Integrating Developed and Developing World Knowledge into Global Discussions and Strategies for Sustainability. 1. Science and Technology

JAMES R. MIHELCIC,*,† JULIE B. ZIMMERMAN,‡ AND ANU RAMASWAMI§

Civil & Environmental Engineering, Sustainable Futures Institute, Michigan Technological University, 1400 Townsend Drive, Houghton, Michigan 49931-1295, Chemical Engineering, School of Forestry and Environmental Studies, Center for Green Chemistry and Engineering, Yale University, New Haven, Connecticut 06511-6815, and Civil Engineering, University of Colorado at Denver and Health Sciences Center, Denver, Colorado 80217-3364

Sustainable development in both the developed and developing world has the common fundamental themes of advancing economic and social prosperity while protecting and restoring natural systems. While many recent efforts have been undertaken to transfer knowledge from the developed to the developing world to achieve a more sustainable future, indigenous knowledge that often originates in developing nations also can contribute significantly to this global dialogue. Selected case studies are presented to describe important knowledge, methodologies, techniques, principles, and practices for sustainable development emerging from developing countries in two critical challenge areas to sustainability: water and energy. These, with additional analysis and quantification, can be adapted and expanded for transfer throughout the developed and developing world in advancing sustainability. A common theme in all of the case studies presented is the integration of natural processes and material flows into the anthropogenic system. Some of these techniques, originating in rural settings, have recently been adapted for use in cities, which is especially important as the global trend of urban population growth accelerates. Innovations in science and technology, specifically applied to two critical issues of today, water and energy, are expected to fundamentally shift the type and efficiency of energy and materials utilized to advance prosperity while protecting and restoring natural systems.

Introduction

Since the release of *Limits to Growth* (*1*) there has been increased global discussion on issues related to sustainability. One definition of sustainable development is "*the design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment*" (*2*).

The United Nations Environment Programme has stated "Sustainable development is the goal. Capacity building is a means to achieve it" (*3*). Ways to build capacity may include technology transfer, dissemination of best practices, and assisting the development of fair governance at the national, regional, and global levels. Capacity can also be increased by facilitating knowledge transfer across developed and developing world boundaries. Therefore, the ideal operational model for sustainable development would be a global partnership, enhanced by integrating the best and most appropriate knowledge, methodologies, techniques, principles, and practices from both the developed and developing worlds.

While most, if not all, absolute and per capita levels of consumption remain higher in Organisation for Economic Co-operation and Development economies than in the developing countries (*4*), most recent efforts to advance global sustainability have focused on the transfer of knowledge from the industrialized world to the developing world (e.g., ref *3*). This paper instead addresses areas of knowledge and experience originating in developing nations that can contribute significantly to the global dialogue on sustainable development with additional understanding and analysis of the underlying processes.

Developing nations typically have a long history of practical innovation and successful application of indigenous knowledge systems (*5*). The U.S. National Academy of Science refers to indigenous and local knowledge systems as "....*specific systems of knowledge and practice, developed and accumulated over generations within a particular cultural group and region, and as such are unique to that group and region*". They provide many historical examples of the successful confluence of indigenous and formal scientific knowledge (*6*). In the context of sustainable development, indigenous knowledge systems provide unique insights as they are time-tested and yet continually evolving adaptations of human systems to their ever-changing locale and complex natural environments. Efforts are now underway to capture the best ideas and practices evolved from these systems (*7*).

In this paper and a companion article (*8*), we use selected case studies to describe important knowledge, methodologies, techniques, principles, and practices for sustainable development emerging from developing countries. We discuss the adaptation and application of these concepts to developed countries by quantifying and understanding the underlying fundamental properties through engineering analysis and the challenges and rewards that often arise from this fusion or hybridization. For example, recent developments in the pharmaceutical industry present an excellent example of knowledge drawn from indigenous and developing societies that, with the application of formal analysis and quantification, is being adapted and used in industrial nations. Since 1985, there are over 120 pharmaceutical products in use that are plant-derived, and some 75% were discovered by examining the use of plant species in traditional medicine (*9*−*11*).

Eschewing the mass screening approach used and subsequent waste generated by many pharmaceutical companies, Shaman Pharmaceuticals has pioneered a novel

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* Corresponding author e-mail: jm41@mtu.edu.
† Michigan Technological University.
‡ Yale University.
§ University of Colorado at Denver and Health Sciences Center.

