WORLDWATCH REPORT

Renewable Revolution: Low-Carbon Energy by 2030

JANET L. SAWIN AND
WILLIAM R. MOOMAW

Worldwatch Institute
reeep renewable energy & energy efficiency partnership
The Fletcher School
Tufts University

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THE FLETCHER SCHOOL
TUFTS UNIVERSITY

ISBN 978-1-878071-93-4

On the cover: A small rural wind farm at Saint Aubin, in northern France.

Photograph courtesy GWEC/Wind Power Works

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Acknowledgments

This report has benefited greatly from input, recommendations, and data provided by many experts in the field, including Marcel Brenninkmeijer, Mark Delucchi, Mark Jacobson, Kristina Juhrich, Skip Laitner, Hugo Lucas Porta, Lily Riahi, Ralph Sims, and Jørgen Villy. We are especially grateful to Travis Bradford, Eric Martinot, Richard Rosen, Kelly Sims Gallagher, Youba Sokona, Leena Srivastava, and Monika Zimmermann for contributing engaging sidebars that added rich content and diverse perspectives to the report.

Many thanks go to colleagues at the Worldwatch Institute. President Christopher Flavin, Climate and Energy Program Director Alexander Ochs, and Visiting Fellow Frauke Thies provided careful review and invaluable input. We also thank MAP Sustainable Energy Fellow John Mulrow for his assistance with research and references. In addition, we are grateful for production and outreach support from Senior Editor Lisa Mastny, Communications Director Darcey Rakestraw, Director of Publications and Marketing Patricia Shyne, and Communications Associate Julia Tier. Report design and layout were skillfully completed by Art Director Lyle Rosbotham. At the Fletcher School, we extend our gratitude to Arthur Ha for his assistance with references.

Special recognition and thanks go to Amanda Chiu, Project Associate at Worldwatch, for her unwavering commitment to assist us with report research, development of the 2030 global scenario, figure design, fact checking, and endnotes. We could not have written this report without her significant contribution.

Finally, we are indebted to the Renewable Energy and Energy Efficiency Partnership (REEEP) for its generous support of this project, and to the Fletcher School at Tufts University for its assistance.

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Summary

Humanity can prevent catastrophic climate change if we act now and adopt policies that reduce energy usage by unleashing the full potential of energy efficiency in concert with renewable energy resources. However, this goal is not likely to be achieved if our only measure of success is emissions reductions; climate change is fundamentally a development issue, not a pollution problem. As a result, target-setting has failed to achieve needed reductions in energy-related carbon dioxide (CO_2) emissions to date.

What is needed is a transformation of the entire global energy system. No one benefits from the release of greenhouse gas emissions, but developed and developing nations alike will benefit in numerous ways from the transition to an energy-efficient and renewable world. A strong international agreement can accelerate this transition, while recognition of the potential that these resources offers can encourage governments to set aggressive targets for renewable energy and energy efficiency as well as emissions reductions. A combination of political will and the right policies can get the world on track to mitigate climate change in the near term while also meeting demand for energy services, providing energy access for the world's poorest, boosting the global economy, bolstering energy security, and improving the natural environment and human health.

Between 1990 and 2007, world gross domestic product increased 156 percent while global energy demand rose 39 percent, pushing up global CO_2 emissions by 38 percent. Were it not for advances in energy efficiency—gains achieved without aggressive policies—the increase in energy use and associated emissions would have been much greater. Even so, more than half of the energy that we consume does not provide us with useful services, and there is enormous potential for improvement in all sectors of the economy.

In 2007, renewable energy provided more than 18 percent of total final energy supply. Solar energy, wind power, and other renewable technologies have experienced double-digit annual growth rates for more than a decade. The renewable share of additional global power generation (excluding large hydropower) jumped from 5 percent in 2003 to 23 percent in 2008, and this ratio is significantly greater in many individual countries. Renewable technologies are already enabling Germany, Spain, Sweden, the United States, and several other countries to avoid CO_2 emissions.

Used in concert, renewable energy and energy efficiency can take us farther than either approach can individually. Synergy between renewable energy and energy efficiency occurs in four key ways:

- Improvements in energy efficiency make it easier, cheaper, and faster for renewable energy to achieve a large share of total energy production, while also rapidly reducing emissions associated with energy use. The money saved through efficiency can help finance additional efficiency and renewable energy generation capacity.
- Wherever renewable energy technologies displace thermal processes (such as fuel combustion or nuclear power), the result is a major reduction in the amount of primary energy required. Fossil fuel or nuclear power plants typically release more than half of their input energy as waste heat.

Summary

- Many renewable technologies are well-suited for distributed uses, generating fuels, electricity, and heat close to where it is consumed and thus reducing transmission and transportation losses so that less primary energy is required to provide the same energy services.
- Direct use of solar energy for passive heating and lighting does not require any energy conversion technology to provide desired energy services.

Global energy scenarios offer wide-ranging estimates of how much energy renewable sources can contribute, and how quickly this can happen. Many scenarios show a gradual shift to renewables that still envisions a major role for fossil fuels for most of this century. The current report, however, offers alternative hypothetical scenarios for 2030 that envision a transformation, or step-change, in how the world produces and uses energy that could lead to much more aggressive change.

Through major improvements in energy efficiency, combined with a rapid scale-up in renewable energy that relies primarily on technologies that are already commercially available today, we could be halfway to an all-renewable world within the next two decades. Such a transition is essential if we are to get on track to achieve emissions reductions that the Intergovernmental Panel on Climate Change (IPCC) says are required by 2050 to prevent runaway climate change.

Around the world, such evolutions are already under way. Güssing in Austria, Rizhao in China, the Danish island of Samsø, and several other communities—from small villages to larger cities—have begun or achieved energy transformations, using various combinations of innovations. Each community has taken its own path, but all have shared a major emphasis on improving energy efficiency in concert with a dramatic ramp-up in renewables.

For the world to avoid catastrophic climate change and an insecure economic future, this transition must be accelerated, with success stories scaled up and strategies shared across national boundaries. Shifting to a sustainable energy system based on efficiency and renewable energy will require replacing a complex, entrenched energy system. It will also require a large dose of political will and strong, sustained policies.

Policy choices have been critical—far more important than renewable resource potential—in driving the energy transformations seen to date. Moving forward, three strategies must be used concurrently, and in concert, to achieve this goal:

1. **Put a price on carbon that increases over time.** This can be achieved through a cap-and-trade system or through a "bottom tax" that sets a floor under fossil fuel prices and increases each year. To encourage an effective transition, most of the revenue generated from these policies in the near term can be redirected to help individuals and businesses adjust to higher prices while adopting and advancing the needed technologies.
2. **Enact policies that overcome institutional and regulatory barriers and path-dependencies and drive the required revolution.** Aggressive near- and long-term policies and regulations are needed to support sustainable markets and significantly accelerate the transition to an efficient and renewable energy system, while eliminating regulatory barriers that favor existing fossil fuel technologies.
3. **Develop a strategy for phasing out existing, inefficient carbon-emitting capital stock (such as old coal-fired power plants) that includes elimination of fossil fuel subsidies.**

The transition to a highly efficient economy that utilizes renewable energy is essential for developed and developing countries alike. This is the only way that degradation of Earth's climate system can be halted, and the only real option for raising billions of people out of poverty. The current reliance on fossil fuels is not supportable by poor developing countries, and increasing demand for fossil fuels is creating dangerous competition for remaining available resources of oil and gas. The challenge is to devise a transition strategy that improves the lives of all citizens by providing them with essential energy services that do not disrupt the climate system, degrade the environment, or create conflict over resources.

Introduction

Recent advances in technology and policy will allow renewable energy and energy efficiency to play major roles in meeting global energy service demand while reducing carbon dioxide emissions in the next two decades—displacing fossil fuels with only modest incremental costs, if any. Renewable energy technologies are rapidly scaling up and, acting in concert with efficiency gains, can achieve far greater emissions reductions than either could independently.

Both renewable energy and efficiency improvements are essential tools for addressing many of the most pressing challenges that the global community faces today. A combination of political will and effective policies can get the world on track to mitigate climate change in the near term while meeting rising global demand for energy services, creating new jobs, stimulating the global economy, providing energy services to the world's poorest people, stabilizing energy prices, reducing energy security concerns and water demand, and improving the natural environment and human health.

This report examines the potential for renewable energy to provide needed energy services for all societies while lowering heat-trapping emissions of greenhouse gases. It concludes that it is not only possible but also essential to effect a massive transformation of the global energy system from its current fossil fuel base between now and 2030 that continues for the rest of the century.

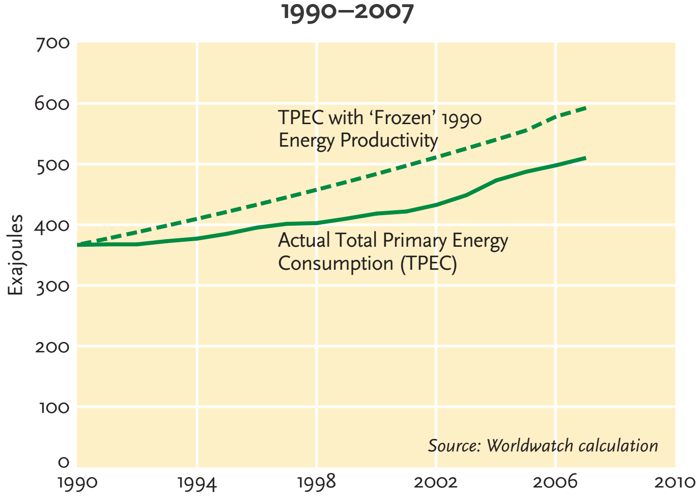
To meet the United Nations Framework Convention on Climate Change's goal to "prevent dangerous anthropogenic interference with the climate system," implementation must begin immediately, and a sound international agreement must be achieved that not only emphasizes emission reductions, but also actively promotes sustainable development in all sectors of the economy in developed and developing countries alike.[1] The commitments and targets required to ensure a sustainable future are fully achievable if we act now and adopt policies that reduce energy usage by unleashing the full potential of energy efficiency in concert with renewable sources.

The Promise of Energy Efficiency

The global community is resting on an enormous yet largely untapped resource: its potential for energy savings. This is despite the fact that efficiency gains in recent decades have been quite significant. Between 1990 and 2007, world gross domestic product (GDP) increased by 156 percent while energy demand rose 39 percent, pushing up global carbon dioxide emissions (CO_2) by 35 percent.[1]*

If energy productivity had remained frozen throughout these years, the world would have consumed 16 percent more energy—another 83 exajoules (EJ)—in 2007 than it actually did.[2]† (See Figure 1.) In other words, over this 17-year period, energy productivity gains saved the world an estimated 915 EJ of energy, the equivalent of almost two times total global primary energy use in 2007.[3]‡ These gains have enabled the world to obtain far more energy services—such as lighting at night, refrigeration, and information services—out of the same amount of primary energy.

Figure 1. World Energy Savings from Energy Efficiency, 1990–2007



Individual countries have done even more. China, for example, cut its energy intensity by more than 5 percent annually over a period exceeding 20 years, and then by almost 8 percent annually through 2001.[4] Through a state program that decoupled utility revenue from sales in 1982, per capita electricity use in California has remained nearly constant for 25 years and is significantly less than that of the average American.[5] U.S. gains in energy efficiency and productivity have met 75 percent of the demand for new energy services since 1970; new energy supply provided the remaining 25 percent.[6] These improvements occurred even as energy prices declined over most of this period.[7] Some major international companies have also succeeded in profitably reducing

* Endnotes are grouped by section and begin on page 40.

† Units of measure throughout this report are metric unless common usage dictates otherwise.

