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for the 21st Century**

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# Global Freshwater Resources: Soft-Path Solutions for the 21st Century

Peter H. Gleick

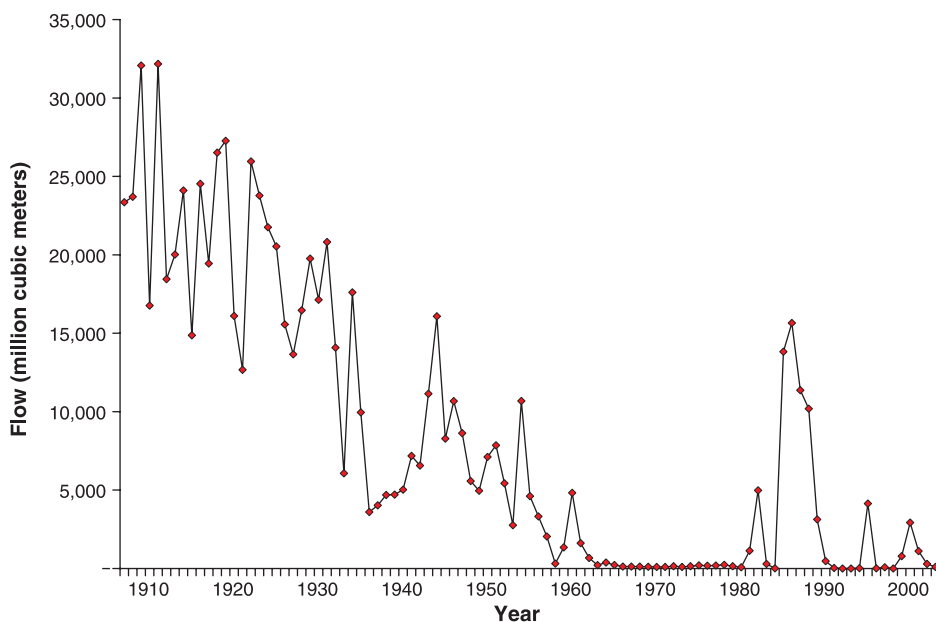
Twentieth-century water policies relied on the construction of massive infrastructure in the form of dams, aqueducts, pipelines, and complex centralized treatment plants to meet human demands. These facilities brought tremendous benefits to billions of people, but they also had serious and often unanticipated social, economical, and ecological costs. Many unsolved water problems remain, and past approaches no longer seem sufficient. A transition is under way to a "soft path" that complements centralized physical infrastructure with lower cost community-scale systems, decentralized and open decision-making, water markets and equitable pricing, application of efficient technology, and environmental protection.

The world is in the midst of a major transition in water resource development, management, and use. This transition is long overdue. The construction of massive infrastructure in the form of dams, aqueducts, pipelines, and complex centralized treatment plants dominated the 20th-century water agenda. This "hard path" approach brought tremendous benefits to billions of people, reduced the incidence of water-related diseases, expanded the generation of hydropower and irrigated agriculture, and moderated the risks of devastating floods and droughts.

But the hard path also had substantial, often unanticipated social, economic, and environ-

mental costs. Tens of millions of people have been displaced from their homes by water projects over the past century, including more than 1 million whose villages are now being flooded by the reservoir behind the Three Gorges Dam in China (1). Twenty-seven percent of all North American freshwater fauna populations are now considered threatened with extinction (2), a trend mirrored elsewhere around the world. Adequate flows no longer reach the deltas of many rivers in average years, including the Nile, Huang He (Yellow), Amu Darya and Syr Darya, and Colorado, leading to nutrient depletion, loss of habitat for native fisheries, plummeting populations of birds, shoreline erosion, and adverse effects on local communities (3–5).

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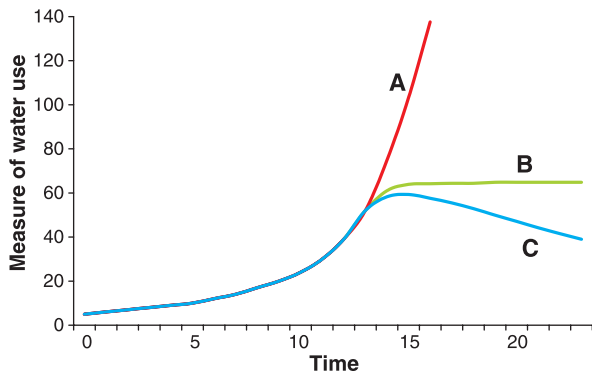


**Fig. 1.** Colorado river flows below all major dams and diversions, 1905 to 2001. Data are flows of the Colorado River as measured at U.S. Geological Survey Gage 09-5222, 35 km downstream from Morelos Dam. As shown, flows reaching the Colorado River delta have dropped to near zero in most years.