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TABLE 1. Developing World and Indigenous Knowledge Technological Solutions that can be Adapted in a Developed World Setting To Achieve Social and Economic Prosperity while Protecting and Restoring Natural Systems

application	technology
power generation	Biogas power generation can be integrated with waste management.
material use in building construction	Appropriate, local, nontoxic, and reusable materials such as rammed earth, adobe, and straw bale can be promoted for building construction. Water can be used as a material in the construction of thermal walls.
water supply	Rainwater harvesting can assist groundwater recharge and provide all or a portion of domestic, commercial, and agricultural needs. It can also be incorporated into a building's cooling system.
water treatment	use of *Moringa oleifera* tree seed extract for turbidity removal UV disinfection from sunlight and fabric filtration for point of use treatment
stormwater management	Green roofs built on top of residential, commercial, and industrial structures not only effectively manage stormwater but also have benefits of reducing a building's energy consumption and regional urban heat island impact.
building design	right-sizing homes that maximize storage, comfort, social interactions, and use while minimizing the use of materials and energy Natural ventilation can be integrated into a design by incorporating porches, central courtyards, other outside seating features, and strategically placed windows. Passive solar design maximizes exposure to the sun and takes advantages of the natural energy characteristics of building materials and air that are exposed to the energy of the sun. Overhangs take advantage of the thermal properties of the sun during the winter months while minimizing the sun's impact during the warmer summer months.

approach to drug discovery, integrating indigenous and developed world knowledge in natural products chemistry, ethnobotany, medicine, and medicinal chemistry. Using this approach two products were brought to clinical trial within 24 months of identification. This can be compared to the lengthy trial and error discovery process carried out by most major pharmaceutical companies where 1 million relevant substances are screened for each new medicine, the associated cost is $897 million, and the typical time to trial is 4.5 years (*12*).

While concerns of biopiracy are valid, basing pharmaceutical discovery on fair and ethical transfer of indigenous knowledge and natural renewable resources represents an approach with reduced environmental impacts and economic costs while providing the indigenous community with economic prosperity and the company with a competitive advantage. Likewise, the initiation of equitable and ethical cross-cultural dialogue on sustainable development strategies originating in the developing world can result in mutual benefits leading to innovative solutions to address the global challenges of equity, health, prosperity, environmental sustainability, and social empowerment.

The case studies described in this paper and in a companion article (*8*) are selected to inform two system areas that have a significant impact on sustainable development in both developing and developed countries, namely, ***science and technology*** and ***economics* and *governance***. Innovations in science and technology, addressed here in part 1, can provide fundamental shifts in the type and efficiency of energy and materials utilized to advance prosperity while protecting and restoring natural systems. The part 2 companion article addresses issues of economics and governance, highlighting community-based cooperative strategies that impact how social and natural capital are valued, exchanged, and governed for sustainable development

By highlighting appropriate strategies in each of these system areas from the developing world, the common underlying principles can be analyzed, elucidated, and incorporated into global strategy discussions on sustainability. This will lead to a model based on the state-of-the art thinking from a global perspective creating a robust and representative effort in achieving the common goal of sustainable development.

Science and Technology

Designing scientific and technological solutions that are cognizant of the quantity and nature of energy and materials utilized by society is a critical component of sustainable development. The principles of green engineering (*13*) can be used as a framework for upfront design or as an evaluation tool in selecting products, processes, and systems that move toward sustainable design. Table 1 provides several examples of technological solutions to sustainability challenges that are found in indigenous cultures and the developing world. Several of these solutions are discussed in greater detail in the examples that follow.

The selected in-depth case studies drawn from the developing world highlight innovative alternative strategies applied in two critical challenge areas to sustainability: water and energy. A common theme in all the case studies is the integration of natural processes and material flows into the anthropogenic system. Some of these techniques, typically originating in rural settings, have recently been quantified and adapted for use in large cities. This is especially important as urban population growth accelerates, resulting in an estimated urban population in the year 2025 of 5 billion, with 90% of the urban population growth occurring in developing nations (*14*).

Water Supply. Water scarcity is a growing problem with over 40 countries currently experiencing water scarcity and approximately one-third of the world's population residing in countries that suffer from moderate to high water stress (*15*). Consumptive and hygienic uses have direct consequences for health, both in relation to physiological needs and in the control of water-related diseases. Productive water use (e.g., animal watering, construction, and small-scale gardening) has considerable indirect influence on health and prosperity (*16*). Thus, access to a sufficient quantity of water is critical for improving health and meeting the goals of sustainable development.