‡ The actual share of these savings that results from efficiency measures is uncertain at the global level. Studies have shown that between one-third and three-quarters of the improvements in energy productivity can be attributed to efficiency improvements; other factors include economic development and change, climate changes, and technological development. Estimate of one-third from Anant Sudarshan and James Sweeney, "Deconstructing the 'Rosenfeld Curve'" (Palo Alto, CA: Stanford University, 1 July 2008); three-quarters from Gilbert E. Metcalf, "Energy Conservation in the United States: Understanding its Role in Climate Policy" (Cambridge, MA: MIT, Joint Program on Science and Policy of Global Change, August 2006), p. 3.

energy intensity by 6–8 percent per year.[8]

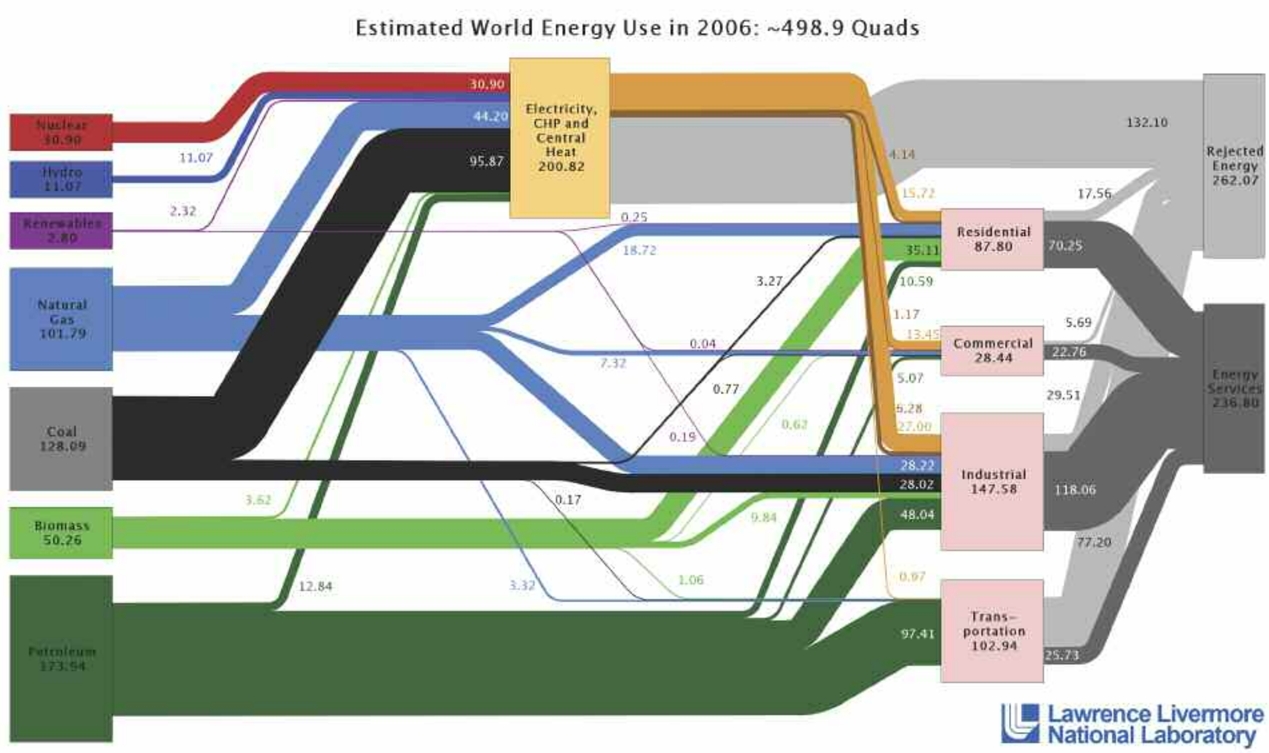
At the global level, energy productivity improvements achieved between 1990 and 2007 avoided the emission of an estimated 53.6 billion tons of CO_2, in addition to the 915 EJ of energy savings and avoided economic costs.[9] This savings is equal to 1.7 times the amount of CO_2 emitted from fossil fuels worldwide in 2008 (31.8 billion tons).[10]

And yet, even with these gains, the human economy continues to function quite differently from the natural world, in which waste from one process provides nutrients for another. Significant losses occur as we extract fuels (such as uranium, coal, and oil) and convert them into energy carriers (including electricity), transport them to where they are needed, and then convert them to energy services (such as mechanical work, motion, light, or heat). Most of the world's power plants, for example, convert fuel to heat, to mechanical energy, and then into electricity; in the process, about two-thirds of the primary energy fed into these plants is released unused into the environment as heat.[11] (Even the most modern coal- and gas-fired plants reach maximum efficiencies of 40–60 percent, and nuclear power plants are only 30–40 percent efficient.[12]) Worldwide, more than half of the energy that we "consume" does not provide us with useful services, such as heat, light, or mobility.

The U.S. Lawrence Livermore National Laboratory estimates that in 2006, 53 percent of the energy used worldwide was rejected as waste heat, providing no useful services.[13] (See Figure 2.) Other calculations show far higher losses. By one estimate, the United States still operates at only about 13-percent useful-energy efficiency, up from 10 percent in 1973.[14] Even in Japan, a worldwide efficiency leader, the rate at which primary energy actually provides useful work or heat is only about 20 percent.[15]

With a concerted effort and strong policies in place, the potential to improve energy efficiency is enormous. Heat is just one form of energy or "waste" that could be captured to dramatically increase useful energy without

Figure 2. Estimated World Energy Use and Losses, 2006



The Promise of Energy Efficiency

burning more fossil fuels. A 2005 study by the Lawrence Berkeley National Laboratory examined 19 different technologies at various scales that can recover energy from waste heat, manure, food industry waste, landfill gas, wastewater, steam and gas pipeline pressure differentials, fuel pipeline leakages and flaring, and numerous other sources.[16] In the United States alone, these technologies and "waste" resources offer the technical potential to profitably generate almost 100,000 megawatts of electrical capacity—enough to provide about 18 percent of U.S. electricity in 2008—in addition to heat or steam.[17] According to other estimates, just the waste heat from all U.S. smokestacks could, if utilized, replace about 30 percent of the nation's electricity that is now generated with fossil fuels, dramatically reducing CO_2 emissions in the process.[18]

The potential elsewhere in the world is vast as well, including in the most rapidly expanding economies. In China, for example, energy-intensive industries account for almost half of total energy use and nearly 30 percent of large steel furnaces, and most cement manufacturers do not capture and reuse waste heat.[19] Thus, China has been called the "Saudi Arabia of waste heat."[20] Meanwhile, efficiency improvement technologies are already in use in many countries. Denmark, for example, now generates more than 50 percent of its electricity with power plants that also capture and utilize waste heat.[21] Finland generates more than 40 percent in this way, and Russia 30 percent.[22]

Buildings are another area where the potential savings are great. Buildings represent about 40 percent of global energy use and account for a comparable share of heat-trapping emissions, and thus must be a key focus in efforts to mitigate climate change.[23] Energy use by U.S. households exceeds the total energy consumption of every country except China.[24] Yet energy demand could be reduced dramatically in both new and existing buildings in every country of the world. In the United States alone, the savings that are readily possible with commercially available technologies by 2020 could reduce national demand by an amount greater than the total energy use of France.[25]

The Passivhaus Institute in Germany has built more than 6,000 dwelling units that consume about one-tenth the energy of standard German homes.[26] These low demand levels are achieved through passive-solar orientation for heating and daylighting, efficient lighting and appliances, super insulation and ultra-tight air barriers on doors and windows, and heat recovery ventilators. As peak loads decline for lighting, heating, ventilation, and cooling, so does the size of fans, boilers, and other equipment, providing additional energy and economic savings.[27]

Transportation accounts for almost 28 percent of global final energy use and the majority of global oil consumption.[28] It is the fastest growing form of energy use, driven in great part by a shift of people and freight to more-flexible but more energy-intensive transport modes, such as private cars.[29] Lowering emissions from transport depends upon several factors. Improving the efficiency of existing modes such as the automobile is one way to lower emissions, but reducing the need for travel is also critical. To achieve enduring reductions in transport emissions requires the development of more efficient modes of transport, which often requires changes in land use patterns, improving infrastructure such as rail transport, and replacing petroleum with alternatives such as electric drive, fuel cells, or sustainably produced biofuels.

Such changes rely on technologies that exist today, most of which are already in use and well-proven. In addition to their environmental merits, their broader adoption could provide major economic and social dividends, often with rapid return on investment.[30]

Renewable Energy's Vast Potential

After efficiency improvements, the other major strategy for lowering heat-trapping emissions is to effect a transition away from fossil fuels, which account for more than 80 percent of global energy use, and toward low- and zero-carbon sources. The diverse range of renewable resources and technologies can meet the same energy needs that today are provided predominantly by fossil fuels and nuclear power. (See Table 1.) Once these technologies are in place, the fuel for most of them is forever available and forever free.

Gains in renewable energy have been dramatic over the past few years.[1] Around the world, renewable energy and fuels are now providing electricity, heating and cooling, and transportation to millions of people. In 2007, renewable energy technologies generated more than 18 percent of global electricity and accounted for almost 13 percent of total primary energy supply (including traditional biomass), or more than 18 percent of total final energy supply.[2]

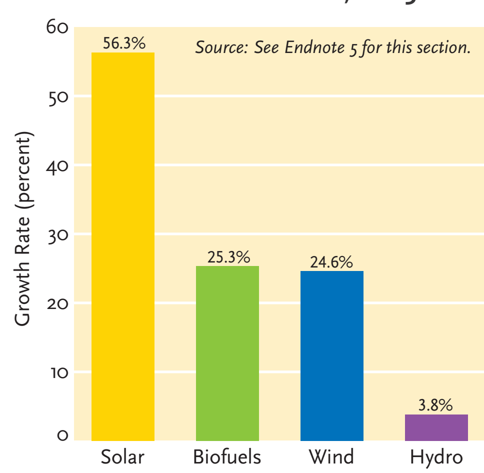
For more than a decade, wind and solar power, biofuels, and other renewables have experienced double-digit growth rates. Since 2004, total global power capacity from new renewables (excluding large-scale hydropower) has increased 75 percent, to 280 gigawatts (GW).[3] When large hydro is included, renewables totaled 1,140 GW, or nearly 26 percent of global power capacity from all sources by the end of 2008.[4]

Annual percentage gains for many renewables in 2008 were even greater than the average over the previous five years, despite the global economic downturn.[5] (See Figure 3.) More than one-fifth of the world's total wind capacity and nearly 40 percent of its solar photovoltaic (PV) capacity were installed in 2008 alone.[6] Solar thermal heating gets little attention but is also expanding rapidly: among non-hydro renewables, it ranks second only to wind

Table 1. Energy Carriers for Renewable Resources

	Energy Carrier			
Resource	Electricity	Heat	Mechanical Energy	Liquid Fuel
Biomass	•	•		•
Geothermal	•	•		
Hydro	•	•	•	
Ocean (tidal, wave, thermal)	•	•	•	
Solar	•	•		
Wind	•		•	

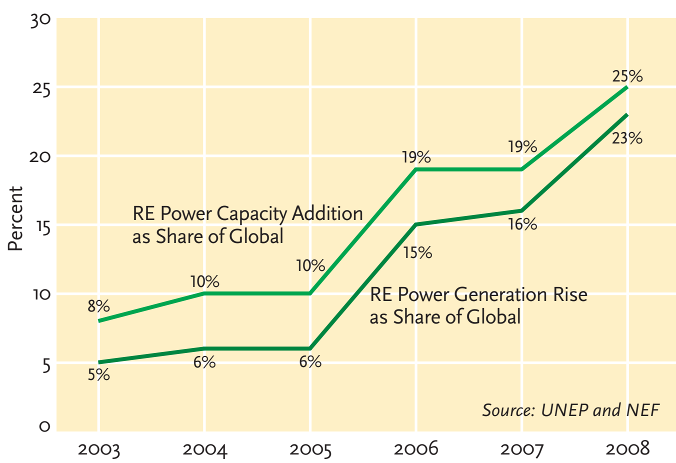
Figure 3. Average Annual Growth Rates for Selected Renewables, 2003–08



power for meeting world energy demands.[7]

Investment in the renewable energy sector has also increased significantly in recent years. Renewables are becoming a top choice for energy investments by investors and developers, driven by government policies, new technologies, and concerns about climate change, energy insecurity, and depletion of fossil fuels.[8] Between 2004 and 2008, global investment in "sustainable energy" (renewables and efficiency) companies and projects increased more than fourfold, from $35 billion to $155 billion ($190 billion including large hydropower).[9]

Figure 4. Renewable Energy Shares of New Global Power Capacity and Generation, 2003–08



Over the past few years, developing countries have accounted for a growing share of global sustainable energy investments, with China alone responsible for just over 10 percent ($15.6 billion) of the 2008 total.[10] In addition, several large economic stimulus packages—in China, the United States, and elsewhere—included an estimated $180 billion more for sustainable energy.[11]

Overall sustainable energy investment in 2008 was up only 5 percent over 2007 due to the global financial crisis.[12] The International Energy Agency (IEA) projects that investment in renewables power generation could fall nearly 20 percent in 2009, and would have dropped more without government stimulus packages.[13] Yet for the first time ever, investment in new renewable power capacity in 2008 exceeded that for fossil-fueled technologies, by an estimated $30 billion.[14] Also for the first time, both the United States and the European Union installed more power capacity from renewable technologies than from all fossil fuels and nuclear combined. Wind power and solar PV alone accounted for more than 50 percent of new capacity installations in these regions.[15]

While non-hydropower renewables still represent a small fraction of total global energy production, their shares are growing rapidly. The renewable share of additional global power generation (excluding large hydropower) has risen from 5 percent in 2003 to 23 percent in 2008.[16] (See Figure 4.) Renewables' share of total generation increased from 2.9 percent to 4.4 percent over this period, but in many individual countries, the share is significantly greater.[17] The modularity of most renewable technologies allows for rapid installation and scaling-up, while technological advances combined with falling prices have enabled rapid penetration of renewables in a growing number of countries.