In arid regions of North America, the hard path for water was pursued especially aggressively. Massive dams and thousands of kilometers of aqueducts were built, permitting human withdrawal of much of the water formerly flowing to wetlands, deltas, and inland sinks, and hydrologic mastery over many watersheds. Since 1905, flows in the Colorado River have decreased markedly because seven states and Mexico withdraw the river's

**Table 1.** Aid to water supply and sanitation by donor (1996–2001).

Country or multilateral aid organization	Millions of U.S. dollars	
	1996–1998 average	1999–2001 average
Australia	23	40
Austria	34	46
Belgium	12	13
Canada	23	22
Denmark	103	73
Finland	18	12
France	259	148
Germany	435	318
Ireland	6	7
Italy	35	29
Japan	1442	999
Luxembourg	2	8
Netherlands	103	75
New Zealand	1	1
Norway	16	32
Portugal	0	5
Spain	23	60
Sweden	43	35
Switzerland	25	25
United Kingdom	116	165
United States	186	252
Subtotal, countries	2906	2368
African Development Fund	56	64
Asian Development Bank	150	88
European Community	—	216
International Development Association	323	331
Inter-American Development Bank, Special Operations Fund	46	32
Subtotal, multilateral organizations	575	730
Total water supply/sanitation aid	3482	3098



**Fig. 2.** Scenarios of future water use. The three curves represent continued exponential growth in demand (A), a leveling off of demand to steady state (B), and declining demand (C).

entire flow for agricultural and urban uses (Fig. 1). In most years no runoff reaches the river's delta in the Sea of Cortez. Yet calls for new dams in the western United States continue, predicated on the assumption that water problems there will finally be resolved with the construction of another increment of infrastructure (6).

The most serious unresolved water problem is the continued failure to meet basic human needs for water. More than 1 billion people worldwide lack access to safe drinking water; 2.4 billion—more people than lived on the planet in 1940—lack access to adequate sanitation services (7, 8). The failure to satisfy basic water needs leads to hundreds of millions of cases of water-related diseases and 2 million to 5 million deaths annually (9).

Growing awareness of these and other complex challenges led the United Nations General Assembly to declare 2003 the International Year of Freshwater (10). Among the Millennium Development Goals adopted by the General Assembly are new efforts aimed at reducing by half the proportion of people unable to reach or afford safe drinking water and adequate sanitation services by 2015 (11). Without these goals, cumulative water-related deaths by 2020 are expected to be between 52 and 118 million deaths, mostly of children. Even if the water targets are reached, cumulative deaths by 2020 will be between 34 and 76 million. In comparison, cumulative early deaths from AIDS over the same period are projected to be 68 million (12, 13).

Unfortunately, the UN's water goals and solutions to other water problems are unlikely to be achieved,

