cities also offer opportunities for capturing cross-cutting efficiencies (for example, across water and energy systems) through joint strategies for resource management and public/private finance.

Change in global energy systems that is concordant with sustainable development will require policy and regulatory actions, as well as other incentives, to be aligned. For new technologies to be accepted in the market, they must be attractive – in terms of performance, convenience, and cost – to investors, purchasers, and users. Regulations and standards that target performance characteristics can help spur technological development and improve market attractiveness.[61]

Many of the alternative energy options needed to address the sustainability challenge are available today. In the United States, existing energy-efficiency technologies could more than offset the projected increase in energy consumption between now and 2030, thereby substantially reducing health impacts, greenhouse gas emissions, and expenditures.[62] Globally, one dollar spent on energy efficiency saves two dollars through investments in new supply, with the savings being even greater in developing countries.[63] In addition, solar, wind, and geothermal technologies are rapidly becoming more efficient and affordable, increasing their viability.[64] These three technologies use little water and can be scaled in size and tailored to local contexts; thus, they can help promote energy security while also reducing greenhouse gas emissions from fossil fuels.[65] Although still only a small percentage of installed energy supply, investments in clean energy grew by 5 percent in 2011, to a record $260 billion, with a total of $30 billion in new solar and $30 billion in new wind investments put into place.[66]

The near-term transition to the cleanest energy choices available requires policy tools to enable and encourage sustainable energy development. Incentives must be tailored to the maturity and costs of technologies as well as to national context. For example, most energy-efficiency measures are financially viable for investors at their current prices, but other barriers must be overcome: the upfront capital necessary to install efficiency devices, lack of financing, market failures, and high transaction costs.[67] Regulatory reform, such as updated standards and codes, and financial incentives, such as fuel surcharges and consumer rebates, are crucial to alleviate these pressures.[68] Many available renewable energy technologies are economically viable but not financially viable; that is, with the exception of hydroelectric power, they are not yet cost competitive with fossil fuels. Global subsidies for fossil fuel production and consumption, estimated to total $400 billion per year, make it difficult for new technologies to compete.[69] Therefore, policies that subsidize renewables or that reduce subsidies to fossil fuels can help level the playing field.

In theory, developing countries could leapfrog to available clean-energy technologies. However, low-income countries face significant market barriers to technology absorption. Meeting development goals and providing access to clean energy requires significantly stepping up international efforts to diffuse existing technologies and to develop and deploy new ones. Public and private investment must be ramped up significantly to several hundreds of billions of dollars annually. "Technology push" policies that increase public investments in R&D will not alone be sufficient; they must be matched with "market pull" policies that create public- and private-sector incentives for entrepreneurship, for collaboration, and for finding innovative solutions in unlikely places. Diffusion of climate-smart technology requires much more than shipping ready-to-use equipment to developing countries: it entails building absorptive capacity and enhancing the ability of the public and private sectors to identify, adopt, adapt, improve, and employ the most appropriate technologies.[70] To establish these conditions, governments must implement enabling policies and build regulatory frameworks – targeting public resources carefully – to leverage private capital, reduce the risk associated with investing capital, stimulate innovation, and create competitive and viable markets for electricity and energy.[71]

In addition to rapid transitions in current energy systems, addressing today's complex, interconnected sustainability challenges will require developing and deploying the next generation of technologies and implementing the tools and approaches needed to make good choices. A successful energy transformation calls for greatly enhanced efforts to support R&D, to finance incremental costs of new technologies and approaches, and to facilitate technology transfer. Nothing short of a paradigm shift is needed to promote a "green growth" economy that can meet burgeoning energy demands, especially for the world's poorest, while also enhancing sustainable development. Poverty reduction remains urgent but growth and equity can be pursued without relying on policies and practices that foul the air, water, and land and that degrade ecosystem services.[72]

Technological innovation and its associated institutional adjustments are key to developing sustainable energy at a reasonable cost. Strengthening national innovation and technology capacity can provide a powerful catalyst for development. High-income economies – the world's major emitters – can replace their stock of high-carbon technologies with climate-smart alternatives and invest in tomorrow's breakthrough innovations. Middle-income countries can invest in low-carbon growth and ensure that their firms take advantage of existing technologies to compete globally. Low-income countries can enhance the technological capacity to meet sustainability goals and adapt to climate change by identifying, assessing, adopting, and improving available technologies with local knowledge and know-how.

Reaping the benefits of low-carbon technologies will require significant changes in individual and organizational behavior, as well as a host of innovative approaches and policies to improve human well-being, reduce human vulnerability, and manage natural resources.[73] Current public expenditures on basic energy R&D amount to about $13 billion – roughly what Americans spend on pet food each year. Despite a recent upsurge in private spending on energy R&D, to about $60 billion per year, the total hovers around 0.5 percent of revenue. That remains an order of magnitude smaller than the 8 percent of revenue invested in R&D in the electronics industry and the 15 percent that goes into the pharmaceuticals sector.[74] For more than a decade, many reports have called for increasing money directed toward basic energy research by anywhere in the range of twofold to tenfold.[75] We will not be able to meet energy needs while sustaining human and ecosystem well-being without a substantially increased and sustained investment in new clean-energy technologies by both the public and private sectors.

Certainly, knowledge institutions such as universities and research centers are engaged in research to help develop such technologies and approaches, but they can also help inform decision-making, including the development of context-specific energy policies. Increasingly, universities must strive to share knowledge, solutions, and experiences with planners, managers, and policy-makers in a two-way dialogue that improves both research and decision-making. There is a tremendous opportunity to share "best practices" with other nations, regions, and localities. Communities and organizations faced with energy-sustainability decisions would benefit from regional sustainability hubs, or "clearinghouses," that could integrate research and practice, share processes and approaches, and make available success stories and options from around the world.[76]

Investments in new kinds of education and training will also be needed.[77] Managing the interconnected issues that affect sustainability will require interdisciplinary perspectives and "systems" thinking. Integrative perspectives will be vital in developing new technologies that can provide affordable, accessible clean energy while they conserve water, ensure reliable food production, and preserve ecosystems and their services. The full suite of social and natural sciences and engineering must be galvanized to develop solutions that are technologically feasible, socially desirable, inclusive, and politically and economically possible.

Fortunately, today's college and graduate students appear to be increasingly interested in, and capable of, tackling these complex interdisciplinary problems. One-third of the graduate students in the School of Natural Resources and Environment at the University of Michigan have chosen to pursue dual master's degrees in such disparate areas as natural resources, engineering, business, economics, public policy, public health, and urban planning. Likewise, at Stanford University, approximately one-third of undergraduates obtain degrees in interdisciplinary programs, and many graduate students select joint, dual, or interdisciplinary programs. The undergraduate Earth Systems Program and the graduate Emmett Interdisciplinary Program in Environment and Resources, both at Stanford, and the Program in the Environment at the University of Michigan help prepare students to address complex global challenges related to energy, food, water, and environmental change. There is great promise in these future problem-solvers working creatively toward a more sustainable world.

Today's choices about energy production and generation will influence, both directly and indirectly, the trajectory of water consumption, food production, public health, national security, ecosystem services, and greenhouse gas emissions for years to come.[78] These issues are linked to one another. Efforts to address the energy challenge – or any other sustainability challenge – will be best served by a systematic and integrative approach, one that seeks to understand costs, trade-offs, and co-benefits across the range of critical concerns. Our choices about current and future energy sources need to be made in the context of the multiple goals of sustainable development. Indeed, the future of humankind and the planet depend on it.

ENDNOTES

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