Germany, for example, had virtually no renewable energy industry in the early 1990s and seemed unlikely ever to be in the forefront of these technologies. Yet within a decade the country had become a world leader, despite the fact that its renewable resources are a fraction of those available in many other countries. In 2000, just over 6 percent of Germany's electricity came from renewable sources.[18] Eight years later, this industrial power—the world's leading exporter (in dollar terms)—generated more than 15 percent of its electricity and produced almost 10 percent of its final energy consumed with renewables, well on its way toward meeting aggressive national targets for 2020.[19] Over the past decade, electricity generation from wind in Germany has increased by a factor of 10, and from solar PV by a factor of more than 100, and the contribution of renewables to the nation's final energy demand has tripled.[20]

The fast pace of growth and associated benefits—from new jobs and industries to savings on fuel imports and an improved environment—have led the German government to aim for renewables to generate 30 percent of the country's electricity and 14 percent of its heat by 2020.[21] Hence, renewables could become the nation's largest power source within the next decade.[22]

Germany's experience provides proof that, with a clear sense of direction and effective policies, rapid change is possible. And Germany is not alone. Examples from other countries include:

- **Denmark's** economy has grown 75 percent since 1980, while the share of energy from renewables increased from 3 percent to 17 percent by mid-2008.[23] In 2007, the country generated 21 percent of its electricity with the wind, and wind power occasionally meets more than 100 percent of peak demand in areas of western Denmark.[24] As part of the European Union's energy package that was finalized in 2009, the Danes aim to get nearly 20 percent of their total energy from renewable sources by 2012 and 30 percent by 2020.[25]
- **Sweden** has seen a major shift from fossil fuels to biomass for district heating over the past two decades.[26] Thanks to taxes on energy and CO_2, about 51 percent of the country's district heat is produced in combined heat and power (CHP) plants, and biomass and waste now account for 61 percent of total district-heat production.[27]
- **China** leads the world in the use of solar water heating, small hydropower, and production of solar cells.[28] The nation has experienced explosive growth in its wind industry, with installed capacity increasing more than fivefold between 2005 and 2008, and China's wind capacity will soon surpass its nuclear capacity.[29] A 2007 national plan aims for renewables to meet 15 percent of China's primary energy demand by 2020. The government has tripled its 2020 wind target, from 30 gigawatts to 100 GW, and recently pushed its 2020 solar target from 1.8 GW to 20 GW.[30]
- **Brazil** met more than 50 percent of its non-diesel vehicle fuel demand with ethanol in 2008.[31] This is up from about 40 percent in 2004.[32]
- **Israel** is a world leader in per capita use of solar water heating. The technology has become mainstream thanks to a 1980s law requiring the use of solar energy for water heating in all new homes.[33]

With increasing market penetration, economies of scale, and technology advances, renewable technologies have seen significant cost reductions. Over most of the past 2–3 decades, wind generation costs declined 12–18 percent for each doubling of global capacity.[34] Solar PV costs fell from $25.30 per Watt in 1980 to $3.68 per Watt in 2001, with the greatest share of the reduction (estimated at 43 percent) due to economies of scale in plant size, and with efficiency improvements accounting for about 30 percent of the price drop.[35] In 2009, PV prices fell below $2.50 per Watt, and historic price declines of 6–7 percent annually are expected to continue for several years, even as conventional energy prices rise.[36] PV is already price-competitive with peak power rates in many markets and is the cheapest option for many remote and off-grid functions.[37]


NREL

Widespread use of rooftop solar hot water systems in Kunming, Yunnan Province, China.

Renewables are already helping to avoid energy-related CO_2 emissions. In the United States, renewables such as solar and wind power serve as variable generators, displacing generation from load-following marginal power plants, such as natural gas plants that are used during periods of peak demand.[38]

In Germany, renewables are actively displacing baseload energy (to meet minimum

Sidebar 1. Climate and Energy Considerations in India

The texts of the ongoing international climate change negotiations are strangely blind to the plight of the world's poor and their need for access to energy services as a key imperative for development. India's demands for an equitable and fair agreement based on the principles of "historical" as well as "common but differentiated" responsibilities arise largely from the challenge of inclusive development. More than 50 percent of India's population is vulnerable to the threat of energy poverty.

In the past, energy—the "unstated" United Nations Millennium Development Goal—was largely an issue of development. Today, in the era of climate change, it has become an issue of human survival. Ensuring access to low-carbon energy would not only address key concerns of developing countries and provide a tremendous opportunity for avoiding future emissions, but, more importantly, it would be a tool for building adaptive capacity and resilience among the world's poorest.

As such, the responsibility for facilitating the transition to low-carbon energy access lies squarely in the court of the developed countries. This would entail the development of low-carbon, "appropriate" technologies that would be consistent with long-term carbon futures as well as provision of necessary financial resources for meeting the costs of transitioning to clean energy technologies and institutions.

India can, however, strive to improve efficiencies of energy consumption in other parts of its economy.

Scenario analyses up to the year 2030/31 undertaken by The Energy and Resources Institute (TERI) reveal that significant short-term efficiency gains of nearly 30 percent are possible by increasing energy efficiencies along the entire value chain. Such measures can also contain India's short-term oil and gas import dependency while reducing electricity shortages and nearly eliminating the need for non-coking coal imports.

The Indian government is aggressively looking at innovative, market-driven approaches to encourage energy efficiency under its National Action Plan for Climate Change. The mechanisms and financial implications are still being finalized, but developed countries can definitely lend a hand in accelerating this process.

This drive for energy efficiency, when combined with an adequate thrust on renewable energy—solar, wind, and biomass in particular—can provide India with more secure and clean long-term energy options that could fuel economic growth while keeping per capita carbon emissions below 2 tons.

Keeping in mind its domestic budgetary capacities, India has already committed to about 20,000 megawatts of solar-based capacity by the year 2020. While this is not a modest undertaking, the renewable energy diffusion in the country will have to be significantly larger to ensure that India stays on a low-carbon pathway and does not suffer from fossil fuel lock-in effects. To effectively address climate change, all nations must commit to significant investments in efficiency and renewable energy capacity over the next 20 years.

—Leena Srivastava, TERI, India

Source: See Endnote 51 for this section.

continuous demand levels), avoiding the use of both coal and natural gas.[39] In 2008, Germany emitted about 748 million tons of CO_2 that were attributable to energy use.[40] If not for the production of heat, electricity, and fuel from renewable sources, total CO_2 emissions from energy would have approached 860 million tons that year. [41]In other words, without renewables (led by wind power, then bioenergy, followed by hydropower), energy-related CO_2 emissions would have been 15-percent higher.[42]

In Spain, the more than 63 Terawatt-hours of electricity produced by renewable electricity during 2007 avoided emissions of about 24 million tons of CO_2.[43] And the shift from fossil fuels to biomass for heating in Sweden reduced associated emissions in 2005 to less than one-third of the 1980 level.[44]

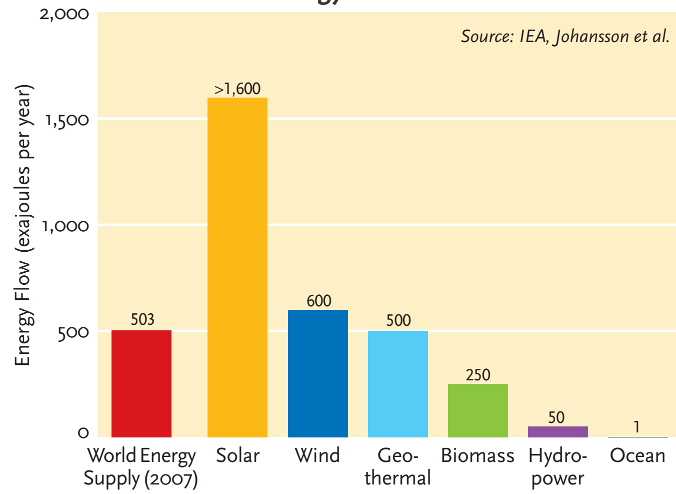
On a worldwide basis, the Global Wind Energy Council estimates that wind power avoided 123 million tons of CO_2 in 2007.[45] The European PV Industry Association estimates that emissions avoided with PV in 2007 totaled

6 million tons.[46] The share of emissions avoided with renewables is projected to increase dramatically in the coming years, particularly with the adoption of strong policies.[47]

The availability of renewable energy is vast, and its current technical potential exceeds the energy use of the global economy many times over.[48] (See Figure 5). Every country in the world has significant sources of renewable energy, as well as the potential to meet most if not all of its energy needs with a combination of renewables and more efficient use of energy.

Some of the world's largest emitters and/or fastest-growing economies have some of the best renewable energy resources. For example, the United States, China, India, and Brazil have vast solar, wind, biomass, geothermal, hydro, and other renewable resources.[49] China's wind resources alone could generate far more electricity than the country currently uses. And the African continent is the richest of all.[50] Renewables offer the potential to meet growing needs for energy services around the world and to provide access to the 1.5 billion people in Asia, Africa, Latin America and elsewhere who remain without such services.[51] (See Sidebar 1.)

Figure 5. Technical Potentials of Renewable Energy Sources



Renewable Energy and Energy Efficiency Synergies

In 1992, Güssing in Austria was a dying town not far from the rusting remains of the Iron Curtain and the capital of one of the country's poorest districts. Just nine years later, it was energy self-sufficient, producing biodiesel from local rapeseed and used cooking oil, generating heat and power from the sun, and operating a new biomass-steam gasification plant that sold surplus electricity to the national grid.[1] New industries and more than 1,000 jobs flocked to the town.[2] Today, not only do local residents enjoy much higher living standards, but they have cut their carbon emissions by more than 90 percent.[3]

Al Hallajo

Green buildings in Berlin, Germany.

Güssing is not an isolated case. Starting in 2001, the government of Rizhao in China set about to adopt several policies and measures to popularize energy efficiency and renewable technologies, including requiring solar water heating on all new buildings. Today, 99 percent of households in the city's central district use the sun to heat their water, most public traffic signals and streetlights are powered with solar PV, marsh gas from agricultural waste water is used to displace some coal for electricity generation and as cooking fuel, and more than 6,000 families use solar cookers.[4] The goal was to promote clean energy to build Rizhao into "an eco-city featuring energy efficiency, sound ecology, and a beautiful environment."[5]

The Danish island of Samsø and several other communities worldwide, from small villages to larger cities, have achieved similar transformations using various combinations of innovations.[6] (See Sidebar 2.) Each community has made the transition toward 100-percent renewables in its own way, but all have had in common a major emphasis on improving energy efficiency in concert with a dramatic ramp-up in renewables.

The synergy between renewable energy and energy efficiency occurs in four key ways:

First, improvements in efficiency make it easier, cheaper, and faster for renewable energy to achieve a large share of total energy production, while also rapidly reducing emissions associated with energy use. For example, if total energy begins at 100 units, with 10 percent from carbon-free renewables, and then global consumption increases by 20 percent, a doubling of renewable capacity to 20 units pushes its share to only 17 percent of the total. Energy-related CO_2 emissions increase by 11 percent. However, if energy efficiency improvements enable demand to decline by 20 percent over the same period, to 80 units, increasing the renewable contribution by the same 20 units raises the renewable share to 25 percent,

Sidebar 2. City and Local Governments Can Be Key Actors

Local governments can play a key role in promoting sustainable energy at the community level. Not only do they have a political mandate to govern and guide their communities, provide services, and manage municipal assets, they also have the legislative and purchasing power necessary to implement changes in their own operations and in the community. Local governments can act as models in their regions or countries, showing how policies and local actions can be shaped to guide the transition to a sustainable energy future.