Faced with future problems of water scarcity, the United Nations Environment Programme reports that rainwater

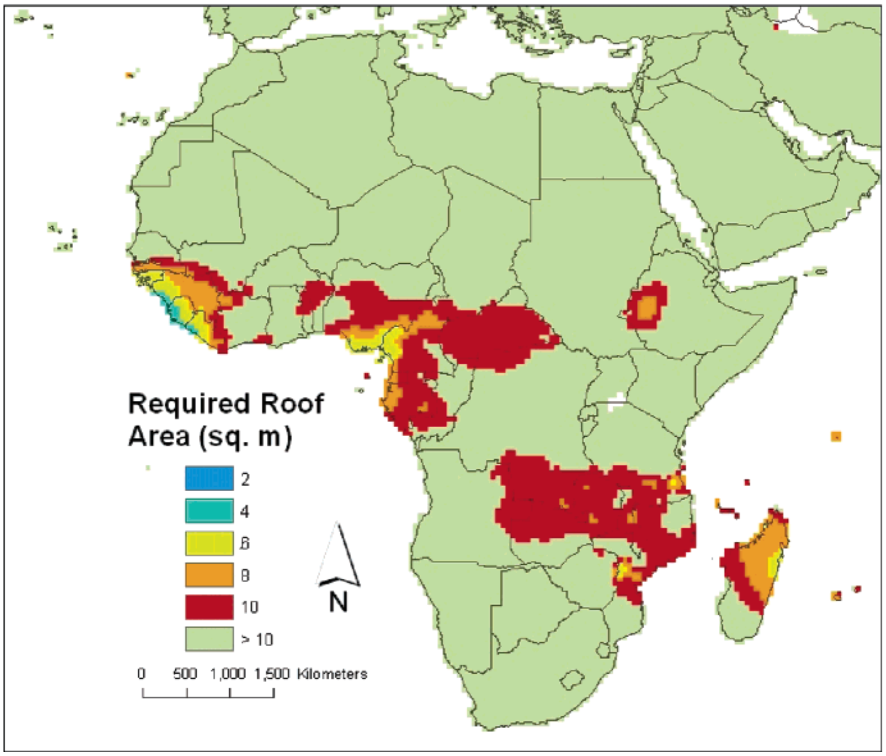

FIGURE 1. Required roof area (m^2/capita) to supply at least 3 months of rainwater to urban slum areas located in Sub-Saharan Africa at 50 L/day-capita (*26*). According to the World Health Organization, this level of water supply is expected to result in low health concerns (*16*).

harvesting (RWH) (defined here as the collection of water from surfaces on which rain falls that is subsequently stored) is one of the most promising alternatives for supplying freshwater in the face of increasing scarcity and demand (*17*). For centuries, rooftop catchments and storage have been the basis of domestic water supply on small islands and continental areas located throughout the world. In parts of Asia RWH can be traced back to the ninth or 10th Century (*17*), and in many rural areas of the developing world rainwater harvesting is an important source of domestic water (*18*).

One advantage of RWH is that local materials can be used to construct collection and storage systems. For example, carved natural rock has been used to store runoff, and banana leaves and stems can be used as temporary gutters. Innovating the world's built environment with appropriate local materials is an important step toward achieving the goal of sustainable development. This is because local materials are typically renewable, contain less embodied energy and water, reduce or eliminate the impacts associated with material transport, and are more culturally and economically appropriate for use by a community.

Rainwater harvesting can also be used to improve groundwater recharge, reduce soil erosion, and support local agriculture. This is important because nonirrigated rain-fed agriculture accounts for 60% of crop production in the developing world (*19*). The desert area of western India serves as an example of how indigenous knowledge can be used to select optimal sites to install rainwater catchments and storage. RWH was initiated in the Alwar district of Rajasthan—a desert with average annual rainfall of only 50 cm/yr. Local villagers constructed small check dams (called *johads*) at strategic locations that facilitated groundwater recharge and pond formation after the monsoon rains (*20*, *21*). The project was initiated by a nongovernmental organization along with traditional village rainwater harvesters who had no formal education or modern computational tools but had in-depth practical knowledge of hydrological cycles, site topography, regional aquifer flows, and design and construction of earthen dams.