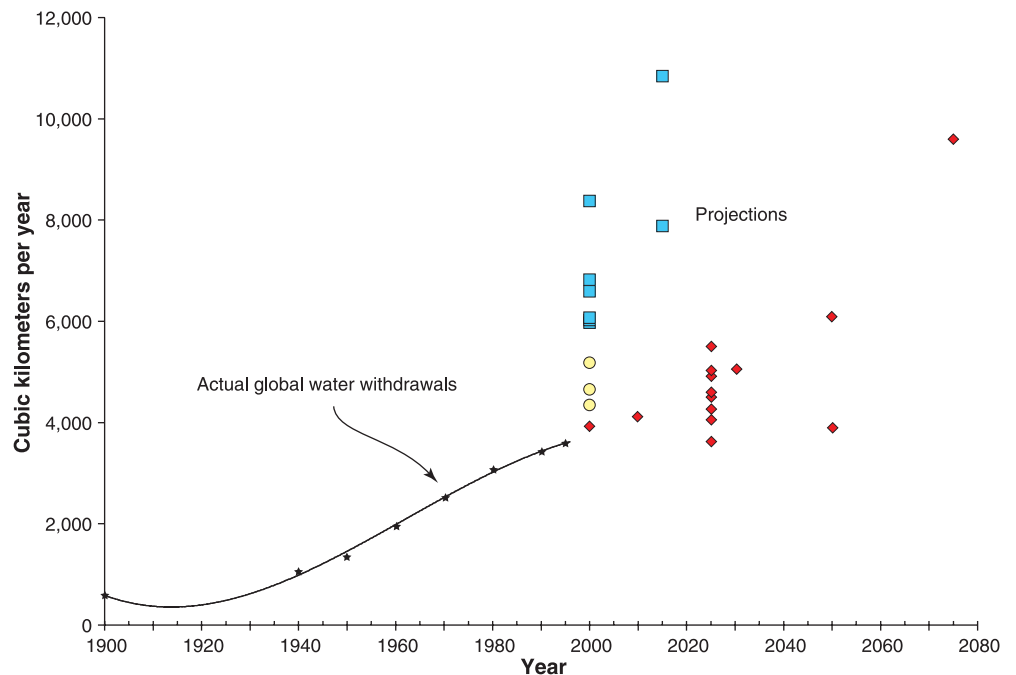
given current levels of financial and political commitments. Despite growing awareness of water issues, international economic support for water projects of all kinds is marginal and declining. Official development assistance for water supply and sanitation projects from countries of the Organization for Economic Cooperation and Development (OECD) and the major international financial institutions has actually declined over the past few years (Table 1), from \$3.4 billion per year (average from 1996 to 1998) to \$3.0 billion per year (average from 1999 to 2001). Moreover, those most in need receive the smallest amount of aid. Ten countries received about half of all water-related aid, while countries where less than 60% of the population has access to an improved water source received only 12% of the money (14).

New challenges further complicate approaches to solving water problems. Issues such as regional and international water conflicts (15), the dependence of many regions

on unsustainable groundwater use (16), the growing threat of anthropogenic climate change (17), and our declining capacity to monitor critical aspects of the global water balance (18) are all inadequately addressed by water planners and policymakers. If these challenges are to be met within ecological, financial, and social constraints, new approaches are needed.

### 20th-Century Water Policy and Planning

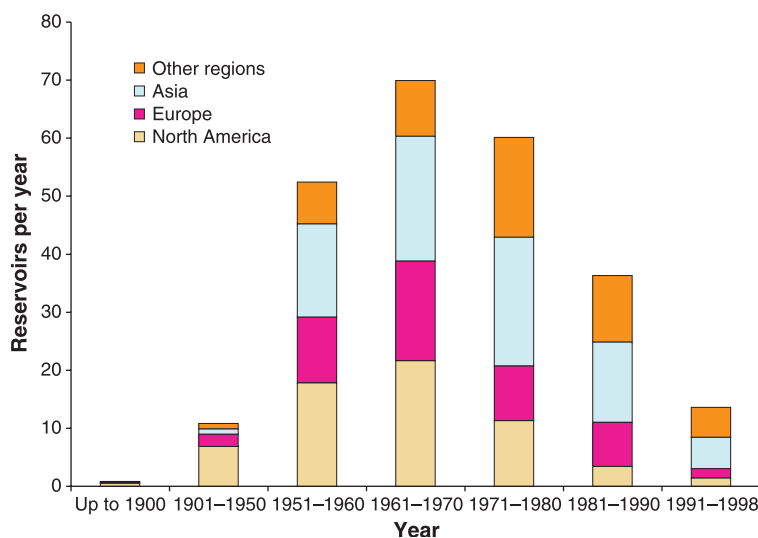
The predominant focus of water planners and managers has been identifying and meeting growing human demands for water. Their principal tools have been long-range demand projections and the construction of tens of thousands of large facilities for storing, moving, and treating water. The long construction times and high capital costs of water infrastructure require that planners try to make long-term forecasts and projections of demand. Yet these are fraught with uncertainty. Three basic futures are possible: (i) exponential growth in water demand as populations and economies grow, (ii) a slowing of demand growth until it reaches a steady state, and (iii) slowing and ultimately a reversal of demand (Fig. 2). Reviewing the last several



**Fig. 3.** Projections of water use and actual global water withdrawals, as compiled from various projections of global water withdrawals made since the 1960s (44), together with an estimate of actual global water withdrawals, as estimated in (45). Note that projections made before 1980 forecast very substantial increases in water use; more recent forecasts have begun to incorporate possible improvements in water productivity to reflect recent historical experience. Symbols: squares, projections made before 1980 (includes forecasts for 2000 or 2015); circles, projections made between 1980 and 1995 (includes forecasts for 2000); diamonds, projections made after 1995 (includes forecasts for 2000, 2010, 2025, 2030, 2050, and 2075).