Because cities are responsible (directly and indirectly) for more than two-thirds of global carbon dioxide emissions, local actions can contribute significantly to addressing climate change. Local governments are closest to the citizens and businesses that they represent and often have direct authority to administer building codes, implement land use and transportation decisions, and manage public buildings and purchases. Often local governments can be accessed and convinced of the benefits of sustainable energy strategies much more effectively than their national governments can.

Cities have been engaged in local climate action and related coordination on a global level since the early 1990s. Although local governments first became engaged in promoting sustainable energy for the purpose of "climate protection," the motivating factors have expanded significantly over the years. The promotion of "Local Renewables"—a strategic combination of energy efficiency, energy saving, and the promotion of renewable energy at the local level—is growing rapidly.

Members of ICLEI - Local Governments for Sustainability and other local governments view Local Renewables as key to mitigating greenhouse gas emissions and to the needed energy transition. They have many good reasons: First, energy is produced locally and securely, ensuring community resilience. Second, less energy is used and money is saved that can be reinvested in additional sustainable energy. Third, local jobs are created and the economy is stimulated. Fourth, local stakeholders promote synergies to encourage change. And fifth, local actions support the achievement of national and international carbon dioxide reduction targets, promote sustainable urban development, and contribute to poverty alleviation.

The year 2009 has seen a great advance in the availability of data on municipal targets and policies as well on the collection of cases and local stories, notably through the Global Status Report on Local Renewable Energy Policies and the "Cities Climate Catalogue." Cities and local governments from all over the world have taken on lead roles in promoting renewable energy.

Since the international climate negotiations in Bali, Indonesia, in December 2007, local governments have conducted an intensive international advocacy campaign—the Local Government Climate Roadmap—to request their inclusion in a new post-2012 climate agreement. Local governments are calling for references to their role within the final text that sets out the formal and binding commitments of nations. The aim is to ensure that the many voluntary and successful model activities of cities and local governments achieve their full potential and play the strong role required for the low-carbon energy transition.

—Monika Zimmermann, ICLEI International Training Centre and ICLEI Local Renewables Initiative

Source: See Endnote 6 for this section.

and emissions drop by 33 percent.[7] And not only can you achieve a large share of renewable energy faster, but the money saved through efficiency can help finance additional efficiency and renewable energy generation capacity.

Moreover, improving the efficiency of end-use devices such as lighting, office machines, appliances, and motors enhances the utility of renewable technologies in supplying energy services. In developed countries, improved end-use efficiency lowers the total cost of supply systems and makes some distributed systems feasible, thereby avoiding transmission and distribution systems. In developing countries, efficient end-use devices such as lighting, power tools, and electronics are the only way that renewables are of a scale to be practical and affordable.

Second, and often overlooked, is the fact that the conversion of thermal energy to

Renewable Energy and Energy Efficiency Synergies

Jennifer Boyer

The Nesjavellir geothermal power plant is the largest such plant in Iceland.

"work" is inherently inefficient. Wherever renewable energy technologies displace thermal processes (fossil combustion or nuclear power), there is a major reduction in the amount of primary energy required. Wind, hydro, wave, tidal, and solar energy convert natural flows of mechanical energy or the sun's light directly to electricity without the losses associated with fossil and nuclear fuels. Electric motors in vehicles (which can be produced with renewable energy) convert electricity to motion at 80-percent efficiency, whereas internal combustion automobile engines convert only 20 percent of the energy in gasoline to propel vehicles forward.[8] According to one global estimate, making the conversion to 100-percent renewable power plants and all-electric vehicles results in a 31-percent decrease in primary energy demand in 2030 relative to business as usual.[9] Due to these significant efficiencies, a major part of any strategy to transition to a more efficient and renewable energy system will require that electricity represents an increasing share of energy demand.

Third, many renewable technologies, such as solar PV, are well suited for distributed generation, producing electricity close to where it is needed and thereby minimizing transmission losses. As a result, less energy must be generated to meet the same level of demand. These technologies are also complemented by a range of new micropower generators, or "home power stations," which can provide heat and power with efficiency ratings of about 94 percent and can help balance out the variability of generation from wind and solar power.[10]

Fourth, the direct use of solar energy for passive heating and lighting does not require any energy conversion technologies to provide desired energy services, thus reducing the amount of primary energy needed to provide desired energy services. However, they also require integrating demand with supply for the most effective utilization.

A 2030 Green Scenario: The United States

What might a low-carbon future that takes advantage of the above synergies look like? The following hypothetical scenario for 2030 explores how the United States, the world's largest energy consumer and the second largest emitter of energy-related greenhouse gas emissions, might make the transition to an efficient and renewable energy economy.

The United States could begin by bringing all states up to the same level of energy productivity and continuing to increase efficiency levels to 2030 and beyond. A recent study revealed that there is an enormous gap between the nation's most and least efficient states and that by simply closing that gap, up to 30 percent of U.S. electricity consumption could be curtailed, displacing more than 60 percent of the nation's coal-fired generation and dramatically reducing national CO_2 emissions.[1]

Then, imagine that by 2030 all new buildings in the country will be "zero-carbon"—the current goal of the American Institute of Architects—and will not emit any heat-trapping gases into the atmosphere.[2] (The U.K. government announced in 2007 that all new homes must be zero-carbon starting in 2016, and all new commercial buildings as of 2019.[3]) For new construction, an integrated design with multiple energy-efficiency measures can reduce energy use to at least half of a conventional building, and gains of greater than 80 percent have already been achieved.[4]

By 2030, two-thirds of currently existing U.S. buildings will have been retrofitted with better insulation and windows, and many low-performance buildings will have been replaced. The resulting energy and economic savings will be enormous, and thousands of new local jobs will be created.[5] The American Institute of Architects estimates that the renovation of existing buildings alone to meet zero-carbon goals would create 4.5 million jobs and generate $1 trillion in construction revenue by 2030.[6] In addition, all buildings will use the most efficient lighting and appliances available. Even today, efficient bulbs are six-to-ten times better than conventional incandescent lamps, and the most efficient appliances are two-to-five times better than existing alternatives.[7]

As Passivhaus Institute projects and other highly efficient buildings have already demonstrated, the remaining modest energy requirements—heating, cooling, electricity—for many buildings can be produced on-site with renewables or other highly efficient conventional systems. Generating a large share of power close to where it is used will reduce the need for transmission and distribution of electricity from central plants, which in turn will lower line losses and further reduce total power demand.

By 2030, industries will also dramatically reduce their energy use by eliminating waste and by cascading heat from higher to lower temperature needs, providing more usable heat with the same amount of fuel. They will follow the example of companies like Mittal Steel, whose plant on the shores of Lake Michigan captures high-temperature heat that was once vented. Today, this heat is used to produce 93 megawatts of electricity plus useful steam, saving the company $23 million and avoiding 5 million tons of CO_2 emissions annually.[8] The expanded use of combined heat and power (CHP) will significantly increase the efficiency

A 2030 Green Scenario: The United States

of remaining U.S. fossil-fueled power plants, while a shift toward renewables will reduce demand for primary energy and related CO_2 emissions.

In the above "green" scenario, most buildings and factories in 2030 will still be connected to the electric grid, but a modern, smarter, and more reliable grid will allow utilities to balance the two-way flow of electricity supply and demand in real time. Interconnected grid systems will work to balance the power output from a variety of renewable sources and projects across regions, while flexible power stations fueled with biomass, biogas, or natural gas will be available to ramp up and down quickly when or if required. This "smart grid," in combination with distributed power production and storage—including electric vehicles that are charged when the sun shines on PV-covered homes or parking lots, or at night when the wind is blowing—will allow even variable renewables to generate a large share of total electricity.[9] (See Sidebar 3.) And electric-drive cars will dominate new vehicle sales, while the share of urban dwellers using public transit will rise substantially and the country will see a considerable increase in rail use for transporting people and goods.


PowerLight Corporation

U.S. Coast Guard Building, Boston, Massachusetts.

In this 2030 scenario, wind energy will meet at least 20 percent of projected U.S. electricity demand. This was found to be feasible in a 2008 report by the U.S. Department of Energy (DOE), even after allowing for a 39-percent increase in U.S. electricity demand between 2008 and 2030.[10] Thanks to major efficiency improvements that will be achieved nationwide within the next two decades, wind power will have the potential to achieve an even larger share by 2030. But other renewable technologies will also play an ever-growing role. As a result, U.S. emissions of CO_2 and other pollutants will be significantly lower than they would have been if the nation had continued with business as usual.[11]

Studies as rigorous as the DOE future wind vision have not been carried out for other renewable technologies in the United States. Yet the potential for increasing energy generation with a "hybrid" electric-power generation system that includes wind, solar, biomass, geothermal, small- and large-scale hydropower, and eventually ocean energy is enormous. A 2007 study concluded that efficiency in concert with renewable energy could reduce U.S. carbon emissions 33–44 percent below 2006 levels by 2030.[12] Efficiency improvements could achieve 57 percent of the needed reductions; renewables could provide the rest, while generating about half of U.S. electricity.[13] And the study did not consider supply-side efficiency improvements, electricity storage, or highly efficient transmission lines for transporting electricity long distances; nor did it include ocean energy, renewable heating, CHP, or distributed generation.[14]

What might it cost to achieve such a transformation to a low-carbon future where energy demand is considerably lower than it is today, and renewables' share in the mix is significantly higher? A recent study by McKinsey and Company found that projected 2020 energy demand could be reduced by an estimated 23 percent—an amount equal to the total energy consumption of Canada today—simply by taking practical steps to use energy more efficiently.[15] The study did not consider potential savings in energy production. In the process, U.S. businesses and households could save $130 billion annually—an amount higher than the GDP of more than half the world's

Sidebar 3. Renewables' Co-Evolution with Power Grids, Energy Storage, and Electric Vehicles

In the coming decade, the rise of new power-grid technologies, energy-storage technologies, and electric vehicles will all make renewable energy more competitive and practical at increasing scales. Electric vehicles themselves, both plug-in hybrid and electric-only, may demand and facilitate a new wave of renewable energy development. Several fundamental changes are currently at work.

Energy storage technologies are emerging that provide new technical opportunities; they may also require existing institutions, policies, and practices to adapt in new ways. Traditionally, large-scale energy storage options have been limited, primarily to pumped-hydropower and oil and gasoline tanks. Although new storage technologies—such as thermal storage, molten salt reservoirs, compressed air, and new battery technologies—are still costly, prices are expected to decline with economies of scale and technology improvements.

Further, power systems are evolving from centralized to distributed, and from dumb to smart. So-called "smart grids" represent a new paradigm in electric power networks, perhaps akin to the Internet and distributed computing revolution that began in the 1990s. Smart grids provide two-way communication and real-time demand and pricing signals between interconnected elements of the power system, enabling electricity customers to also be micro-generators.

Distributed generators using renewables and energy storage, including vehicle batteries connected to the grid, can supply peaking power when the grid needs it most, at premium prices, and then soak up excess power at non-peak times. Or they can help smooth short-term variations in grid supply-demand balance. Smart-grid operation, especially when combined with energy storage, can make the entire system more efficient, both technically and economically, and increase the value of renewable energy connected to the system.

These emerging technologies allow the system to recognize the supply situation and adjust loads automatically (for example, discretionary vehicle charging) within pre-established parameters as supply changes—as renewable power output varies, for example. As a result, a radical new concept is emerging that "load follows supply," turning on its head the conventional concept that has dominated power systems for the past 100 years—that supply must follow load.

With enough storage on a power system—for example, from millions of electric vehicles all connected simultaneously—aggregate system demand can shift significantly in response to variable output from even large installations of renewables, such as centralized wind farms. This may not be intuitive until one realizes that the power output capacity, in equivalent gigawatts, of all existing vehicle engines in the United States today is an order of magnitude larger than the nation's entire power output capacity, and that most vehicles are idle for most of the day.

For the first time in history, the electric power industry and transport systems are becoming technically, institutionally, and commercially interconnected. Never before have they had significant common ground or reason to interact. New forms of interaction and possibly new operational and management structures will be required to ensure that the global community seizes the enormous opportunities that these changes hold for renewable energy. For example, regulatory changes will be needed to allow controllable loads that follow supply and to mandate that utilities implement such regimes.

Public policies will need to anticipate and ensure that the economic, social, and climate benefits made possible by such fundamental changes are realized and spread adequately among power producers and consumers, vehicle owners, and grid operators, so that all players have incentives to make efficient investment and operational decisions.