Data from the year 2000 showed a general rise of the groundwater level of almost 6 m and a 33% increase in the area's forest cover (*22*) demonstrating the effectiveness of these johads. This success has led to revival of this technique in over 1000 surrounding villages with 4500 johads constructed in a region of 6500 km^2 (*20*). As a result, five seasonal rivers have now become perennial, and agricultural revenues have improved contributing to socioeconomic revival.

A unique aspect of RWH is that it can also be used for landscaping as well as cooling and heating of buildings in urban settings. Urban rainwater harvesting has been showcased in a large urban building in Nairobi. Similarly, many cities in North America, Europe, and Asia have adopted RWH at the building-scale. For example, the State of Washington's King Street office building (Seattle) supplies more than 60% of its water use from stored rainwater (*23*). One reason RWH is critical to urban sustainable development is due to the increase in interbasin transfer of water to urban areas that requires significant energy and infrastructure investment (*24*). Renewed interest in the technology is also reflected in the water policies of many developing countries where rainwater is now considered domestic water.

The water yield from rainwater harvesting systems can be determined from

$$P_t = \frac{S_\mathrm{d} t}{CA} \tag{1}$$

where P_t is the minimum rainfall needed over time t, S_d is the desired daily consumption, C is a runoff coefficient (typically 0.8−0.85 (*25*)), and A is the guttered roof area. Equation 1 can be rearranged to fit a user's application. For example, Cowden et al. (*26*) identified urban slum areas of Africa where RWH could provide a water consumption level

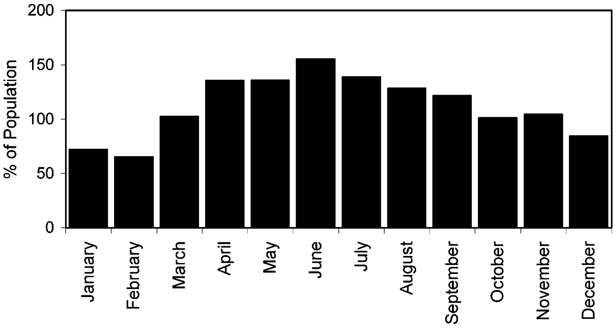

FIGURE 2. Percent of Chicago's population whose municipal water supply could be provided by rainwater harvested over the calendar year. Assessment assumes a total roof area in metropolitan Chicago of 680 km^2 (*27*), a 2003 population of 2 869 121 (*28*), a residential water use of 416 L/day/capita (*29*), and a runoff coefficient of 0.8. Storage capacity will ultimately determine how much of the roof's yield is captured and available for use.

to meet an access level of 50 L/capita-day (Figure 1). This analysis has been extended to determine the percent of Africa's urban population that could potentially benefit from an enhanced water supply of 50 L/capita-day from RWH based on alternative roof design. Applying eq 1 to the Chicago metropolitan area, Figure 2 shows that rainwater could supply 50−100% of the population with a daily residential supply of 416 L. Storage capacity ultimately determines how much of the yield will be captured and available for use, obviously a potential limiting factor in cities such as Chicago. Storage capacity also dictates the temporal resolution of the rainfall data required for assessing the system's reliability. Subsequently, the results shown in Figure 2 most likely overestimate the actual potential for RWH.

Future directions in rainwater harvesting research are as varied as the potential applications of the technology. One area of interest is creating socioeconomically feasible systems for wide-scale application throughout the world. Another area of research is climate change impact assessment on rainwater harvesting using innovative methods in weather generation modeling and downscaling of climate change model outputs.

Thermal Heating and Cooling Technologies that Use Water as a Material. Water can be used in thermal storage walls for heating buildings, especially as a substitute for traditional building materials such as concrete that adversely impact the environment. A thermal storage wall employs a large concrete or masonry wall to collect and store solar energy and then distributes this energy as heat into a building space (Figure 3a). Thermal walls are sized by performing a heat balance on a building and determining how much of the required heating load the thermal wall can replace.