decades of projections shows that planners consistently assumed continued, and even accelerated, exponential growth in total water demand (Fig. 3). Some projections were that water withdrawals would have to triple and even quadruple in coming years, requiring additional dams and diversions on previously untapped water resources in remote or pristine areas once declared off-limits to development. Proposals have been made to flood the Grand Canyon, dam the Amazon, and divert Siberian and Alaskan rivers to southern population centers.

Instead, as Figs. 3 and 4 show, total water withdrawals began to stabilize in the 1970s and 1980s, and construction activities began to slow as the unquantified but real environmental and social costs of dams began to be recognized. More recently, the economic costs of the traditional hard path have also risen to levels that society now seems unwilling or unable to bear. The most cited estimate of the cost of meeting future infrastructure needs for water is \$180 billion per year to 2025 for water supply, sanitation, wastewater treatment, agriculture, and environmental protection—a daunting figure, given current levels of spending on water (19). This figure is based on the assumption that future global demand for water and water-related services will reach the level of industrialized nations and that centralized and expensive water supply and treatment infrastructure will have to provide it. If we focus on meeting basic human needs for water for all with appropriate-scale technology, the cost instead could be in the range of \$10 billion to \$25 billion per year for the next two decades—a far more achievable level of investment (20). Similarly, as large-infrastructure solutions have become less attractive, new ideas are being developed and tried and some old ideas are being revived, such as rainwater harvesting and integrated land and water management. These alternative approaches must be woven together to offer a comprehensive toolbox of possible solutions.



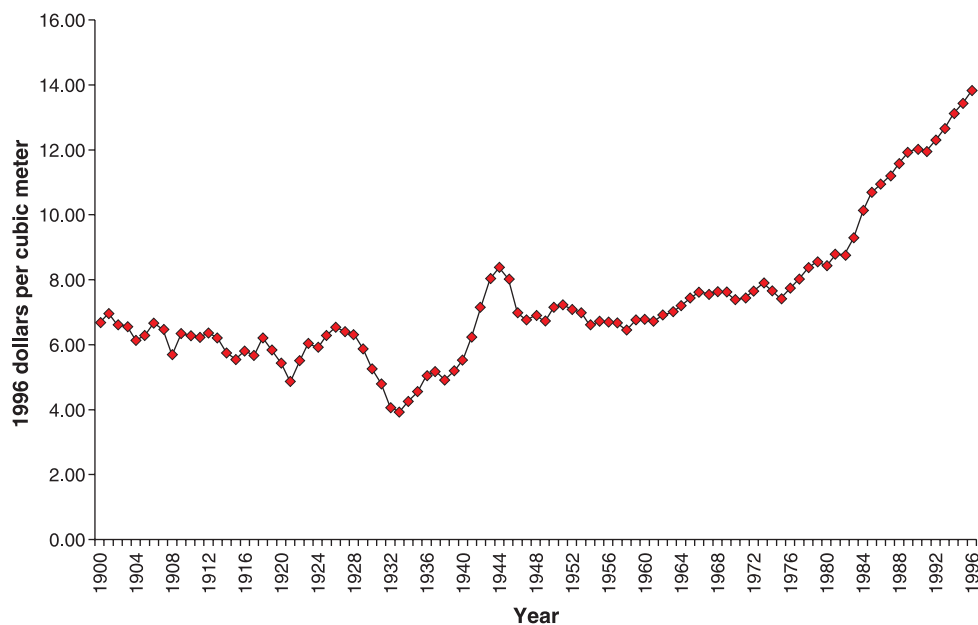
**Fig. 4.** Construction of large reservoirs worldwide in the 20th century. Average numbers of reservoirs with volume greater than  $0.1 \text{ km}^3$  built by decade, through the late 1990s, are normalized to dams per year for different periods. Note that there was a peak in construction activities in the middle of the 20th century, tapering off toward the end of the century. The period 1991 to 1998 is not a complete decade; note also that the period 1901 to 1950 is half a century. "Other regions" include Latin America, Africa, and Oceania (46).