—Eric Martinot, Institute for Sustainable Energy Policies, Tokyo, Japan, and REN21

Source: See Endnote 9 for this section.

nations.[16] A holistic approach would cost approximately $520 billion in upfront investment through 2020 but would save the nation more than $1.2 trillion, avoid up to 1.1 billion tons of greenhouse gases per year (19 percent of U.S. energy-related CO_2 emissions in 2008), and reduce energy imports relative to business-as-usual projections.[17]

A 2030 Green Scenario: The United States


NREL, Warren Gretz

A wind farm on Buffalo Ridge, Minnesota.

If this trend were continued to 2030, even greater reductions in energy use and emissions as well as economic savings would be possible. The limiting factor is not the availability of technology but the many regulatory barriers that support central electric-power production, the very large subsidies for fossil fuels and nuclear power, and a poor understanding of the potential gains that might be realized along with active opposition by many economic interests and the public.[18]

On the renewable energy side, costs will likely be minimal-to-negative. The DOE wind study projects that even if fossil fuel prices remain stable between 2008 and 2030 (an unlikely assumption), the 20-percent wind portfolio would cost less than an additional 0.06 cents per kilowatt-hour in 2030, or about 50 cents a month for the average household.[19] In addition, it estimates that thousands of new jobs will be created and rural economies will flourish as wind farms provide new sources of income for landowners and tax revenue for local communities.[20]

An analysis performed by the Union of Concerned Scientists concluded that a carbon cap-and-trade system, combined with specific policies to implement energy efficiency and renewable energy technologies, could achieve U.S. CO_2 emissions reductions of 26 percent below 2005 levels by 2020, and reductions of 56 percent by 2030.[21] Annual savings in avoided energy costs could reach an estimated $465 billion by 2030, with accumulated savings of $1.7 trillion between 2010 and 2030.[22]

In addition are the external costs associated with burning fossil fuels that would be avoided through such measures. A recent U.S. National Research Council study estimates the related economic damages in 2005 to be $120 billion, due primarily to health impacts associated with air pollution from electricity generation and motor vehicle transportation. The figure does not include effects of some air pollutants such as mercury, impacts on ecosystems, risks to national security, or damages from climate change.[23]

The key to the success of this scenario is the targeting of policies that take advantage of synergies between energy-efficiency measures and renewable energy technologies, in order to replace fossil fuels between now and 2030. Other countries around the world can expect similar benefits, in addition to dramatic reductions in CO_2 emissions, with a scale-up of renewable energy and improvements in energy efficiency.

Global Scenarios for 2030

At the global level, energy scenarios offer widely varying estimates of how much energy renewable sources can contribute, and how fast. These range from a gradual shift that envisions a major role for fossil fuels through most of this century, to a step change in how the world produces and uses energy that results in a rapid transition to a renewable energy economy.[1]

The International Energy Agency recently projected, under a "business-as-usual" scenario, that primary global energy demand would increase by 40 percent while the share contributed by renewable sources would rise from 12.6 percent to just over 14 percent between 2007 and 2030.[2] Under this scenario, the world could witness a warming of 6-degrees Celsius, with long-term atmospheric CO_2-equivalent concentrations reaching 1,000 parts per million (ppm) or higher by 2100.[3]

Under a second IEA scenario, which targets climate stabilization at 450 ppm of CO_2-equivalent, total primary energy use would rise by 20 percent and renewable energy's share of total primary energy would increase to 22 percent; renewables would be generating 37 percent of global electricity by 2030, up from 18 percent today.[4] Yet the IEA acknowledges that even this scenario—under which energy-related emissions would be about 25 percent higher in 2030 than they were in 1990—offers only a 50/50 chance to cap global warming at 2-degrees Celsius, an increase that many scientists believe to be too high.[5] Of the nearly 13.8 million tons of emissions abated annually by 2030 under this "450 ppm scenario," renewable energy and efficiency gains would account for 76 percent of the reduction (with efficiency at 57 percent), while nuclear power and carbon capture and storage (CCS) would each provide 10 percent.[6]

In recent years, both the U.S. Energy Information Administration and the IEA have increased their projections for the potential role of energy efficiency to reduce energy-demand growth, and for the share of total global energy that renewables can provide over the next two decades.[7] Still, their estimates tend to be on the lower end of the scale. In its 2007 report, the Intergovernmental Panel on Climate Change (IPCC) projected that renewables could generate 30–35 percent of electricity by 2030 with a CO_2-equivalent price of up to $50 per ton.[8] Other scenarios show even higher potential. For example, in 2009, U.S. researchers Mark Jacobson and Mark Delucchi identified what would be required to obtain 100 percent of the world's total energy from

Tom Chance, BioRegional

The BedZED development in London is designed to use only energy from renewable sources generated on site.

renewable sources by 2030, through a combination of more efficient energy production and use alongside a rapid increase in renewable energy installations.[9] (See Table 2.)

Projections for the potential share of energy from renewables vary depending on assumptions about energy costs, expected energy demand growth, government policies, investments, and other unforeseeable factors. Most economic models used today to project future energy demand and sources significantly underestimate the potential for improvements in efficiency and renewables to meet future global energy demand.[10] (See Sidebar 4.) Yet the potential for both options is enormous. As a recent report on the United States finds, "we have only begun to scratch the surface of the potential" for energy-efficiency improvements.[11] Similarly, a 2007 review of global energy scenarios observes that the "energy future we ultimately experience is the result of choice; it is not fate."[12]

Not wanting to tempt fate, the current report offers an alternative scenario for 2030 that envisions a transformation, or step change, in how the world produces and uses energy.[13] (See Figure 6.) Such a transition is essential if we are to achieve emissions reductions on the scale that the IPCC says is required by 2050 in order to limit global warming to 2-degrees Celsius.[14]

In our hypothetical scenario, total primary world energy demand would reach 492 EJ in 2030, just short of 2007 total consumption. The share of energy provided by renewable energy would increase from 13 percent of total primary energy demand in 2007 to 50 percent in 2030, and then continue to rise.[15] An increasing portion of the total would be in the form of electricity, as the heat and transportation sectors become more electrified. While primary energy demand would be essentially the same as in 2007, it would provide significantly more energy services to more people. More important from a climate perspective, global CO_2 emissions associated with energy production and use would drop an estimated 52 percent from 2007 levels by 2030, and 34 percent below 1990 levels—on track to achieve the needed 80-percent or greater reduction in total emissions below 2000 levels by 2050.[16] (See Figure 7.)

We begin with the IEA's reference scenario. It is assumed in our scenario that world population will expand from 6.6 billion in 2007 to

Table 2. Share of Renewables in Global Energy Demand, Projections for 2030

Source	Electricity	Heating	Total Primary Energy Demand
		(percent)	
German Aerospace Center/ REN21	40*	40†	—
IPCC	30–35‡	—	—
Greenpeace International/ European Renewable Energy Council	48.1	45	30.9
International Energy Agency (reference scenario)	22	—	14
International Energy Agency (450 ppm scenario)	37	—	22
U.S. Energy Information Administration	13.5	—	9.6 (end-use only)
Jacobson and Delucchi	100	100	100

** In 13 of the world's 20 largest economies/emitters.*
† In 12 of the world's 20 largest economies/emitters.
‡ With CO2-equivalent price of up to $50/ton.
Source: See Endnote 9 for this section.

8.2 billion in 2030, and that there will be universal access to electricity (pushing up total demand an additional 3.2 EJ, or 0.46 percent, above IEA's reference-scenario level in 2030).[17] Following all of IEA's reference-scenario assumptions, this increase would bring total primary energy demand in 2030 to about 40 percent above 2007 levels. However, we envision instead a 30-percent "reduction" in energy demand by 2030 (relative to the IEA reference scenario) that is achieved through a combination of factors that more than offset increased demand for energy services due to rising population and universal access to electricity.

On the production side, the transition away from fossil fuels to a world that relies on 50-

Sidebar 4. Modeling the Potential for Renewable Energy Resources

Any reasonable scenario for mitigating climate change must include the deployment of massive amounts of renewable energy, almost no matter the net cost. The world must begin now to invest massively in renewable technologies in order to "bend the carbon dioxide emissions curve" toward decreasing emissions. Even if a new technology such as carbon sequestration proves reliable, safe, and well-distributed geographically during the next two decades, it will need to supplement the role of renewables in reducing carbon emissions. Given the likelihood that fossil fuel supplies will decrease far faster than most models assume, renewables will need to be the only major new energy resource—starting now.

Yet most scenarios significantly underestimate the economic potential of renewables to meet future global energy needs. Reasons for this include:

- Most climate scenarios modeled for the IPCC, and related studies, assume too high an allowable level of greenhouse gases in the atmosphere by 2100. By underestimating the physical impact of a given level of greenhouse gases on the climate, these analyses also underestimate the need for renewables.
- Almost all energy-system models are based on projections of a future price of crude oil, and therefore other fossil fuels, that is too low. As a result, they dramatically underestimate the benefits of renewable resources, both through direct cost reductions and through the ability of renewables (combined with efficiency improvements) to extend the availability of fossil fuels into the future, which is itself an economic benefit.
- The "production functions" incorporated into most economic models of climate change impacts cannot correctly incorporate details of both the demand and supply side of the economy. Generally, they are far too "aggregate" to effectively model the costs and benefits of renewables, or any other new technology.
- The neo-classical economic framework used in most models to predict future climate impacts implicitly assumes that the energy system is in equilibrium with all other costs and factors of production at all times, including now. Because this assumption is false, these models fail to correctly indicate how much new renewable energy would be cost-effective for society to purchase, especially early in the forecast period. Specifically, the models do not allow for a sudden discontinuity toward dramatically more renewables (or efficiency), even if that would be highly cost-effective in the short-to-medium term.

On this last point, most economic modeling is based on continuous functions (production functions) and thus can model only slowly varying changes from year to year. Unless the possibility of discontinuous change is built in, a model's output will never exhibit a discontinuous shift in any variable. Modeling improvements in typewriter technology, for example, would never have anticipated its abrupt replacement by digital word processing.

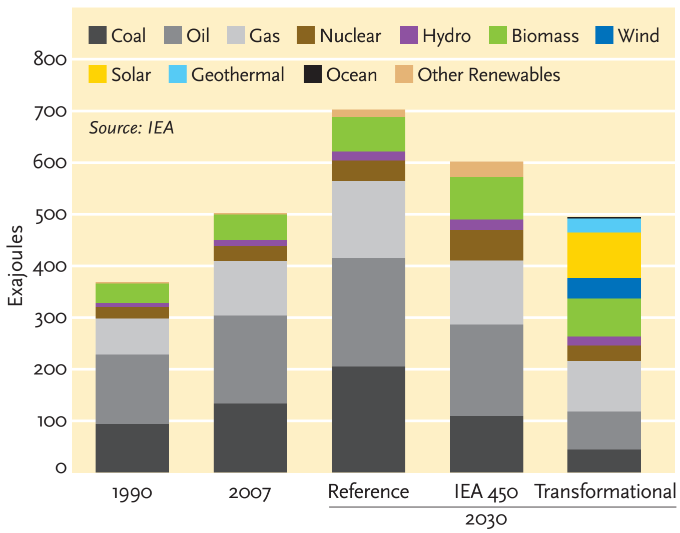
Once they are modeled correctly in economic models, many renewable technologies—particularly in combination with efficiency improvements—will likely be found to have massive net economic benefits to society very quickly, and certainly over their lifetimes.

—Richard Rosen, Tellus Institute

Source: See Endnote 10 for this section.

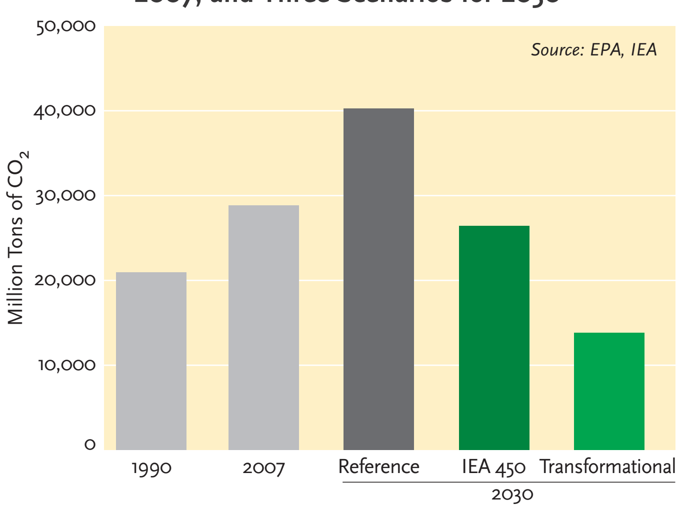
Global Scenarios for 2030

Figure 6. Global Primary Energy Demand, 1990, 2007, and Three Scenarios for 2030



Note: IEA includes solar, wind, geothermal, and biomass in "Other Renewables." Solar includes electric power generation and heat.