An ideal material for constructing a thermal wall would be readily available, inexpensive, nontoxic, and have optimal thermal properties (e.g., heat capacity and conductivity). Water has a higher volumetric heat capacity (62 BTU/ft^3-°F) than wood, adobe, and concrete (heat capacity values ranging in the 20's). It is also an ideal material to release stored thermal energy as heat into a building space. This is because fluids can use convection to distribute heat and the thermal conductivity of water (0.35 BTU-ft/ft^2-h-°F) is also much higher than wood and dry adobe. Thus, a thermal wall constructed of water will provide a larger fraction of the required heating load than a similarly sized wall built of concrete or stone. Because of its high effective conductivity, water is an especially attractive material in instances where heat is required early in the day (e.g., schools and offices). In residential situations where heat is needed in the evening a conventional mass wall may be a better choice because it releases its stored energy at a slower rate (*30*). Because water is an ideal material to store and dissipate heat, its use as a material in a thermal wall can result in a greater use of solar energy to meet a building's heating load. Furthermore, in regions of the world where water is available and inexpensive its application in thermal walls may have life cycle benefits in terms of materials and energy compared to concrete.

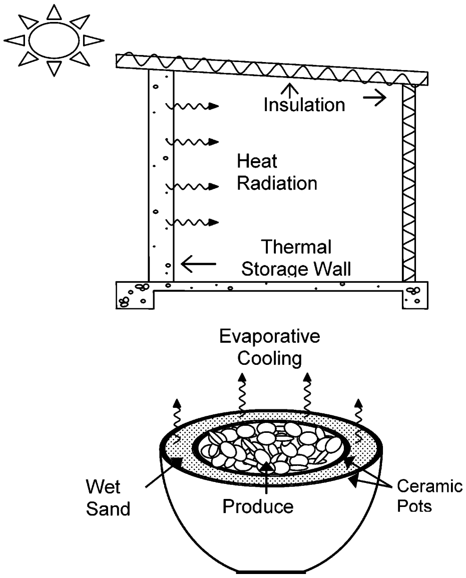

FIGURE 3. Water can be viewed as a material for thermal heating and cooling. a. Passive solar design and ventilation can be used to eliminate or minimize the need for energy intensive mechanical heating. Thermal walls can collect and dissipate heat. Materials can consist of concrete, stone, brick, adobe, and water. (adapted from ref *30*). b. Water can be employed as an evaporative coolant. Food preservation takes place in the pot-in-pot refrigerator that was developed in Nigeria.

Water is also valuable for its ability to cool. As a ubiquitous nontoxic liquid that undergoes freezing and evaporation in nature, water has been used for cooling and preserving foods by many ancient cultures. In India and Africa, evaporative cooling has been employed both to cool water in porous pots and to cool buildings by directing intake air through simplified variations of swamp coolers. Specific examples include the "bahadoori" tradition in Egypt where wind catchers passed dry hot ambient air over water pots; the "uchimizu" tradition in Japan, which involves the scattering of rainwater on surfaces; and the placement of thin water chutes (i.e., salsabil) in Mogul palaces in medieval India (*31*, *32*). Many of these water-based thermal cooling techniques are practiced today in developing nations (*33*−*35*), and in the summer of 2005 the city of Tokyo revived the Japanese uchimizu tradition by sprinkling water onto roads to mitigate the urban heat island effect (*36*).

In contrast, although water and natural ice were used for cooling and refrigeration in Europe and the U.S. until the late 1800s, the use of water in these applications diminished rapidly. These decreases were due to hygiene concerns arising from sewage contamination of surface waters and the invention of mechanical refrigeration. The basic principle of mechanical refrigeration—that of pumping a liquid refrigerant through radiating coils that absorb heat yielding a gaseous refrigerant that is then mechanically compressed into a liquid state for recirculation within a closed loop using external energy sources—is still being used in many refrigerators and air conditioners today. The refrigerants employed have historically raised concerns over toxicity, starting with ammonia, SO$_2$, and methylene chloride that were explored in the early 1900s (*37*). The production of freon and other CFCs in the 1920s ushered in a new stable era for mechanical refrigeration until their impact on stratospheric ozone depletion was discovered in the 1980s. This lead to the global phase out of CFC by the year 2010 and eventually their substitute HCFCs over the 2030−2040 decade (*38*).

Even without these adverse chemical impacts, the vast amount of energy actively consumed through mechanical air cooling and refrigeration poses a challenge to sustainable development. For example, mechanical air cooling and refrigeration account for approximately 18% of the approximately 39 quadrillion BTUs associated with total annual energy use in U.S. buildings (*39*). Additionally, more than 7 billion gallons of gasoline are used to provide air conditioning for U.S. motor vehicles (*40*).