### A New Approach for Water

What is required is a "soft path," one that continues to rely on carefully planned and managed centralized infrastructure but complements it with small-scale decentralized facilities. The soft path for water

strives to improve the productivity of water use rather than seek endless sources of new supply. It delivers water services and qualities matched to users' needs, rather than just delivering quantities of water. It applies economic tools such as markets and pricing, but with the goal of encouraging efficient use, equitable distribution of the resource, and sustainable system operation over time. And it includes local communities in decisions about water management, allocation, and use (21–23). As Lovins noted for the energy industry, the industrial dynamics of this approach are very different, the technical risks are smaller, and the dollars risked far fewer than those of the hard path (24).

Rethinking water use means reevaluating the objectives of using water. Hard-path planners erroneously equate the idea of using less water, or failing to use much more water, with a loss of well-being. This is a fallacy. Soft-path planners believe that people want to satisfy demands for goods and services, such as food, fiber, and



**Fig. 5.** Economic productivity of water use in the United States, 1900 to 1996. The economic productivity of water use in the United States, measured as \$GNP (gross national product, corrected for inflation) per cubic meter of water withdrawn, has risen sharply in recent years, from around \$6 to  $\$8/\text{m}^3$  to around  $\$14/\text{m}^3$ . Although GNP is an imperfect measure of economic well-being, it provides a consistent way to begin to evaluate the economic productivity of water use.

waste disposal, and may not care how much water is used—or even whether water is used at all—as long as these services are produced in convenient, cost-effective, and socially acceptable ways. Thus, society's goal should be not the use of water, but improved social and individual well-being per unit water used.

Waste disposal, for example, does not require any water, although some water for this purpose may be appropriate or desirable for social or cultural reasons. Industrial nations have grown accustomed to water-based sanitation; indeed, in the United States, the largest indoor user of water in homes is the flush toilet, which requires and then contaminates huge volumes of potable water. In the last two decades, however, the amount of water required by toilets in the United States has declined by up to 75% as new efficiency standards have been adopted (25), and even greater reductions are possible (26).

Another example of one piece of the soft path can be seen in a new study of the potential for water conservation and efficiency improvements in California's urban sector. This analysis shows that the same services now being provided in urban areas, including residential, commercial, and industrial activities, can be provided with 67% of the water now used for those purposes with current technology at current prices (27).

In the agricultural sector, farmers do not want to use water per se; they want to grow crops profitably. Changing irrigation technology or crop characteristics permits growers to produce more food and fiber per unit water. Efficiency improvements can result from furrow diking, land leveling, direct seeding, drip irrigation, changes in plant varieties, low-energy precision-application sprinklers, and simply better information about when and where to irrigate. Drip irrigation and microsprinklers can achieve efficiencies in excess of 95%, compared to flood irrigation efficiencies of 60% or less (28). As of 2000, however, the area under micro-irrigation worldwide was less than 3 million hectares, only about 1% of all irrigated land (29). In China, furrow and flood irrigation was used on 97% of irrigated land; only 3% was watered with sprinklers and drip systems (30).

Industrial facilities are also finding new ways to reduce water use and recycle existing withdrawals. The dairy industry in the 1970s required 3 to 6 liters of process water to make a liter of milk; today, the most efficient dairies use less than 1 liter of water per liter of milk (31). Producing a 200-mm semiconductor silicon wafer used about 30 gal/in<sup>2</sup> in 1997, and this is expected to drop to 6 gal/in<sup>2</sup> by the end of 2003 (32).

All of these factors have already begun to

lead to substantial improvements in the economic productivity of water use, measured in dollars of economic production per cubic meter of water withdrawn. Figure 5 shows the substantial increase in U.S. economic productivity of water from 1900 to the late 1990s as water use efficiency has improved and as our economy has shifted from water-intensive production. Other countries show similar gains (33). These improvements mean that the United States used less water for all purposes in the late 1990s than it did two decades earlier, despite large increases in our economy and population (34).

Ultimately, meeting basic human and ecological needs for water, improving water quality, eliminating overdraft of groundwater, and reducing the risks of political conflict over shared water require fundamental changes in water management and use. More money and effort should be devoted to providing safe water and sanitation services to those without them, using technologies and policies appropriate to the scale of the problem. Economic tools should be used to encourage efficient use of water and reallocation of water among different users. Ecological water needs should be quantified and guaranteed by local or national laws. And long-term water planning must include all stakeholders, not just those traditionally trained in engineering and hydrologic sciences.