Figure 7. Global Energy-Related CO_2 Emissions, 1990, 2007, and Three Scenarios for 2030



percent renewables results in about a 15-percent reduction in primary energy demand by eliminating substantial losses associated with converting fuels to useful energy.[18] Productive use of "waste" heat in remaining thermal plants increases efficiency as well, reducing primary energy demand by another 5 percent in this scenario. An increase in the share of electricity produced by distributed systems, close to where the energy is used, will eliminate a large portion of the transmission and distribution losses that now range from a low of 4–7 percent in some developed countries, to 20 percent in others and far higher losses in parts of the developing world.[19]

In its reference scenario for 2030, the IEA estimates that it will cost about $2 trillion for new transmission, $4.5 trillion for distribution, and $7.2 trillion for generating capacity.[20] Remote generation from central plants sited to take advantage of major renewable resources will require additional investments in transmission systems, and policies will be needed to assure access to rights-of-way, which in many cases may cross international borders.

However, an increase in distributed generation offers the potential for significant savings. This is because much of the projected investment in transmission and distribution (T & D) infrastructure will not be required, and lower T & D losses mean that less power must be generated to meet the same demand.[21] A system that relies on diverse and multiple production nodes, much like the Internet, will also be more resilient and reliable than today's system, especially where the power grid is subject to frequent interruptions from accidents or other failures. Having more, but smaller, power-production units reduces a system's vulnerability to major disruptions.[22]

On the demand side of the efficiency coin, far less energy will be required in 2030 to meet desired energy services than is needed today. Energy-efficiency gains can be introduced very rapidly, as has been demonstrated by the decoupling of economic growth and energy consumption over the past 35 years. Several countries, including China, the United States, Germany, and Sweden, have seen significant reductions in energy intensity (less energy and emissions per unit of GDP). And behavioral changes, such as managing energy use better, have the potential to provide the most rapid energy and emission reductions in businesses and households.[23]

In addition, energy use will decline under our scenario relative to business as usual in 2030 because 50 percent of the world's vehicle fleet will be electric, reducing world oil demand by an estimated 35 percent.[24] Electricity demand will rise as a result, but because electric vehicles are more efficient than conventional ones, less primary energy will be required to propel them forward. Those vehicles that are still oil-dependent will be lightweight and aerodynamic, and thus far more efficient than they are today. More people and goods will move via rail, public transit, bicycle, and on foot rather than with personal vehicles and trucks, requiring far less energy per kilometer of distance traveled. Biofuels and natural gas will meet the remaining transportation needs under this scenario.

In the buildings sector, it will be critical to renovate and upgrade existing structures to make them as efficient as possible. But it will also be important to take advantage of the need for new buildings and the natural turnover rate of capital, or replacement. Integrated design will maximize efficiency in new buildings by combining passive-solar lighting and heating and thermal storage, and by using judicious placement of windows and roof shading to reduce cooling needs. It is estimated that new construction, demolition, and renovations will provide an opportunity to lower energy use and emissions in three-quarters of U.S. building space by 2030. Based on recent case studies, we can expect an average efficiency improvement of more than 50 percent.[25] In countries like Japan, where the replacement rate is faster, there are major opportunities to improve building performance through refurbishment or new construction.[26] China is expected to build 20–22 billion square meters, the equivalent of the entire EU housing area between now and 2020.[27]

More-efficient lighting and appliances will also reduce energy needs. Lighting alone currently accounts for 19 percent of world electricity consumption. Yet technologies now available—including compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs)—could halve electricity use for lighting. In other words, nearly 10 percent of global electricity consumption could be eliminated today simply by changing lightbulbs—saving energy and money and avoiding about 675 million tons of CO_2 in the process.[28]

With these opportunities in mind, this scenario assumes that, through widespread use of passive-solar heating and lighting, as well as improvements in building efficiency, appliances, lighting, and vehicle technologies, end-use efficiency reduces primary energy demand by a further conservative 10 percent relative to the IEA reference scenario. This brings total "reductions" to 30 percent below IEA's business-as-usual projection for 2030, or back to about where we are today.

Reuters/Thomas Mukoya

A Massai herdsman looks after his cattle under a wind turbine in the Ngong Hills of Kenya.

The share of fossil and nuclear fuels in global primary energy supply will fall from 87 percent today to 50 percent in 2030.[29] The priority must be on phasing out coal, the most carbon-intensive fossil fuel, which will become a marginal energy source, decreasing from more than one-fourth of primary energy supply in 2007 to 9 percent in 2030. In order to achieve emissions reductions, it will be essential to shut down old, inefficient coal plants and to replace them with renewable power, including solar and wind, and to an extent natural gas. Natural gas will maintain its current share of 20 percent, but absolute consumption levels will be slightly lower due to efficiency gains. Largely displaced by electricity and biofuels in the transport sector, oil will provide 15 percent of primary energy in 2030, down from 34 percent in 2007.[30] And nuclear power capacity will remain fairly constant as new capacity balances out retirement of existing stock. We assume that the high costs and safety and security risks of nuclear power will prevent a resurgence, despite nuclear's low emissions relative to fossil fuels.[31]

How will we achieve 50-percent renewables? Just as increased use of renewable energy results in a reduction in primary energy demand, efficiency improvements in turn make it easier for renewables to realize a greater share. Among renewables, solar and bioenergy will have the largest shares, together accounting for more than one-third of global primary energy demand. Solar includes the use of solar thermal for water and space heating, for high-temperature industrial heat, absorption cooling, concentrating solar power, and direct use of the sun's light to generate electricity with PVs.

While solar's 18 percent might seem aggressive for 20 years out, given its current share, the potential for solar energy is enormous. By late 2007, about 90 solar thermal plants provided process heat for a broad range of industries, from chemical production to desalination and the food and textile industries.[32] Existing plants worldwide represent a tiny fraction of the industrial heat potential available in Europe alone.

A 2002 study prepared for the IEA found that building-integrated PV alone could meet about 14 percent of electricity demand in Japan, 30 percent in Germany, 46 percent in Australia, and close to 60 percent in the United States.[33] Once solar PV hits grid parity (the price at which it is competitive with the retail rate of grid-based power) in the coming decade, global demand will take off. Significant venture capital and private equity investment is now being directed toward advancing solar energy technologies, with solar ranking first among sustainable energy technologies for investment in 2008.[34]

Biomass will remain an important source of power and heat, although its use in much of the developing world will shift from traditional open burning to more efficient processes. In the transport sector, bio-based fuels will be used primarily for aviation and shipping, areas where it is more difficult to substitute for oil. Due to problematic issues surrounding production of some biomass feedstocks, including potential land-use clearing and resultant CO_2 emissions, our scenario relies primarily on energy derived from algae with high oil content and organic waste, including biogas and heat from sewage and garbage, and fuel from waste oil.[35]

Dozens of municipalities in Sweden already convert human sewage to biogas for transport fuel; biogas is also available as vehicle fuel in Austria, France, Germany, and Switzerland.[36] Agricultural and human waste can be used to produce everything from cooking fuel for individual households to grid-based electricity for office buildings and homes or biofuels for modern vehicles. Thus, two pressing challenges—what to do with a never-ending organic waste stream and how to meet energy service needs sustainably—are addressed with one solution.

Wind energy will continue to expand rapidly, accounting for a significant share of electricity generation by 2030. A recent study of the global potential for wind power found that this resource alone could supply more than 40 times current global electricity consumption.[37]

In addition to its increased use for power production, geothermal energy will increasingly be used to meet heating and cooling needs, particularly through the use of ground-source heat pumps, which can be used virtually anywhere, in both rural and urban settings.

Much of the potential for large hydropower has already been developed, but this will continue to expand somewhat, with small- and medium-scale hydropower growing much more rapidly. Hydropower's share of primary energy will increase from 2 to 3 percent. Finally, while ocean energy—wave, tidal, current and ocean thermal—has vast potential for energy generation, it remains a small portion of total primary energy demand in our scenario.

It is worth noting that even some of the most aggressive past projections for renewable energy capacity and generation have fallen far short of reality. Past achievements have fallen short of targets as well: The United States, for example, predicted in 1973 that wind could provide more than 5 percent of total electricity demand before the end of the century.[38] Immature technology and inconsistent government policies kept this target at bay.[39] However, a recent survey of nearly 50 forecasts for renewables in Germany, Europe, and the world found that nearly all of them had underestimated the future increase in renewable generation, and some had failed to even account for certain technologies that have become significant players in recent years.[40] In its 2002 *World Energy Outlook*, the IEA projected that global wind energy capacity would reach 100,000 megawatts by 2020; the wind industry passed this mark in early 2008. German Chancellor Angela Merkel said during a speech in 2005: "Increasing the share of electricity consumption covered by renewable energy sources to 20 percent is unrealistic."[41] As mentioned earlier, Germany is now well on its way to achieving its goal of 30 percent by 2020.

The modular nature of renewable technologies means that systems can be scaled-up rapidly through conventional manufacturing processes, much as automobiles and gas turbines are manufactured today. A large central coal, nuclear, or hydropower plant cannot begin producing electricity until the entire project is finished, whereas modular generating systems such as wind turbines and solar panels can be brought on in increments. Rapid installation means a lower cost of borrowing and immediate production of power upon installation. In fact, the rapid rise in gas turbines has only been possible because of the ability to produce the individual units rapidly through manufacturing, rather than through much slower on-site construction. The power of the motors of automobiles and trucks produced each year exceeds the total power required to replace the electrical power system with modular renewable energy.

Such massive undertakings have succeeded in the past. The U.S. public-works projects of the Great Depression, the vast numbers of airplanes and warships built for two World Wars, and the enormous number of automobiles manufactured annually provide testimony to possible rates of scaling-up. It is a matter of setting priorities and having the political will to establish effective and long-term policies that support a new energy economy. The resources and capabilities exist. By one estimate, if two-thirds of U.S. truck production were redirected to the production of wind turbines, then about 100,000 megawatts of wind capacity—the cumulative total installed globally by early 2008—could be manufactured annually in the United States alone.[42]

Abengoa Solar

PS10 and PS20, two solar tower power systems together generate 31 megawatts outside of Seville, Spain.

Despite an ongoing skepticism about renewable energy's ability to reliably provide power 24 hours a day, electric utilities have balanced supply and demand through the interconnection of grid systems over large regions with a diversity of loads and resources, use of hydropower as temporary storage, dispersal of renewable power plants over large geographic areas, and solar and wind forecasting an hour or a day ahead.[43] The Combined Power Plant, a project linking 36 wind, solar, biomass, and hydropower installations throughout Germany, has already demonstrated that a combination of renewable sources and more-effective control can balance out short-term fluctuations and provide reliable electricity with 100-percent renewable sources.[44]

A recent study in California calculated that by 2020, even on a typical July day when demand is at its peak, the state could theoretically meet all of its power demand reliably around the clock by balancing a mix of four renewable sources: geothermal, wind, solar, and hydropower.[45] In an interview about the future of the electric industry, S. David Freeman, a 50-year veteran of the U.S. industry, said "it still will take 25, 30 years to phase out the existing coal-fired plants and have an all-renewable world." But, he concludes, "I'm a utility executive that ran major utilities, and I can tell you there is no reason why the electric-power industry can't be all renewable."[46]

Even if it is possible, how much will such a transition cost? Enormous investments will be needed in transmission and other infrastructure, as well as the manufacture of renewable energy technologies. But to some extent these

Sidebar 5. Declining Cost of PV

Global photovoltaic (PV) prices have declined steadily over many decades, with historic price and experience curves reflecting similar trends in semiconductors and other electronics. Since the 1970s, PV module prices have fallen by a factor of 10—or more than 6 percent annually for more than 30 years—due to the combination of technology research and development, economies of scale in manufacturing, and feedstock improvements. The nominal price of a module has declined from over $5.00 per Watt in 1993 to below $2.50 per Watt in 2009, an even steeper drop when real prices are considered.