Given these impacts, the historical origins of refrigeration and cooling appear to have come full circle now with renewed explorations of nontoxic water as a coolant as well as the use of solar energy for thermal cooling and refrigeration. In the developing world, a pot-in-pot refrigerator, which innovates upon the traditional ceramic pot evaporative cooling technology, was recently developed in rural Nigeria by Mohammend Bah Abba (*41*). In this process, improved cooling efficiencies are obtained by placing one earthenware pot inside another, with a layer of wet sand between the two pots (Figure 3b). Water evaporation from the sand cools and maintains the freshness of vegetables stored in the pots. Eggplants, for example, are reported to stay fresh for 27 days instead of 3, and tomatoes and peppers last for 3 weeks or more (*41*). Local labor can be used to manufacture the pots; thus, for a very low cost farmers' livelihoods are improved by creating a longer-term market for previously short-lived perishable farm produce, all without the use of toxic chemicals or grid electricity.

The principle in these thermal or heat-driven cooling applications is that when water evaporates the required latent heat of vaporization is extracted from the surface on which the evaporation takes place, which subsequently cool down. Increasing the air−water surface area enhances water evaporation rates, and hence water to be cooled is traditionally stored in porous earthenware pots and fruits and vegetables are wrapped in moist fabric. For evaporative cooling of indoor air, water conduits were integrated into building design, and unique architectural features such as central courtyards were employed through which cooled air would descend due to its higher density, a process called passive down-draft evaporative cooling.

The amount of heat absorbed in the process of water evaporation is very high in comparison with other modes of heat transfer that are common in buildings. Every gram of water that is evaporated without external heat input extracts heat from the surface on which the evaporation takes place, about 0.66 Wh or 0.6 Btu/lb-°F. This is achieved by an adiabatic process, since no system energy is gained or lost (*32*). The surface that is cooled by evaporation can subsequently cool the air by convection, conduction, or radiation.

An analysis of the pot-in-pot refrigerator depicted in Figure 3b can show how the technology could be further refined or transferred to other applications. The energy flux balance at the pot surface, assuming no heat storage at the surface (thin layer), can be written as

$$Q_h + Q_r + Q_p - Q_e = 0 \tag{2}$$

where Q_h is the sensible heat flux, Q_r is the radiative heat flux, Q_p is heat conduction from the pot and its contents to the surface, and Q_e is the evaporative (latent) heat flux (flux units such as J m^{-2} s^{-1}).

The maximum cooling temperature difference obtainable with this process would be to the dew point temperature of the surrounding air. Thus, the process is most optimal in dry climates where there is a large difference between the ambient air temperature and dew point temperature. Evaporative cooling occurs if the pot surface temperature is warmer than the dew point temperature of the surrounding air. In this case, the surface of the pot begins to cool. As the pot surface temperature decreases, the evaporative heat flux cooling the surface decreases and the other fluxes heating the surface increase until a steady-state temperature is reached.

This analysis reveals that free transport of heat from inside the pot to the surface is an important design consideration. Evaporation will be most rapid when the pot surface is warm, so heat transport from the contents of the pot to the outer surface should be efficient with a small temperature difference, thus requiring a high thermal conductance for the pot shell. Decreasing the thickness of the double-pot and sand layer would likely improve the thermal conductance of the system. A further advantage would be to decrease the thermal mass of pot material that has to be cooled. The disadvantage would be decreased water storage, meaning that water would need to be added more often.

Increased air movement around the pot would increase the transport of moisture away from the surface; however, transport of heat to the surface by convection would also increase. The net effect of increased air movement would favor evaporative cooling over convective heating because of the large latent heat of vaporization of water compared to the specific heat capacity of air. The latent heat flux is usually 2−5 times greater than sensible heat flux for moist surfaces.

As explained, the pot-in-pot system would not work well in humid environments, and other thermal-based technologies employing water as a coolant and solar energy for cooling are currently being explored. Of particular interest is the zeolite adsorption refrigerator that capitalizes on the high adsorptive capacity of water onto zeolite surfaces at low pressure (*42*). Instead of relying on natural evaporation, the zeolite adsorption process drives water conversion to vapor, yielding the same attendant cooling. Solar energy is then applied to desorb the water from the zeolite. Zeolite-based refrigerators for rural applications have been designed and studied in Nigeria (*43*, *47*) and India (*44*), with further analysis and expansion in Japan (*45*) and Germany (*46*). The water-zeolite adsorption system is also being researched at the U.S. National Renewable Energy Laboratory for application for air conditioning of motor vehicle using waste heat from engines (*47*) as well as for cooling of urban buildings.