The transition to a comprehensive "soft path" is already under way, but we must move more quickly to address serious unresolved water problems. We cannot follow both paths.

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## Web Resources

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## Energy Resources and Global Development

Jeffrey Chow, Raymond J. Kopp, Paul R. Portney

In order to address the economic and environmental consequences of our global energy system, we consider the availability and consumption of energy resources. Problems arise from our dependence on combustible fuels, the environmental risks associated with their extraction, and the environmental damage caused by their emissions. Yet no primary energy source, be it renewable or nonrenewable, is free of environmental or economic limitations. As developed and developing economies continue to grow, conversion to and adoption of environmentally benign energy technology will depend on political and economic realities.

Energy is the lifeblood of technological and economic development. The energy choices made by the United States and the rest of the world have ramifications for economic growth; the local, national, and global environment; and even the shape of international political alliances and national defense commitments. Countries of varying levels of wealth also face different energy challenges (*1*). Here, we discuss the availability of global energy resources, how they are used and by whom, and the consequences of the global distribution and use of energy resources.

Although estimates vary, the world's proved, economically recoverable fossil fuel reserves include almost 1 trillion metric tons of coal, more than 1 trillion barrels of petroleum, and over 150 trillion cubic meters of natural gas (Table 1) (*2*). In addition to fossil fuels, mineral resources important to energy generation include over 3 million metric tons of uranium reserves (*3*). To put this into context, consider that the world's annual 2000 consumption of coal was about 5 billion metric tons or 0.5% of reserves. Natural gas consumption was 1.6% of reserves, whereas oil was almost 3% of reserves, and nuclear electricity generation consumed the equivalent of 2% of uranium reserves (*4*). Reported recoverable reserves have tended to increase

over time, keeping pace with consumption, and now are at or near all-time highs. In relation to current consumption, there remain vast reserves that are adequate for continued worldwide economic development, not even accounting for reserves that will become economically recoverable through continuing discovery and technological advance (*5*). Thus, it seems that the world is not running out of mineral fuels.

Large fossil fuel reserves are concentrated in a small number of countries, with half of the low-income countries and more than a third of the middle-income countries having no fossil fuel reserves whatsoever (*6*). If energy reserves were necessary for economic development, several of the world's poorest nations would be disadvantaged. However, many energy-bereft countries (such as Japan) have become highly developed through sufficient access to international energy markets. Conversely, Nigeria possesses substantial reserves but remains one of the poorest countries, its energy production activities mired in corruption. Thus, simply possessing large fossil energy reserves is of questionable value to a country's development if there is no well-functioning and adequately equitable socioeconomic system enabling it to extract and deploy those energy resources for their full social benefit.

Total global energy use exceeds 370 exajoules (EJ) [350 quadrillion British thermal units (Btus)] per year, which is equivalent to

over 170 million barrels of oil each day (*7*). Approximately 95% of this energy comes from fossil fuels. Global energy consumption draws from six primary sources: 44% petroleum, 26% natural gas, 25% coal, 2.5% hydroelectric power, 2.4% nuclear power, and 0.2% nonhydro renewable energy (*8, 9*). A considerable amount of primary energy is converted to electricity either in the course of initial harvesting (as for hydroelectric, wind, and geothermal) or by combustion (as for fossil, biomass, and waste fuels). These estimates do not include nonmarket fuelwood and farm residues that are prevalent in many developing countries, because global estimates of noncommercial energy use are often incomplete and unreliable. However, the International Energy Agency (IEA) suggests that biomass provides on average one-third of the energy needs in Africa, Asia, and Latin America, and as much as 80 to 90% in the poorest countries of these regions (*10*).

Processing and conversion of primary sources permit enormous versatility in energy use. The end applications of this consumption can be categorized into five major sectors: industry, transportation, agriculture, commercial and public services, and residential (*11*). Developing countries use the most energy in the residential sector (*12*), followed by industrial uses and then transportation (Fig. 1A). The opposite is true for developed countries, where transportation consumes the largest amount of energy, followed by industrial and then residential consumption (Fig. 1B).

Unsurprisingly, the developing and industrialized worlds demonstrate striking disparities in annual energy consumption per capita (*13*). Industrialized country energy use exceeds that of the developing countries for all five end-use sectors by 3 to 14 times, depending on the sector (Fig. 1, A and B) (*14*). In aggregate, the average person in the developing countries consumes the equivalent of 6

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