Despite this long-term trend, circumstances occasionally occur that cause PV prices to rise. During the period 2003–07, strong policy-led demand in Germany and other European countries led to a market surge that outstripped manufacturers' ability to keep up. Predictably, both new producers and new capital came into the industry to take advantage of this surging demand.

The period of temporary manufacturing constraints ended in 2008 as several factors, from oversupply to economic recession, combined to normalize pricing trends. Between mid-2008 and mid-2009, average system prices plummeted by 30–40 percent. Prices continue to fall throughout the supply chain, and many manufacturers have been forced to renegotiate contracts with customers as well as vendors. Significant near-term overcapacity remains in traditional crystalline technologies, and there is a growing market share of new-generation thin-film PV products that are substantially cheaper to make. Supply and demand forecasts from the Prometheus Institute suggest that prices should fall by another one-third through 2012, even while worldwide demand doubles.

Today, many places in the world find that solar electricity, properly financed, is the most cost-effective source of delivered electricity. Analyses suggesting that solar has a high generation cost often do not consider the cost of delivery (i.e., transmission and distribution), which if included makes distributed PV the cheapest way to deliver electrons to customers. Over the next decade, PV should continue to track its historic price declines of 6–7 percent annually, even while conventional electricity rates are flat to rising.

As a result, the next decade will witness the achievement of grid parity, the point at which PV electricity generated on a home or business will be cheaper than delivered grid electricity. Studies from the U.S. National Renewable Energy Laboratory suggest that by 2015, as many as two-thirds of U.S. households will find solar the cheapest electricity option. Spain, Italy, Germany, Japan, and many other countries are expected to achieve broad grid parity by then as well. System prices will continue to fall for many years beyond that point—thanks to further reductions in component costs, increased efficiency, and better installation methods. Improved policy support and financing that spreads costs over the useful life of a system will make PV even more affordable.

Solar electricity is now a powerful and permanent contributor to increased use of renewable energy. And it will only become more so.

—Travis Bradford, Prometheus Institute

Source: See Endnote 49 for this section.

will be balanced by the investments that are not required to build new conventional capacity to meet far higher primary energy demand, or to replace aging capital stock.

As economies of scale improve and conventional fuel costs rise, renewables are rapidly becoming cost-competitive. Electricity from wind is cheaper today than that from natural gas in many markets and might compete with coal in China by 2015, if not sooner.[47] Solar thermal power now competes with gas peaking plants in California and is close to being economically feasible in China and India, while solar heat is already competitive in many markets.[48] Experts project that PVs will be cost-competitive without subsidies in much of the

Table 3. Energy Efficiency Targets in Selected Countries/Regions

Country/Region	Economywide Target	Target Period
European Union (EU-27)	Reduce final energy consumption by 9 percent compared to 2001–05 average	2015
	Reduce primary energy consumption by 20 percent compared to forecasted 2020 energy demand	2020
Germany	Double energy productivity compared to 1990 levels	2020
China	Reduce energy intensity by 20 percent over a five-year period. Planning for Twelfth Five-Year Plan under way	2010
India	Reduce annual energy consumption by 5 percent, avoiding 100 million tons of CO_2 emissions	2015

Source: See Endnote 53 for this section.

Table 4. Renewable Energy Targets in Selected Countries/Regions

Country/Region	Economywide Target
Albania	Increase renewable share of primary energy demand to 40 percent by 2020
Australia	Increase renewable share of electricity to 20 percent by 2020
China	Increase renewable share of primary energy demand to 15 percent by 2020 2 GW of solar generation by 2011 and 20 GW by 2020; 100 GW of wind by 2020
European Union (EU-27)	Increase renewable share of final energy consumption to 20 percent by 2020
Germany	Increase renewable share of electricity and heating to at least 30 percent and 14 percent, respectively, by 2020 Increase renewable share of primary energy demand to 50 percent by 2050
India	1 GW of solar generation by 2013, 20 GW by 2022
Israel	Increase renewable share of electricity to 10 percent by 2020
Japan	14 GW of solar PV by 2020 and 53 GW by 2030
Nicaragua	Increase renewable share of electricity to 38 percent by 2011
Pakistan	Increase renewable share of primary energy demand to 10 percent by 2012
Rwanda	Increase renewable share of electricity to 90 percent by 2012
South Africa	Generate 10,000 gigawatt-hours of final energy consumption from renewables by 2013, in addition to existing renewables in 2000

Source: See Endnote 53 for this section.

world within a decade as solar costs continue to decline and as fossil fuel prices rise.[49] (See Sidebar 5.)

A study by the IEA found that solar, biomass, and ground-source (ground and near-surface water storage of solar energy) and geothermal (deep-heat) energy are among the lowest-cost heating options for reducing reliance on fossil fuels and CO_2 emissions, and they could provide net savings in lifecycle costs relative to conventional systems.[50] And detailed analyses suggest that mass-produced electric vehicles with advanced batteries could have a lifecycle cost that is equivalent per kilometer driven to a conventional vehicle when gasoline costs more than $2 per gallon.[51]

Under our transformational energy scenario, energy-efficiency improvements on the supply and demand sides combine to offset growth in primary energy demand and to keep emissions level. Fuel shifting and a transition to 50-percent renewable energy reduce emissions significantly below today's levels. This scenario envisions a future in which emissions in 2030 are 66 percent lower than in the IEA reference scenario, 48 percent below the 450 ppm scenario, and approximately 52 percent below 2007 levels, setting the world on track to avoid catastrophic climate change. (Note, however, that emissions calculations consider only the impacts of energy generation.) The purpose of this scenario is to explore what might be possible and to consider what kind of future is necessary if we are to avert catastrophic climate change.[52]

By tapping the potential of energy efficiency and all renewables, the world can move away from fossil fuels in the next few decades, not only reducing the threat of climate change but also creating a more secure and far less polluting energy system. The benefits in terms of job creation, energy security and energy price stability, and improved human and environmental health will be enormous as well. Many countries and regions are already setting aggressive targets for energy efficiency improvements and renewables, though more are needed.[53] (See Tables 3 and 4.)

Getting From Here to There: Policies Are Key

Shifting to a sustainable energy system based on efficiency and renewable energy will require replacing an entire complex system. It will also require a large dose of political will and strong, sustained policies. Can such a transformation truly be accomplished in time to avoid the worst consequences of climate change? Several communities and countries provide hope that it can, and that something along the lines of the above global scenario can be achieved. They also offer important lessons for the rest of us to follow.

Some of the most rapid transformations to date have taken place at the local level, with entire communities and cities—such as Güssing in Austria, Samsø in Denmark, and Rizhao in China—devising innovative means to finance renewable energy and transition to 100-percent sustainable energy systems. And several countries are demonstrating that transformation can happen quickly even on a national scale.

For the world to avoid catastrophic climate change and an insecure economic future, the transition already under way must be accelerated. Success stories must be scaled up, and strategies must be shared across national boundaries. Many countries are at different points in their development trajectory; they must therefore tailor their approaches to their particular resources and customize technologies to meet specific needs. At the same time, several key regulatory and policy changes, if implemented broadly worldwide, could put humanity on course to steer clear of the worst impacts of climate change.

Policy choices have been critical—far more important than renewable resource potential—in driving transformations seen to date. Moving forward, three strategies must be used concurrently, and in concert, to achieve this goal:

1. Put a price on carbon that increases over time.

Ensuring a clear minimum price for fossil fuels that rises over time may be the most effective way to avoid backsliding when fossil fuel prices drop—a potential consequence of efficiency improvements. One way to assure this is to apply a "bottom tax" that sets a floor under fossil fuel prices, and that increases each year. To encourage an effective transition, most of the revenue generated in the near term can be redirected to help individuals and businesses adjust to higher prices while adopting and advancing the needed technologies. An alternative pricing option is to use a cap-and-trade strategy.

In the 1990s, Denmark began taxing industry for the carbon it emitted and subsidizing environmental innovation with the tax revenues. At the same time, the government made significant investments in renewable energy. The tax gave industry a reason to stop using carbon-intensive fuel, and advances in renewables provided a viable alternative. By 2005, per capita CO_2 emissions in Denmark were almost 15 percent below 1990 levels.[1] But the price per ton of carbon will have to rise considerably before needed changes and investments come about worldwide.

2. Use appropriate policies to overcome institutional and regulatory barriers and drive the required revolution.

Aggressive near- and long-term policies and regulations are needed to support sustainable markets and significantly accelerate the transition to an efficient and renewable energy system. This includes eliminating regulatory barriers that favor existing fossil fuel technologies.

Regulatory barriers to the introduction of distributed energy and CHP generation must be removed, and codes must be introduced to ensure improved building performance and the use of renewable space-conditioning and daylighting. Establishing an energy-rating system for all buildings at the time of sale, as some European countries have done, would encourage continuous upgrading of existing structures.[2] Training of architects, construction tradespeople, and inspectors is essential for designing and constructing more-efficient buildings. Efficiency improvements will reduce energy use and provide lifecycle economic savings as well as reducing heat-trapping emissions.

Regulatory systems must foster innovation and motivate vested interests to speed the transition rather than fighting to maintain the status quo. Governments at the state/provincial and national levels must make it more profitable for electric utilities, for example, to invest in renewable energy and efficiency than it is to build new fossil fuel plants or even continue operating old ones.

Windpowerworks.net

Boys play near the Rio do Fogo Wind Farm in northeastern Brazil. Output is highest in the dry season when water storage for hydropower is often at its lowest levels.

Policies that begin to wring out energy waste and increase efficiency will be crucial for reducing demand growth and actually reducing demand in many nations. A combination of financial incentives, such as low-cost loans and tax benefits to purchase renewable and energy-saving technologies, plus continuously tightening efficiency standards for lighting, vehicles, and appliances, is needed to unleash this potential and encourage investment in efficiency projects, even many with short payback periods.

As Germany's experience demonstrates, policies that create markets for renewable technologies and promote ease of financing can drive dramatic and rapid change. Under the German feed-in tariff, priority grid access combined with a guaranteed market and long-term minimum payments for renewable power have reduced investment risks, making it profitable to invest in a variety of renewable technologies and easier to obtain financing. The policy has created nearly 300,000 jobs, strong and broad public support for renewable energy, robust new industries, and significant reductions in CO_2 emissions—all for the cost of a loaf of bread a month for the average German household.[3]

Of the 109 million tons of CO_2 that Germany avoided by using renewables in 2008, 56 million tons, or just over half of the total, are attributed to the nation's feed-in law, which is considered Germany's primary climate-protection policy.[4] Numerous studies—including reports by the European Commission and IEA, as well as the *Stern Review on the Economics of Climate Change*—have determined that feed-in laws are the most effective and economically efficient policy option for advancing renewable electricity generation.[5] Following Germany's lead, more than 45 developed and developing countries and 18 states, provinces, or territories had adopted variations of this law by early 2009.[6]

Although feed-in laws and other policies that encourage private investment in research and development (R&D) can play a critical role in technology advancement, public R&D funding is also important. According to the IEA, R&D funding for low-emission technologies including energy efficiency and renewables declined 50 percent between 1980 and 2004.[7] And these technologies continue to receive a relatively small share of R&D funds. Between 2002 and 2007 in the United States, for example, R&D expenditures on energy technologies totaled $11.5 billion, but only 12 percent was directed to renewable technologies; the vast majority went to nuclear power and fossil fuels.[8] Globally, an estimated $16.9 billion was spent on corporate ($9.8 billion) and government ($7.1 billion) R&D for renewable energy and energy efficiency combined in 2007.[9]

And governments must work with utilities to strengthen and extend transmission lines that can bring remote renewable power to population centers. They must also upgrade the electric grid to use a multiplicity of technologies, both distributed and centralized, and take advantage of active demand management through information technology. Otherwise, it will not be possible to take full advantage of renewable energy sources or many energy efficiency measures.

3. Develop a strategy for phasing out inefficient, carbon-emitting capital stock (such as old, polluting power plants) that includes the elimination of fossil fuel subsidies.

Focusing on the electricity sector will be key—particularly as the transportation sector shifts from oil to electricity—because electricity production is so heavily reliant on coal in much of the world. Within the next decade, many power plants in developed countries will reach the end of their technical lifetimes, and it is imperative that they be replaced with renewable options rather than new fossil fuel plants that will continue to emit CO_2, as well as other pollutants, for another 40 to 60 years.

Some countries are starting to phase out subsidies for coal production and even coal use (the province of Ontario in Canada plans to stop burning coal by 2014), but others have major plans to build new coal-fired power plants.[10] It will be critical to minimize such activity and to enact policies that encourage developed and rapidly developing countries, such as India and China, to blaze new development paths.[11] (See Sidebar 6.)