Biogas for Waste Management and Power Generation. Anaerobic digestion and biogas production provide another example where knowledge transfer between the developed and developing world has led to global enhancements of the technology. Anaerobic digestion (AD) is the microbial decomposition of organic matter in the absence of oxygen resulting in the production of liquid manure and biogas that consists primarily of methane and carbon dioxide. The biogas can be used directly as a heating fuel or transformed to electricity. AD thus generates energy from waste, while also yielding a high-nutrient manure byproduct that has had its organic nitrogen transformed into a usable inorganic form.

The first biogas plant is believed to have been developed in India in 1859 (*48*). With urban sanitation concerns growing in England during the late 1800s, this technology was applied both to stabilize wastes in lagoons as well as to produce fuel for street lamps (*49*). Engineered control of the AD process by heating and mixing waste in closed tanks was introduced in the 1920s and 1930s. The dominant application of AD in Europe and U.S. up until the 1970s was the stabilization of sludge generated from aerobic treatment of municipal sewage. In contrast, the energy derived from biogas motivated technological innovation for direct anaerobic treatment of animal and human manure mingled with agricultural wastes in many Asian nations.

With the energy crisis of the 1970s, developed nations started recognizing methane as a valuable product of the digestion process. However, technology had not kept pace with the demand for biogas and the reported failure rates of biogas plants in China, India and Thailand were of the order of 50%, while the U.S. observed failure rates of 80% for farm-based digesters (*49*). These failures ultimately lead to improved designs appropriate for small-scale biogas plants in the developing world (*50*, *51*). New configurations, such as fixed film digesters, were developed in Europe and North America. To make the process economically viable AD was applied effectively to treat comingled high strength industrial wastes as well as municipal solid waste (*52*), thereby minimizing these waste streams while also generating power. Biogas is now recognized as a valuable renewable energy resource, with several "green pricing" options in place in many industrialized countries.

While the basic technology is the same, developed and developing nations offer a contrast between large numbers of home-scale or village-scale systems operating in developing nations versus a small number of large centralized plants favored in developed nations. For example, by the year 2001 it was estimated that 6 million community-based biogas plants were installed in China and 2 million in India, making biogas one of the most useful decentralized sources of energy in the developing world (*53*). In contrast, 22 large-scale centralized biogas plants were in operation in Denmark in 2003, supplemented with several smaller farm plants (*54*). The Denmark model of centralized biogas production is part of a national goal of using renewable energy to meet 33% of the energy needs by 2030. Furthermore, in Sweden biogas presently contributes 45% of all natural gas sales, and theoretically biogas could supply 20% of all vehicle fuel needs for the country (*55*).

Further Science and Technology Innovations for the Global Sustainability Dialogue. The pipeline of innovations from the developing world based on indigenous knowledge is still being explored, analyzed, and quantified for inclusion in the global dialogue on sustainable development. For example, in the case of water treatment, indigenous knowledge systems originating in developing countries also provide natural water treatment methods such as the utilization of natural coagulants like the extract of the seed of *Moringa oleifera*. This tree grows in most tropical regions and has been used to treat water in the developing world. Its coagulation and water softening properties have been shown to meet WHO standards for turbidity in treated effluent, while also demonstrating better performance in removing microorganisms when compared to alum (*56*). There is growing interest in the developed world to quantify the mechanism and behavior of this process under field conditions and to develop a strategy for implementation in locations appropriate for decentralized water treatment in both the developed and developing world (*57*, *58*).

Initiation of a dialogue on sustainable development that combines developing world knowledge with developed world analysis and quantification will significantly assist global efforts to achieve mutual goals of sustainable development. This is especially important as the world's expanding population is forced to innovate sustainable technological, economic, and societal solutions for critical areas such as material usage, water supply, food production, and energy generation. Development of a common framework to allow decision makers to evaluate mutually beneficial types of technology will require that scientists and engineers not only consider the value of community-based solutions and culturally appropriate technology but also understand how to apply the principles of green engineering (*13*) and life cycle thinking to sustainable development (*59*). It is our hope that this manuscript and its companion (*8*) initiate this important dialogue.

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