One of the most important steps that governments can take to improve energy markets and address climate change is to eliminate subsidies for conventional fuels and technologies. According to the United Nations Environment Programme (UNEP), global energy subsidies now approach $400 billion annually, with the vast majority going to fossil fuels. UNEP estimates that eliminating fossil fuel subsidies could have reduced global CO_2 emissions at least 6 percent between 2000 and 2010 while giving a small boost to the global economy.[12] A coalition of environment, business, development, and other sectors estimates that removing fossil fuel subsidies would reduce CO_2 emissions by 10 percent globally.[13]

Recent analysis shows that 96 percent of the annual rise in energy use is occurring in developing countries that subsidize the price of energy at well below world market prices.[14] By shifting subsidies from conventional fuels to renewable energy and more-efficient technologies, particularly in the developing world, governments can not only reduce national emissions but also help make clean energy more affordable for even the poorest people who currently lack access to modern energy services.

Finally, evidence shows that policies are most successful if they are well-designed and implemented and are predictable and long-term. Policy consistency is critical for ensuring continuous market growth, enabling the development of a domestic manufacturing industry, reducing the risk of investing in a technology, and making it easier to obtain financing. It is also cheaper because higher incentives might be required to coax investors back into the market as uncertainty increases the perception of risk, and because stop-and-go policies force funds to be reappropriated, new programs administered, information distributed to stakeholders, and so on.[15]

Government commitment to developing renewable energy and energy efficiency technologies and industries must be strong and long-term, just as it has been over the past several decades with fossil fuels and nuclear power.[16]

Every country that has succeeded thus far in developing renewable energy on a substantial scale has been committed over the long term to this goal, with consistent policies that include a package of policy mechanisms.[17]

Sidebar 6. Recent Progress on Energy Efficiency and Renewable Energy in China

The Chinese government has implemented a panoply of climate-related policies during the last decade, and energy efficiency is the central organizing principle in its strategies. Between 1980 and 2000, according to official statistics, China's GDP grew sixfold while energy consumption merely doubled. As a result, China's energy intensity (ratio of energy consumption to GDP), and consequently the emissions intensity of its economy (ratio of CO2-equivalent emissions to GDP), declined dramatically, marking a remarkable achievement in energy-intensity gains unparalleled in any other country at a similar stage of industrialization. This has important implications not just for China's energy security and economic growth trajectory, but also for the quantity of the nation's energy-related emissions. Without this reduction in the energy intensity of its economy, China would have used nearly three times as much energy during this period as it actually did.

The current decade has brought new challenges to China and the relationship among energy consumption, emissions, and economic growth. Between 2002 and 2005, China's energy intensity actually increased, and energy growth surpassed economic growth for the first time in decades. National emissions increased 8 percent in 2007, making China the world's largest emitter in aggregate terms for the first time (surpassing U.S. emissions by 14 percent). But since 2006, the economy's energy intensity has been declining again, and experts believe that China is on track to meet its domestic target of reducing energy intensity 20 percent by 2010.

The government has implemented many policies to achieve dramatic improvements in energy efficiency. China's fuel-economy standards for passenger cars, for example, are more aggressive than those in the United States, and only Japan and Germany have more-stringent standards. A recent study found that "before and after" snapshots of light-duty passenger car models made in China indicate a clear shift in the fuel economy of vehicles as a result of existing standards. The government plans to implement new fuel-economy standards by 2015 that are up to 18 percent more stringent.

Under the National Renewable Energy Law adopted in 2005, China aims to meet 15 percent of its primary energy demand with renewable sources by 2020, up from about 8 percent at present. For the electricity sector, the target is to achieve 20 percent of capacity from renewables by 2020, which will require substantial increases in wind, biomass, solar, and hydropower installations. Although increases in wind power in particular have been impressive in recent years, this energy source is still dwarfed by large-scale hydropower. Hydropower capacity is projected to more than double by 2020, requiring the equivalent of a new dam the size of the Three Gorges project every two years.

Policies to promote renewable energy include mandates and incentives to support the development of domestic technologies and industries. Spurred by a requirement that newly installed wind turbines contain 70-percent local content, Chinese manufacturers now produce more than 40 percent of the turbines sold domestically and 3 percent of those sold globally. Tax and other incentives have targeted the solar photovoltaic industry, stimulating dramatic growth in production, from about 9 megawatts in 2003 (1 percent of world production) to 1.8 megawatts (26 percent) in 2008, making China the world's leading manufacturer of PV cells.

These impressive gains in energy efficiency and renewable energy must be placed in context, however. China is the world's largest consumer of coal, which still accounts for approximately 70 percent of primary energy supply. To the extent that China implements energy efficiency policies, they will clearly reduce coal consumption below what it would have been otherwise. Although renewable energy is growing remarkably fast in China, it still only accounts for a small fraction of overall energy supply. And yet, China's long-term energy security depends not only on having sufficient supplies of energy to sustain its incredible rate of economic growth, but equally on its ability to manage energy demand growth without causing intolerable environmental damage.

—Kelly Sims Gallagher, The Fletcher School, Tufts University

Source: See Endnote 11 for this section.

Reframing the Debate

Since we cannot negotiate with the planet, we must find a way to negotiate more effectively with each other at the national and international levels. Existing climate agreements and the negotiation process for a post-2012 agreement treat climate change as a pollution problem that can be solved only by placing ever-stricter emission reduction standards on all nations. This is seen by most developing countries, and by many developed countries, as a restriction on economic development.

Total annual emissions must be reduced by at least 80 percent below 2000 levels by 2050 in order to stabilize concentrations of CO_2 at a level that avoids "dangerous anthropogenic climate change."[1] This requires compounded annual reductions of 3–4 percent. However, the underlying issue is not just a pollution problem; rather, the underlying cause of climate change is fundamentally one of "unsustainable economic development."

Much of the discussion around potential climate change solutions revolves around the common misconception that development cannot occur without carbon emissions—or, a failure to distinguish the differences among CO_2 emissions, energy, and energy services. Thus, developed countries fear major economic losses associated with reduced consumption of fossil fuels, and developing countries argue that they cannot develop without them.

In fact, continued use of fossil fuels and their associated emissions is not essential to ensure economic development. No one gains economically by increasing carbon dioxide emissions. Economic and social gains are made through energy services. And there is now sufficient evidence that the amount of energy required to carry out a specific economic activity can vary by at least a factor of 5–10 or more.[2]

The way forward must be to focus on development that is sustainable—for developed and developing countries, and for humanity and Earth's other species. This will be a future in which all people are entitled to necessary energy services that do not adversely affect the climate system or create undue environmental or economic burdens.

Renewable energy used in concert with energy efficiency has the potential to address many of the most significant challenges that governments and their people around the world face today: climate change, energy security, national security, energy access, and (rural) economic development. Renewable resources are readily available, reliable, and secure, and no battles will ever be waged over access to the wind or sun.

First-movers will benefit most from the transition to a more efficient and renewable energy system, seeing an influx of investment, jobs, and other benefits. Just as the United States dominated the petroleum economy of the last century, countries that invest in renewable energy technologies early on will be in a strong position to reap the economic rewards of a rapidly growing new sector.

Experience also shows that in addition to the "global learning curve" that drives down technology costs at the global level, all countries that develop strong, sustained markets for renewable energy through effective policies can realize "national learning curves" as well. These forces drive domestic costs down even further and faster as countries develop domestic industries to manufacture, install, and maintain renewable energy systems using local equipment and labor.[3]

Some of the best renewable resources are in some of the poorest regions of the world, which currently undermine their economic development by sending billions of dollars of hard currency abroad each year to import fossil fuels.[4] (See Sidebar 7.) Developing countries need assistance with technology and financing to shift to a new development trajectory.

Renewable energy and energy efficiency create jobs—by conservative estimates, about 2.3 million people currently work directly in renewable technologies fields or indirectly in supplier industries—and can open up vast economic opportunities around the world.[5] While fossil fuel prices continue to rise, renewable energy prices will fall as technologies continue to advance and economies of scale increase. Once these technologies are in place, the fuel for most of them is forever available and forever free.

Sidebar 7. Sketching the Outlines of Africa's Energy Future

Depicting Africa's energy future is an arduous task given the high level of uncertainty associated with the main drivers of change in the energy sector across the continent. History shows that abrupt and unpredictable changes occur in Africa faster than anywhere else in the world. It also shows the continent's ability to quickly assimilate and adapt innovative concepts and new technologies. Africa's telecom leapfrogging, as illustrated by the widespread use of mobile phones, indicates that cultural aspects will play a limited role in defining the future. Instead, the future will essentially depend upon the availability and affordability of modern renewable energy along with the infrastructure that delivers it to end-users.

Africa has the lowest electricity utilization in the world; average electricity consumption does not exceed 23 percent of total energy use, with rural electrification rates often below 5 percent and even as low as 1 percent. The main obstacle to scaling up the use of modern energy remains the low purchasing power of the vast majority of Africans and the prohibitive cost of electricity. Widespread use of low-quality energy sources such as firewood and charcoal is a major cause of death and compromised health, in addition to being a driver of environmental degradation.

Africa's fragmentation is an obstacle to a more equitable and efficient energy sector. Action from Africa as a whole to provide an enabling framework for change, notably through greater continent-wide integration, constitutes an important prerequisite for that change.

Against a backdrop of a failing traditional energy infrastructure and widespread energy poverty, the unfolding climate crisis may make things worse. Combined with soaring demographics, unabated environmental degradation, and rising poverty, climate change might divert official development assistance and public investment, and exacerbate the plight of millions of energy-deprived Africans.

Yet Africa has vast renewable energy resources and the human capacity to bridge the energy gap. Regional integration and good governance will certainly be major components of a continental strategy aimed at mainstreaming the continent into the virtuous circle of prosperity. This is primarily the African challenge but also that of the international community.

An effective international response to climate change could create massive opportunities such as widening energy access for most if not all people in Africa, in addition to new jobs and economic development, a cleaner environment, and potential income from energy export to the rest of world. With adequate financial resources, technology transfer, and capacity-building for adaptation and mitigation, Africa can harness its extraordinary renewable energy potential and, just like it did in the telecom sector, leapfrog to a green, energy-secure future.

—Youba Sokona, IPCC Working Group III and Sahara and Sahel Observatory

Source: See Endnote 4 for this section.

The Way Forward

The dramatic and rapid changes needed to create this new energy economy appear daunting, but remember that the world underwent an energy revolution of comparable scale a century ago. In 1907, only 8 percent of U.S. homes had electricity.[1] Henry Ford had produced about 3,000 vehicles in his four-year-old factory, and the mass-produced Model T was not introduced until 1908.[2] Few of those who supplied town gas for lighting or who met the needs of the extensive market for horse-drawn carriages felt threatened by impending change. Who could have imagined that by the mid-twentieth century, virtually every American home—and millions of others around the world—would have electric light; that the automobile would redefine American lifestyles; and that the economy would be fundamentally transformed as a result?[3]

Fast forward to the current day. Non-hydro renewables generate approximately 4.4 percent of the world's electricity, about 1.5 percent of its liquid fuels, and 2 to 3 percent of its heating and cooling.[4] We are only beginning to construct zero-carbon buildings, and plug-in hybrid vehicles and high performance electric cars are just making their debut. Yet it is possible to imagine that by 2030 the global economy will be transformed by more-efficient use of energy and cost-effective renewable energy sources that will limit the release of greenhouse gases into the atmosphere.

This transition to a highly efficient economy utilizing renewable energy is essential for both developed and developing countries. This is the only way that the degradation of the climate system can be halted, and the only real option for raising billions of people out of poverty. The current reliance on fossil fuels is not supportable by poor developing countries, and increasing demand for fossil fuels is creating dangerous competition for remaining available resources of oil and gas.

The IEA's *World Energy Outlook 2009* finds that while a transition over the next two decades will be expensive, the cost of waiting could be $500 billion for each year of delay.[5] The challenge is to devise a transition strategy that improves the lives of all citizens of the planet by providing them with essential energy services that do not disrupt the climate system, degrade the environment, or create conflict over resources.

We have a once-in-a-century opportunity to make a transformation from an unsustainable economy fueled by poorly distributed fossil fuels to an enduring and secure economy that runs on renewable energy that lasts forever. The energy choices made by policymakers and negotiators, and those made by all people during the next few years, will determine the energy future of much of the world for decades to come—and the future of the global climate and human civilization for centuries.

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